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Cognitive Feedback in GDSS: Improving Control and Convergence

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Abstract

Cognitive feedback in group decision making is information that provides decision makers with a better understanding of their own decision processes and that of the other group members. It appears to be an effective aid in group decision making. Although it has been suggested as a potential feature of group decision support systems (GDSS), little research has examined its use and impact. This article investigates the effect of computer generated cognitive feedback in computer-supported group decision processes. It views group decision making as a combination of individual and collective activity. The article tests whether cognitive feedback can enhance control over the individual and collective decision making processes and can facilitate the process of convergence among group members. In a laboratory experiment with groups of three decision makers, 15 groups received online cognitive feedback and 15 groups did not. Users receiving cognitive feedback maintained a higher level of control over the decision-making process as their decision strategies converged. This research indicates that (1) developers should include cognitive feedback as an integral part of the GDSS at every level, and (2) they should design the human-computer interaction so there is an intuitive and effective transition across the components of feedback at all levels. Researchers should extend the concepts explored here to other models of conflict that deal with ill-structured decisions, as well as study the impact of cognitive feedback over time. Finally, researchers trying to enhance the capabilities of GDSS should continue examining how to take advantage of the differences between individual, interpersonal, and collective decision making.

Keywords: Group decision making, group decision support systems, group processes, cognitive feedback

ACM Categories: H.0, H.4

Introduction

Feedback to users about their decision processes has received relatively little attention in the group decision support systems (GDSS) literature. Interestingly, findings from studies at the level of individual support systems (Kleinmuntz, 1985; Te'eni, 1991; 1992) indicate that computerized systems offer opportunities for providing feedback effectively—opportunities that rely on instant retrieval and computation that are impractical under manual conditions. This is important because feedback in individual decision making has been shown to increase decision quality and confidence (Hogarth, 1987). DeSanctis and Gallupe (1987) have suggested that feedback about decision processes might also be provided in GDSS environments, particularly in cognitive conflict tasks—tasks that involve the resolution of conflicting viewpoints as opposed to conflicting motives. This study takes some first steps in conceptualizing and testing the impact of feedback on GDSS.

Studying feedback in a group context, as opposed to an individual, requires consideration of additional levels of analysis and decision-making activity. Group decision making incorporates not only individual activity but also interpersonal and collective aspects of behavior:

1. At the individual level, group members process information individually, concentrating only on their own decision-making processes.

2. At the interpersonal level, they begin to learn about the opinions of other members and take them into account in their own decision-making processes to make an individual decision.
3. At the collective level, the group exchanges and processes information as a collective activity in order to make a group decision.

Figure 1 depicts these levels as concentric circles to denote that the higher levels encapsulate the lower levels of activity.

Nadler (1979) suggests that feedback can be provided regarding all three levels of group decision making. Information technology makes this perspective particularly plausible. Group members can work individually at workstations to analyze problems, receive information about the decision-making processes of other group members through a computer network, and then engage in an electronic meeting, using the information generated individually whenever necessary. Some collaborative tools, such as Colab (Stefik, et al., 1987) and Groupware (Ellis, et al., 1991), are designed to support such a scenario. This article takes this approach one step further. By modeling the decision-making process with quantitative techniques and using computers to instantly generate feedback about the process, decision makers can use the feedback to affect the outcome of the very same process.

Past research on using computers to provide feedback about decision making has concentrated on feedback about the outcome of the decision-making process (Tindale, 1989). In contrast, this study concentrates on feedback about the decision-making process itself. Feedback about the decision-making process is provided interactively as an integral part of the individual and group processes (loosely, this is what we mean by *cognitive feedback*).

The objective in this paper is to conceptualize and empirically test the effects of feedback on cognitive aspects of decision-making behavior. The paper looks at the effects of cognitive feedback on phenomena that exist at each level of the decision making activity: individual, interpersonal, and collective. The next section develops the conceptual link between feedback and the three levels of decision-making activity. The subsequent sections describe an experiment and the experimental results, followed by a discussion of the results and their implications for practice and future research.

Cognitive Feedback and Cognitive Conflict

Two theoretical frameworks will be employed in analyzing the effects of cognitive feedback at the

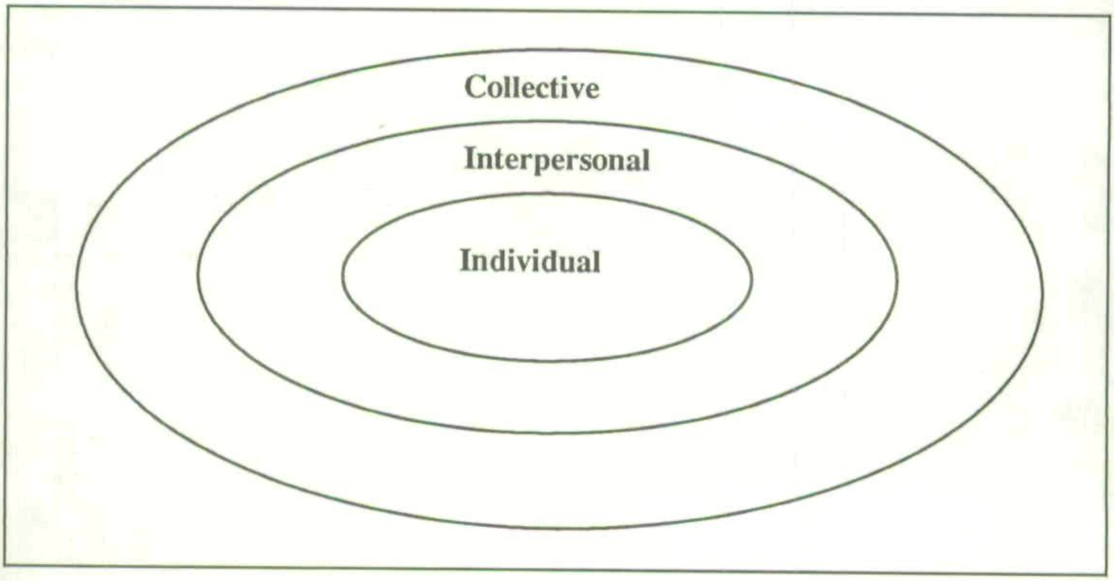


Figure 1. Levels of Analysis in the Context of a GDSS

individual, interpersonal, and collective levels. Social judgment theory (Hammond, et al., 1980) is suitable for understanding how individuals take into account the decisions of others but is not rich enough to describe the dynamics of collective decision making. In contrast, social decision schemes theory (Davis, 1973) is concerned with the interaction between group members that leads to a collective decision. Both are quantitative frameworks that can serve as platforms for developing hypotheses and empirical testing.

In order to clarify the ensuing discussion, consider a group-based procedure for personnel screening. A group of decision makers meets to screen candidates from a pool of applicants for an entry-level position (such sessions are frequently conducted by large corporations prior to personal interviews). Before the meeting, each member rates the applicants on the basis of three cues: work experience, test scores, and education. Each decision maker works individually on a computer system that presents the three cues for each applicant and records the decision maker's rating. At the meeting, the group collectively reviews the ratings given by each group member and agrees on a collective rating for each applicant.

This discussion assumes that individuals formulate a *decision strategy* before executing it (Payne, 1982). The individual's decision strategy describes a sequence of subtasks and the necessary control over their execution. An example of a decision strategy would be to compute a weighted average of the three cues using equal weights, and then take the integer of the result as the rating. Individual group members may have different decision strategies with different weighting schemes.

We can now define cognitive feedback more concisely as information about the decision maker's decision strategy and the extent to which the strategy is applied accurately. In contrast to outcome feedback, which describes the accuracy of a decision, cognitive feedback provides decision makers with insight into their decision processes (Balzer, et al., 1989). Cognitive feedback is effective in enhancing the quality of the decision process by clarifying the decision maker's intentions and controlling their implementation (Doherty and Balzer, 1988). In the personnel screening example, cognitive feedback can take several forms. Cognitive feedback at the individual level may be information about relative weights assigned to cues by a decision maker in rating a group of applicants, the functional relations between cues and the decision criterion, and the integration rules for combining information. Cognitive feedback at the interpersonal level may be a measure of agreement among group members on their individual ratings. Cognitive feedback at the group level may be the consistency with which the group has been making collective decisions. The next two subsections relate cognitive feedback, in turn, to the individual and interpersonal levels (using social judgment theory) and to the collective level (using social decision schemes theory).

Cognitive feedback at the individual and interpersonal levels

Group decisions are often characterized by cognitive conflicts, i.e., conflicts among group members that exist despite similar interests. In other words, the existence of interest differentials (or strategic motives) among players is not a necessary condition for conflict to exist. Cognitive conflicts arise when group members differ in their understanding of the problem (even when their respective interests converge) and are due to cognitive limitations (Brehmer, 1976; Hammond, 1965). In the personnel screening task, group members may use different strategies in rating candidates and, hence, disagree, but they may fail to realize exactly how their strategies differ. Cognitive conflicts appear regularly in group decision making, constituting a more persistent problem than is generally realized (Balke, et al., 1973; Carroll, et al., 1988).

On the whole, cognitive conflicts should be minimized (Hammond, 1965). A better understanding of other views is important for individual performance (Piaget, 1954) as well as group performance (Hirokawa and Pace, 1983). An understanding of other views may reveal shortcomings in an individual's own strategy or disagreement between members over values or assumptions. (This is not to say that conflict in general disrupts effective decision making. Indeed, several techniques for injecting conflict into group processes have been advocated. However, these techniques are predicated on the assumption that the group members are aware of the conflicting views and understand them.) Moreover, a lower level of cognitive conflict will usually make it easier to attain consensus when consensus is feasible (Castore and Murnighan, 1978; Svenson, 1989).

According to social judgment theory (Hammond, et al., 1980), two constructs determine the level of cognitive conflict experienced by a group. At the level of individual analysis, *cognitive control* is the extent to which the decision maker controls the execution of his or her decision strategy. At the level of interpersonal analysis, *strategy convergence* is the degree of similarity between the decision strategies of the group members. It captures differences in how each group member integrates cues in forming an overall rating, e.g., one member may weigh work experience more heavily than education, whereas another member may do the reverse. Cognitive conflict is the result of incomplete cognitive control, a lack of strategy convergence, or both. We will review past work that links cognitive control and strategy convergence to cognitive conflict and then argue that cognitive feedback enhances cognitive control and strategy convergence and, thereby, reduces cognitive conflict. The upper right corner of Figure 2 shows the relationships among the elements of social judgment theory.

Both cognitive control and strategy convergence are affected by cognitive limitations. Decision makers lack insight into their decision strategies (Hoffman, 1960; Hogarth, 1987) and are inconsistent in executing their intended decision strategies because of a limited capacity to control execution (Bowman, 1963; Dawes and Corrigan, 1974). Even more so, individuals lack insight into the strategies of others. Thus, two individuals engaged in formulating a joint decision are unlikely to know the extent to which their respective strategies differ (Balke, et al., 1973). In the absence of interest differentials, strategy convergence will depend primarily on understanding the strategies of other group members.

Research on cognitive conflict has uncovered two related phenomena: (1) the level of cognitive conflict in collective decision making is initially high and gradually declines, and (2) the structure of the conflict changes over time. Initially, cognitive conflict emerges from a disagreement over decision strategy. Over time, the strategy differences tend to decrease, but in the process, decision makers tend to lose cognitive control. Brehmer (1972) attributes this behavior to cognitive limitations. In order to apply the newly acquired strategies consistently, decision makers increasingly have to use new cues in place of the cues they had used initially, but they apparently fail to do so in a systematic manner. Instead, they decrease their dependency on the original cues without a corresponding increase in the use of new cues. In doing so, decision makers lose their cognitive control and cannot apply their knowledge of decision strategies in a consistent manner. As a result, the reduction in cognitive conflict due to converging strategies is counter-affected by lower cognitive control. These findings have been replicated over a variety of task conditions, individual differences, and payoff conditions (Brehmer, 1976).

Regarding the effects of cognitive feedback (see Figure 2), research on individual decision making has shown that cognitive feedback can increase cognitive control (Hammond and Summers, 1972) and facilitate the learning of new decision strategies (Hogarth, 1987; Jacoby, et al., 1984). We hypothesize that these effects carry over to the group context. In order to attain cognitive control, decision makers need to know their own decision strategy, to know that they are diverging from the strategy, and to know how they are diverging. Cognitive feedback provides this information and is therefore expected to enhance cognitive control and, moreover, maintain cognitive control uniformly over time. That is, in contrast to an expected decrease in cognitive control as strategies converge, we hypothesize that decision makers that are provided with cognitive feedback will maintain control while converging in their strategies. Recall that in the absence of a decision aid, decision makers lose cognitive control as they execute new strategies but regain control with the repeated use of the same strategy. These arguments are formulated as hypotheses in the context of an experimental design that has two conditions (with and without cognitive feedback), which are measured over time.

H1a: Cognitive feedback will increase cognitive control.

H1b: Cognitive feedback will result in a uniformly high level of cognitive control over time.

To attain strategy convergence, the decision maker needs to know the other members' decision strategies and to be aware of the strategy

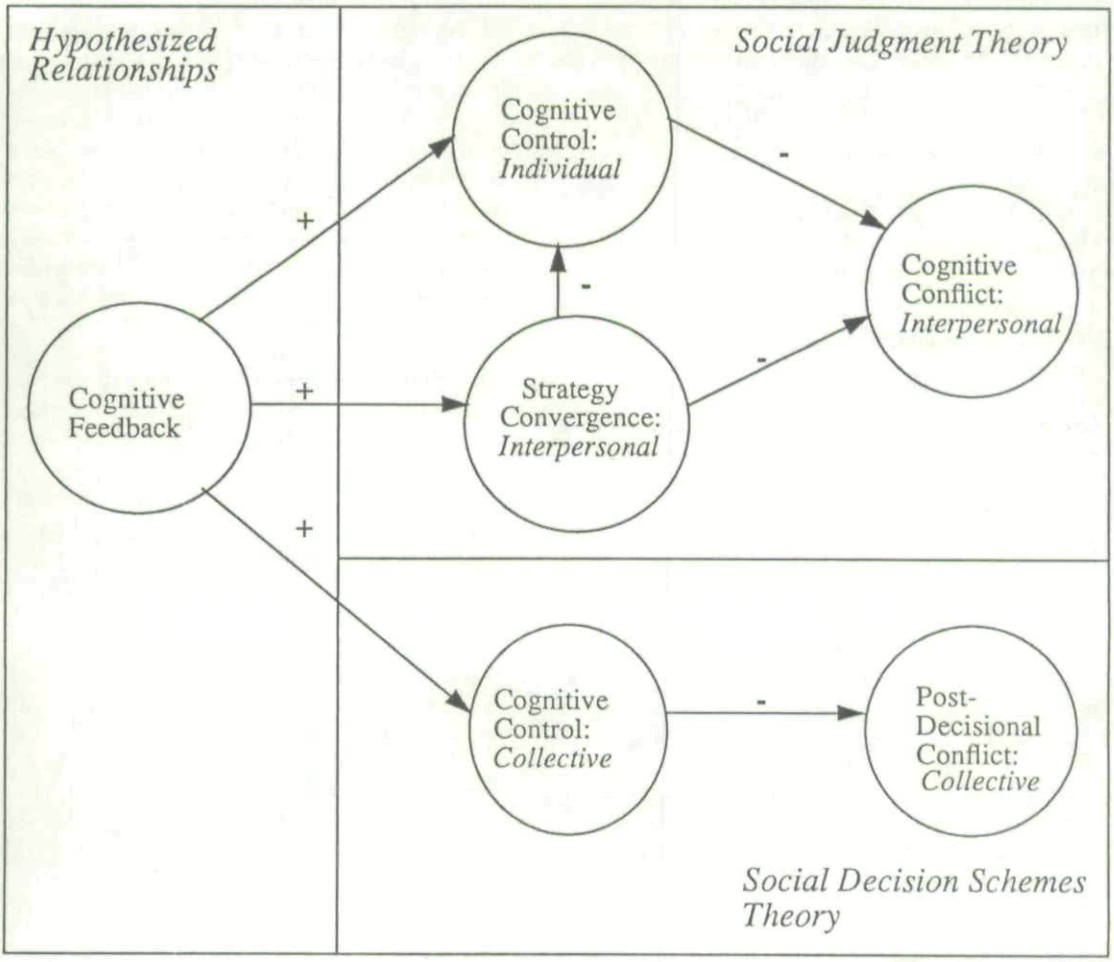


Figure 2. Impact of Cognitive Feedback at Different Levels of Analysis

differences among members. Apparently, given enough time, group members will learn about each other's viewpoint even if structured information is not provided (Brehmer, 1976). However, Jacoby, et al. (1984) stress the need for cognitive feedback that can explain deviations in decisions in order to efficiently learn the appropriate decision strategy for new situations. Brehmer (1979) also suggests that cognitive feedback, such as information about the relative weights for cues and the integration rules for combining information, is typically needed to learn new decision strategies. Furthermore, such information is needed to compare the new decision strategy with other decision strategies.

H2a: Cognitive feedback will increase strategy convergence.

H2b: Strategy convergence will increase over time regardless of whether cognitive feedback is provided.

Most of the studies mentioned above have been conducted with a regression formulation of social judgment theory (cf. Balzer, et al., 1989; Hammond, et al., 1980). This formulation provides indices of decision-making activity at the individual level (cognitive control) and the interpersonal level (strategy convergence). It is particularly effective in modeling the information integration phase of decision making, which is prevalent in the personnel screening example (Einhorn, et al., 1979; Goldberg, 1970). An extended version of this framework is used in this study (see Appendix).

In summary, it is hypothesized that cognitive feedback will increase cognitive control and strategy convergence of decision makers. It is also hypothesized that cognitive feedback will change their behavior over time. Furthermore, as long as strategies do not diverge, we should expect higher cognitive control to be reflected in lower cognitive conflict. The next section identifies an aspect of the collective level of decision making that may also be affected by cognitive feedback.

Cognitive feedback at the collective level

Recall the example of personnel screening. After the interpersonal activity, the group meets face to face to reach a collective rating for each job applicant. In contrast to the interpersonal activity, the group is viewed as a level of analysis with its own laws of functioning (Von Cranach, et al., 1986). Although these laws include social and task-related aspects of the collective activity (De Keyser, 1983), we concentrate only on task-related laws that bear on the cognitive aspects of group decision making. Unlike the interpersonal activity, strategy at the collective phase must include group decision rules for combining individual opinions into a collective decision.

Of the several theories that build on the idea of group decision rules, social decision schemes theory is the most relevant to this discussion (see Stasser, et al., 1989, for a review of the theory and its recent extensions). This theory assumes that (1) groups adopt group decision rules to yield group outcomes; (2) the same groups will use different rules in different situations; and (3) different groups may use different rules in the same situations. For example, for tasks in which members will recognize a correct answer when it is proposed, a good description is a continuous debate until truth "wins" unanimously. For judgment tasks, such as the personnel screening task in which there is no recognizable correct answer, a voting scheme may be more appropriate (Laughlin and Adamapoulos, 1982). Social decision schemes do not necessarily change individual decision strategies. Indeed, some group decision rules can produce group/individual differences without members changing but merely acquiescing (Davis, 1973).

The group members' personal consequences of having participated in collective decision may result in *post-decisional* conflict, i.e., a situation in which a person has committed to a decision that to him or her seems incorrect (Janis and Mann, 1977). This happens when there is public conformity without private acceptance, and it can be distinguished from the situation of public conformity with private acceptance by removing the group influence and eliciting individual behavior to see whether the compliant behavior disappears (Festinger, 1953).

A *group decision rule* specifies how to combine the members' decision outcomes into a group outcome (e.g., an average of the individual ratings of applicants) or how to combine members' decision strategies into a group decision strategy that will be applied to the specific cases (e.g., a majority rule on the appropriate weights to use in evaluating applicants). Like individual decision-making activity, collective activity also requires control to ensure the correct execution of group decision rules (Johnson and Davis, 1972; Savoyant, 1984). Indeed, effective groups usually exercise some form of control (Edinger and Patterson, 1983; Hirokawa and Pace, 1983). Groups, like individuals, suffer from cognitive limitations in exercising collective control (Chalos and Pickard, 1985; Steiner, 1972). For example, there are cognitive limitations on the task-related communication between the group members during the collective activity. In general, group members will be unaware of differences in decision strategies. Janis (1972) and Allison and Messick (1987) suggest that this occurs because groups tend to overestimate their unanimity. Stasser, et al. (1989) note that group discussions are usually dominated by information that is shared and supportive of existing preferences, barring the discussion of unshared information that may reveal distinct decision strategies. Cognitive feedback that describes the members' decision strategies and the differences between them should, therefore, reduce such process losses. The lower right corner of Figure 2 shows this relationship.

The objective here is to posit the impact of cognitive feedback on collective control. To do so, two dimensions to characterize collective control are introduced: level and degree. The *level* of collective control refers to whether the group decision rules determine how to combine individuals' decision outcomes (denoted as a lower level) or individuals' decision strategies (denoted as a higher level). The *degree* of collective control is the extent that a group decision rule exists and is executed. For higher levels of collective control, a high degree of collective control includes control over the execution of the combined decision strategy, which is analogous to cognitive control at the interpersonal level.

Because cognitive feedback includes information about decision strategies, we hypothesize that cognitive feedback will increase the level of collective cognitive control by focusing the group's decision-making activity on decision strategies as opposed to decision outcomes (Te'eni, 1991; Vallacher and Wegner, 1987). This should result in the formulation of group decision rules on how to combine decision strategies and how to control the execution of the combined strategy. Following the rationale of Hypothesis 1a, cognitive feedback should also increase the degree of collective control.

H3a: Cognitive feedback will increase the level of collective control.

H3b: Cognitive feedback will increase the degree of collective control.

Social decision schemes theory cannot predict post-decisional conflict. It, does however suggest that in situations of cognitive conflict, as opposed to interest differentials, a higher level of mutual understanding will lead to personal change rather than acquiescence. In other words, rather than comply with the collective decision but retain their personal decision strategies, group members will change their personal decision strategies (Davis, 1973). We should therefore expect that a higher level of collective control, if exercised, will result in a lower level of post-decisional conflict, as shown in the lower right corner of Figure 2.

In summary, social decision schemes theory suggests a phenomenon (collective control) at the collective level of analysis that may be affected by cognitive feedback. We introduced two dimensions of collective control (level and degree) and hypothesized that cognitive feedback would increase control along both dimensions. The next section discusses the methodology used to test the three hypotheses presented above.

Method

This section describes an experiment based on the personnel screening task used to illustrate concepts in earlier sections. Pilot tests with eight groups (four in each condition) were conducted in order to test the software and ensure that subjects could follow the instructions. The experimental procedures and software interfaces were revised as a result of the pilot studies. The final form of the experiment is described below.

Experimental design

Ninety graduate and undergraduate subjects (66 males and 24 females) participated in the experiment. The subjects were students majoring in information systems, and they received course credit for the experiment. Subject to students' time constraints, they were randomly assigned to 30 groups of three members. The groups were randomly divided into two conditions: 15 groups that were provided with cognitive feedback and 15 groups that were not. Other than the availability of feedback data (described later in detail), the human-computer interaction in both conditions was identical.

The experiment had three stages: training, experimental tasks, and post-experimental debriefing.

The purpose of the *training* session was to ensure that each group member used a different set of weights for aggregating the cues, thereby creating cognitive conflict within groups as a starting condition of the experiment (cf. Brehmer, 1980). Subjects were asked to learn, through a series of examples, the decision strategy followed by a hypothetical team of experts. The system provided each subject with a series of three-cue descriptions of applicants, one at a time, and asked the subject to rate each applicant. (In our example, the three cues were work experience, test scores, and education.) The system then provided the "actual" rating, i.e., the rating given to that applicant by the hypothetical "committee." This process was repeated for 60 trials. Committee scores given to different members of a group were made up of different sets of weights. For example, the committee scores for Member 1 of a group used weights of 0.8, 0.1, and 0.1 for the three cues, whereas scores for Member 3 used weights of 0.1, 0.1, and 0.8, respectively. Subjects performed the task individually, and no time limit was stipulated. The predictability of the task was high (R^2 = 0.90). The training took between 10 and 20 minutes.

The effectiveness of the training can be evaluated in two ways. We can ascertain the match between a subject's decision strategy and that of the committee (Brehmer and Hagafors, 1986). Our training produced a high matching value (0.95) and is consistent with past findings on high-predictability tasks (Brehmer and Hagafors, 1986; Hammond and Summers, 1972). The effectiveness of training can also be measured through the level of cognitive conflict in the group at the end of the training task. Our training produced a high level of cognitive conflict (0.61), consistent with values obtained in past studies (cf. Brehmer, 1976). Before starting on the experimental tasks, subjects in the feedback condition were also trained on how to interpret and use the cognitive feedback.

The *experimental tasks* included repeated instances of the personnel screening task. This stage was organized in four blocks, each block containing 10 cases, i.e., 10 applicants to be rated. The use of blocks enables an analysis of behavior over time. There is no agreement on the optimal number of blocks and trials within blocks (see Adelman, 1981; Hoffman, 1960; Schmitt, et al., 1976). The pilot study used five blocks (of 10 trials each), but the sessions proved to be too long for the subjects, and the number of blocks was reduced to four.

At the *debriefing* stage, subjects were asked to provide information on decision strategies and the use of feedback. Subjects described through self-reports whether they adopted explicit decision strategies in the individual and collective phases of the experiment, and if they did, what those strategies were. Cognitive feedback subjects also provided descriptions of how they used the feedback provided to them. Additionally, each subject was given 10 cases (i.e., applicants) and was asked to rate these cases (these ratings were taken to ascertain the post-decisional conflict).

The three stages of the experiment followed one after the other, in continuous sessions that lasted from 50 to 90 minutes in total. The sessions were conducted in a closed room in the presence of at least one experimenter.

Experimental task

Subjects were asked to screen applicants whose profiles were given as three integer evaluations of work experience, test scores, and education. Tasks with a similar structure have been used extensively in research on individual and group decision making (e.g., Tindale, 1989; Zigurs, et al., 1988) as well as in research on personnel selection (e.g., Dougherty, et al., 1986; Lane, et al., 1983). Additionally, personnel screening tasks with a similar structure are frequently used by large corporations and are performed in group settings.

Subjects worked with personal computers (IBM-compatible) that were linked through a local area network. Three computers were arranged in a 20 x 15 room so subjects could see only their own screens. Table 1 describes the experimental tasks. At the beginning of each block, each group member worked on a separate machine to rate 10 applicants. The system presented each applicant's profile through three cues (each on a 1-9 scale), and the subject keyed in an overall rating of that applicant (also on a 1-9 scale). The choice of the number of cues and the structure of the scales is in conformance with previous studies (e.g., Dougherty, et al., 1986).

Once a subject had completed the rating process for an applicant, the subject was provided access to information concerning the ratings provided by other group members (and cognitive feedback for subjects in the cognitive feedback condition). While no face-to-face communication took place at this stage, subjects had the opportunity to consider new information and adapt their own behavior by changing ratings. The subjects could revise their own decisions as often as they wished in view of updated information concerning the behavior of others (and cognitive feedback where applicable).

After all members completed their individual ratings, group members joined together at a single machine to formulate a collective rating for each applicant. There were no restrictions on communication while subjects arrived at their collective rating. Each group had a scribe who keyed in the ratings once the group as a whole agreed on a value. The scribe was chosen at random. An analysis of the results showed no differences in performance between the scribe and other members.

Table 1. Sequence of Events Within Each Block of the Experimental Tasks

	At the start of each block, each individual is given 10 cases. The individual does the following:
Individual Rating	(1) Each subject rates all 10 cases. (2) Subjects receive additional information concerning the ratings provided by other group members (and cognitive feedback if in cognitive feedback condition). (3) Subject revises ratings as desired. (4) Subject is free to iterate between steps (1) and (3) until he or she indicates that the ratings are final.
	After all members of a group have finalized their ratings, the group works together to arrive at a group rating for the same 10 cases.
Collective Rating	(1) Group makes estimates on all 10 cases. (2) Groups in cognitive feedback condition receive feedback. (3) Group revises ratings as desired. (4) Group iterates between steps (1) and (3) until the group members indicate that the ratings are final.

Human-computer interaction

For subjects who did not receive cognitive feedback, the computer screen used to complete the task appeared as in Figure 3. While subjects worked individually, the human-computer interaction was as follows:

> Subject S begins the interaction with a set of online instructions. After pressing any key, S sees 10 cases (i.e., applicants) in the bottom left window of the screen. S formulates a judgment on each case, rating each applicant with a value on a 1-9 scale. S can move up or down using the arrow keys and change ratings by typing over previous values. The bottom row always contains instructions on what is to be done next. When satisfied with the 10 ratings, S presses the END key. The screen is then refreshed with updated information (whatever information in the remaining windows of Figure 3 is available at that time). S then evaluates the information, and has the opportunity to revise any ratings. This process can be repeated until S presses the HOME key, which signifies that S has finalized his or her decisions.

In order to minimize learning problems, the interface for the support systems was the same in both phases. The following describes how group Member 1 performs the task, beginning with the interpersonal phase. Concentrate on the four windows on the bottom left side of Figure 3. In the left-most window, the numbers 6, 1, and 4 on the first line are an applicant's evaluations on work experience, test score, and education. Member 1 studies these evaluations and gives this applicant an overall rating of "3," which is shown in the second window. When information is available from Member 2, it is displayed in the third window at Member 1's request (similarly, Member 3's ratings are displayed in the fourth window). Member 1 continues to rate the applicants and revise the ratings until he or she is satisfied with the ratings. When all the group members finish their individual work, they begin the collective rating. At that time, the group observes the information in the first four windows and inputs its ratings in the fifth window (entitled "Group Estimate").

For subjects in the cognitive feedback condition, the screen used to complete the task appeared as in Figure 4. In comparison with Figure 3, several forms of cognitive feedback have been added in the three windows in the upper part of the screen. The cognitive feedback, along with the rest of the screen, was updated upon request.

Cognitive feedback was defined earlier as structured information about the decision strategy and its execution. It consisted of information on deci-

WORK EXP.	TEST SCORES	EDUCA-TION	MEMBER 1'S ESTIMATE	MEMBER 2'S ESTIMATE	MEMBER 3'S ESTIMATE	GROUP ESTIMATE
6	1	4	3	5	3	3
1	9	1	3	4	4	3
8	2	7	4	5	4	5
6	6	1	3	4	5	5
3	6	1	5	2	4	2
9	3	7	4	4	5	5
1	4	9	3	3	9	3
1	6	5	5	2	1	2
3	2	8	3	6	8	8
2	9	9	5	6	6	6

Enter a number between 1 and 9, then press END. Press HOME if the estimates are final

Figure 3. Screen for No Feedback Subjects

sion strategies, cognitive control, and strategy convergence, which were computed according to the formula of the regression formulation described in the Appendix. To the extent possible, we used graphical displays that have been found to be effective for approximate comparisons of quantitative information (Brehmer, 1984).

The relative weights given to cues are shown as horizontal stacked bars (Figure 4, top center window). The system calculated cue weights as follows. Beta weights were calculated from a multiple regression of cue values and the subject's estimates. Each weight was then transformed to represent percentages of the sum of squared weights (cf. Hoffman, et al., 1981). For example, the first beta value was transformed as follows:

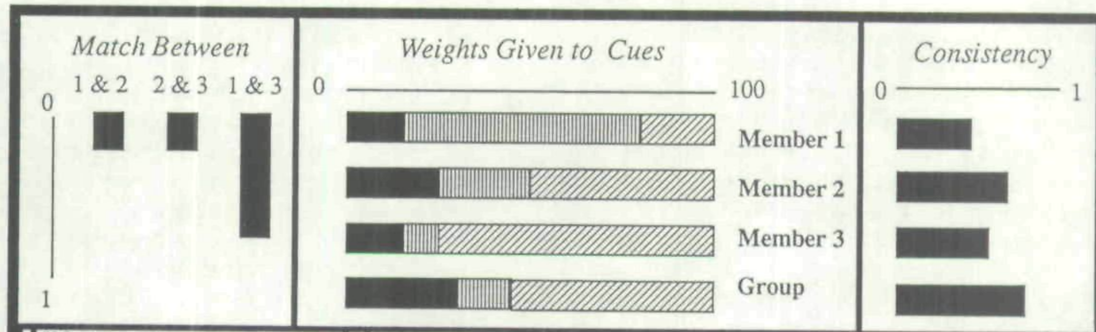
$$\beta_1^* = \beta_1^2 / (\beta_1^2 + \beta_2^2 + \beta_3^2)$$

Thus, beta values of 0.4, 0.8, and 0.2 were shown as 0.19, 0.76, and 0.05, respectively. Transformed weights on the three cues were then displayed by the system as a horizontal stacked bar.

Cognitive control is presented through individual consistency scores and an index of cognitive control, i.e., the cognitive control exercised by the decision maker. The individual consistency scores are the ratings that would be given by decision makers if they were entirely consistent in weighting the cues. The scores are displayed in the second columns of the four windows on the bottom of Figure 4. For example, Member 1 rated the first and second applicants with "3," and the respective consistency scores were "3" and "6." The horizontal bars, labeled as consistency in the top right window, display, for each member, the index of his/her cognitive control.[1]

The vertical bars (Figure 4, top left window) depict, for each of the three possible pairs, an index of strategy convergence, labeled as the

[1] Computations of the index of cognitive control are shown in the Appendix. The indices of matching and consistency are calculated on a continuum of 0-1. A score of 0 means completely inconsistent (or no match at all, as the case may be), and a score of 1 means complete consistency or matching. Subjects usually start off at the lower end. The idea of the feedback is to move them to as high a level as possible.



Work Exp.	Test Scores	Education	Member 1's Estimate		Member 2's Estimate		Member 3's Estimate		Group Estimate	
6	1	4	3	3	5	4	3	1	3	5
1	9	1	3	6	4	2	4	1	3	3
8	2	7	4	5	5	7	4	2	5	7
6	6	1	3	5	4	4	5	1	5	4
3	6	1	5	4	2	3	4	1	2	3
9	3	7	4	6	4	7	5	2	5	8
1	4	9	3	5	3	5	9	4	3	6
1	6	5	5	5	2	4	1	2	2	4
3	2	8	3	4	6	5	8	3	8	6
2	9	9	5	8	6	7	6	4	6	8

Enter a number between 1 and 9, then press END. Press HOME if the estimates are final

Note: ■ *Weight for work experience* ▥ *Weight for test scores* ▨ *Weight for education*

Figure 4. Screen for Cognitive Feedback Subjects

match between two members. The index of strategy convergence represents the extent to which the decision strategies of two decision makers are similar (the computation of the index of strategy convergence is shown in the Appendix).

Dependent measures

Table 2 summarizes the dependent measures used in the study. In order to test Hypothesis 1, we calculated an index of cognitive control in each block for each subject. For Hypothesis 2, an index of strategy convergence was computed for each group in each block. *Strategy convergence* is the average of strategy convergence indices between the possible pair combinations of members. Additionally, we computed the index of cognitive conflict to test the social judgment theory predictions related to it, as shown in Figure 2. The above measures were derived from estimates made in the final iteration within each block.

For process and manipulation checks, three variables were used to capture subjects' decision behavior and their use of cognitive feedback: the number of iterations made by each individual during each block, the average time taken for each iteration, and attention to feedback. The number of iterations indicates the extent to which a subject formulated and revised his or her own decision strategy. The average time for an iteration is a surrogate measure for the cognitive effort required in that iteration. Since the interpretation and use of feedback requires cognitive resources, we expect cognitive feedback subjects to iterate more often and spend more time per iteration than those not receiving cognitive feedback. Attention to feedback was assessed through a short questionnaire given during the debriefing stage. The questionnaire showed each element of feedback and asked the participant to identify it on a multiple choice format. They were then asked if they used the feedback in making their decisions, and in what manner.

For Hypothesis 3, the group decision rule was determined from the experimenter's notes and cross-checked with self-reports by group members. The self-reports on the formulation and use of group decision rules were matched with the experimenter's notes in the following manner. Subjects' responses were compared with the experimenter's notes and aggregated into an agreement matrix. The proportion of agreement and the Kappa coefficient were then compared. The raw proportion of agreement was 0.86. The Kappa coefficient, which measures the proportion of agreement obtained after separating the agreement attributable to chance (cf. Cohen, 1960) was 0.79, with a less than 0.01 probability that the true Kappa coefficient was outside the range 0.765 and 0.843. Information on group decision rules was separated into (a) whether groups formulated

Table 2. Measures

Test		Measure	Activity/Level of Analysis
Hypothesis 1		Index of cognitive control	Individual
Hypothesis 2		Index of strategy convergence (among group members)	Interpersonal
Process and manipulation checks (individual and interpersonal levels)	(1)	Computer log on number of iterations in each block and its association with cognitive control	Individual
	(2)	Computer log on average time for each iteration and its association with cognitive control	Individual
	(3)	Self-report on subjects' attention to cognitive feedback	Individual
Hypothesis 3	(1)	Group decision rules: experimenter's evaluation	Collective
	(2)	Group decision rules: members' self-reports	Collective
Process and manipulation checks (collective level)	(1)	Group's use of cognitive feedback: experimenter's evaluation	Collective
	(2)	Group's use of cognitive feedback: members' self-reports	Collective

an explicit decision strategy, and (b) at which point of time (i.e, block) in the experiment they did so.

The data on group decision rules were then combined to create a social decision schemes matrix (Tindale, 1989). A social decision schemes matrix enables us to analyze processes through which group members combine their individual decisions to form a group decision. For ascertaining a group's level of control, we counted the number of instances where group members decided on cue weights first and ratings later and the number of times when group members decided on ratings without explicitly considering cue weights. A group's degree of control was evaluated by determining when, if at all, a group decision rule was explicitly formed and followed. Additionally, post-decisional conflict was measured in each group by computing the distance (the inverse of the multiple correlation) between the group decision strategy and that of each member as derived from the ratings given during the post-experimental debriefing stage.

For the process and manipulation checks associated with the collective level of analysis, we evaluated the extent to which groups used cognitive feedback. The group's use of cognitive feedback was determined from the experimenter's notes on specific references made by group members about feedback, and cross-checked with self-reports of group members. For example, if a group member directed the group's attention to consistency scores, the group was considered to have used feedback in that block. We ascertained whether groups used cognitive feedback and the blocks in which they used such feedback.

Results

Cognitive feedback at the individual and interpersonal levels

Figure 5 depicts the cognitive control of individuals at the end of training and during the interpersonal phase. As Table 3a shows, subjects in the cognitive feedback condition exhibited higher cognitive control than subjects in the no feedback condition, across all blocks. Table 3b summarizes the MANOVA, which shows that the overall cognitive control of subjects was significantly higher in the feedback condition ($p < 0.001$). Hypothesis 1a is thus supported. Furthermore, the possibility that individual cognitive control was a function of membership in a particular group is ruled out.

Figure 5 also indicates that individuals in the cognitive feedback condition reached a high degree of cognitive control at the end of the first block (mean = 0.92, block 1) and maintained it over the remaining blocks (mean = 0.92, block 4). Subjects in the no feedback condition, on the other hand, appeared to have lost cognitive control in the second block and then recovered it gradually. The trend analysis in Table 3c indicates a quadratic trend. Table 3b shows a significant block*feedback interaction ($p < 0.01$), thereby suggesting that the quadratic trend is primarily present in the no feedback condition. Thus, the analysis confirms that while cognitive control in the cognitive feedback condition was uniformly high, control in the no-feedback condition decreased initially and then increased gradually. Hypothesis 1b is thus supported.

Figure 6 and Table 4a, which show the means of strategy convergence, indicate that cognitive feedback groups had higher strategy convergence than the no feedback groups. However, as the MANOVA in Table 4b indicates, the difference was not significant. Thus, Hypothesis 2a is not supported by the data. Hypothesis 2b predicts that strategy convergence increases over time. The MANOVA in Table 4b shows a significant within-subjects effect ($p < 0.001$), confirming our prediction.

Figure 2 posits an association between cognitive conflict and cognitive control, and between cognitive conflict and strategy convergence, respectively. The analysis shows a high negative correlation between cognitive control and cognitive conflict (-0.41, $p < 0.001$), thereby confirming that high cognitive control is associated with low cognitive conflict. The correlation between strategy convergence and cognitive conflict is also negative (-0.39, $p < 0.01$), indicating that high strategy convergence is associated with low cognitive conflict, as shown in Figure 2.

Overall, the process and manipulation checks indicate that individuals used the cognitive feedback. Computer logs show that subjects in the cognitive feedback condition iterated through

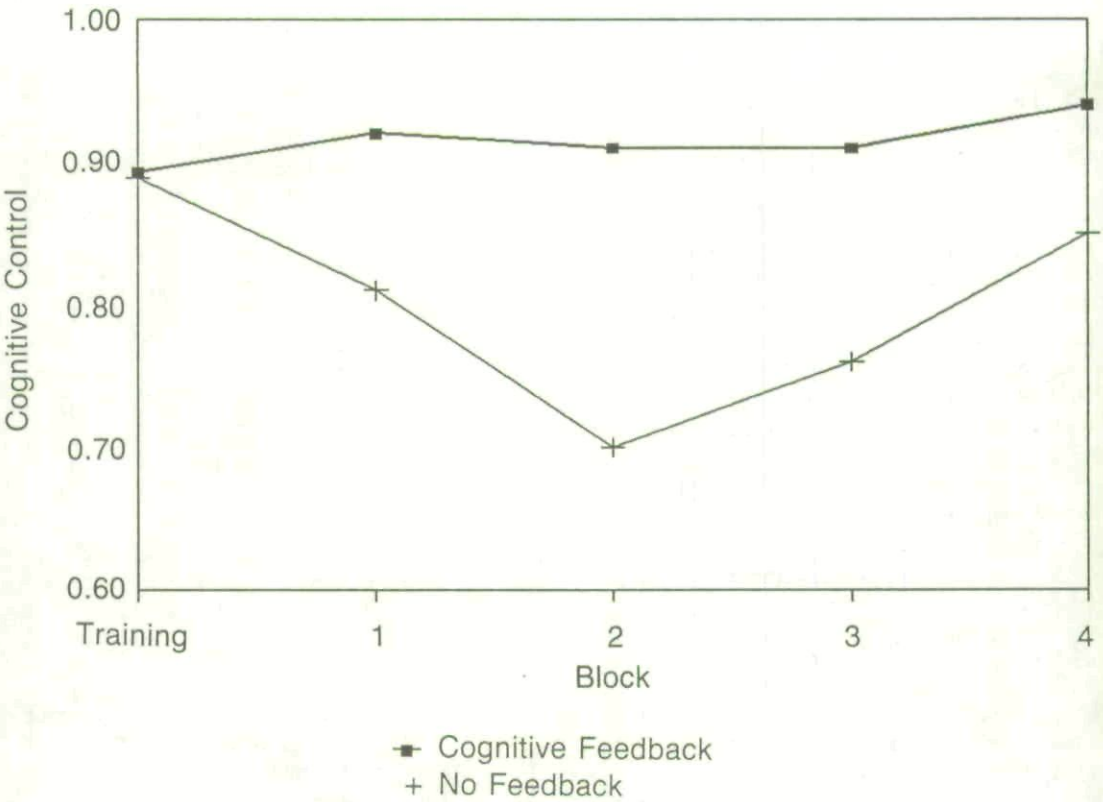


Figure 5. Cognitive Control of Individuals

their decisions more often than others. They made, on the average, 3.5 iterations per block in their decision processes, in comparison with an average of 1.9 iterations for subjects not receiving cognitive feedback (F[1,88] = 37.49, $p < 0.001$). Within the cognitive feedback condition, a comparison of the iteration patterns of the five best subjects in terms of cognitive control scores with the five worst subjects reveals that subjects with the best scores iterated, on average, significantly more often than those with the worst scores ($p < 0.05$). The corresponding difference in the no feedback condition is not significant. Thus, cognitive feedback is associated with more iterations, and more iterations are associated with higher cognitive control.

The logs also show that subjects receiving cognitive feedback spent more time adapting their decisions, an average of 176 seconds for each iteration, compared with an average of 136 seconds in the no feedback condition (F[1,88] = 21.19, $p < 0.001$). A test of comparison (like the one stated above) shows a significant difference ($p < 0.05$) between the best and worst subjects in the cognitive feedback condition, but none in the no feedback condition. Thus, there is a clear association between time per iteration and cognitive control when cognitive feedback is provided.

Self-reports indicate that the subjects attended to and used the feedback. In answering the questionnaire on the use of feedback, most subjects (40 out of 45) indicated that they used the feedback provided. Their responses indicate that such feedback was used in formulating and revising decision strategies and ensuring cognitive control. In summary, the iteration measures and self-reports indicate that the feedback provided was used by subjects to enhance their decision making.

Table 3. Effect of Cognitive Feedback on Subjects' Cognitive Control

3a. Means (and Standard Deviations)

	N	Block 1	Block 2	Block 3	Block 4
Cognitive Feedback	45	0.92 (0.06)	0.91 (0.08)	0.91 (0.07)	0.94 (0.06)
No Cognitive Feedback	45	0.81 (0.07)	0.70 (0.05)	0.76 (0.10)	0.85 (0.06)

3b. Multivariate Analysis of Variance for Dependent Variable: Cognitive Control (n = 90)

Source of Variation	SS	Degrees of Freedom	F-Value	*p*
Between Subjects				
Cognitive Feedback	1.894	1	83.80	0.0001
Cognitive Feedback(Group)	0.778	28	1.23	0.2485
Subjects Within Cells	1.356	60		
Within Subjects				
Block	0.605	3, 58	12.61	0.0001
Block*Cognitive Feedback	0.799	3, 58	4.84	0.0045
Block*Cognitive Feedback(Group)	0.279	84, 174	1.11	0.2872

3c. Analysis of Variance for Tests on Trends for Dependent Variable: Cognitive Control

Trend	Source of Variation	SS	Degrees of Freedom	F-Value	*p*
Linear					
	Mean	0.055	1	5.39	0.0237
	Cognitive Feedback	0.015	1	1.44	0.2351
	Cognitive Feedback(Group)	0.347	28	1.21	0.2614
	Subjects Within Cells	0.614	60		
Quadratic					
	Mean	0.349	1	29.90	0.0001
	Cognitive Feedback	0.158	1	13.51	0.0005
	Cognitive Feedback(Group)	0.293	28	0.90	0.6153
	Subjects Within Cells	0.700	60		

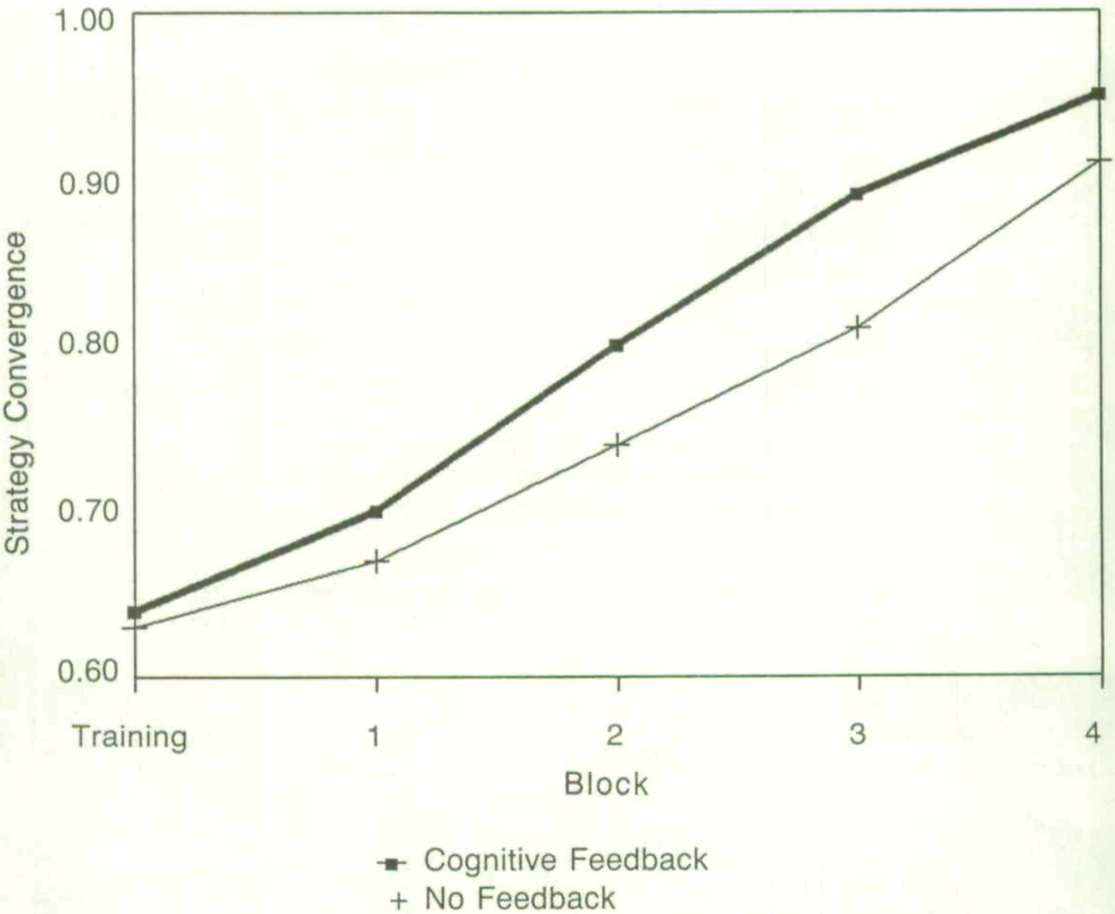


Figure 6. Interpersonal Strategy Convergence

Cognitive feedback at the collective level

Hypothesis 3 predicts the effect of feedback on group decision rules. A log-linear analysis of the data shows that the proportion of groups that first considered decision strategies (and then derived ratings after agreeing on cue weights) was significantly higher in the cognitive feedback condition (G-Square = 27.31; $p < 0.04$). In sharp contrast, the proportion of groups that considered ratings without any explicit formulation of decision strategies was significantly higher in the no feedback condition (G-Square = 31.27; $p < 0.01$). Thus, Hypothesis 3a is supported by the evidence.

Tables 5a and 5b provide information on the degree of group control. Table 5a shows whether groups formulated an explicit decision strategy to guide their decisions. Significantly more groups in the feedback condition formulated a decision strategy (Chi-Square(1) = 3.59, $p < 0.059$). As Table 5b indicates, feedback groups also managed to arrive at a strategy much earlier in the decision process (Chi-Square(2) = 5.664, $p < 0.059$). Hypothesis 3b is supported. Moreover, as Table 6 indicates, groups in the feedback condition actually used feedback, confirming that the experimental manipulation was successful.

Furthermore, there was a strong negative correlation between the level of collective control and

Table 4. Effect of Cognitive Feedback on Strategy Convergence

4a. Means (and Standard Deviations)

	N	Block 1	Block 2	Block 3	Block 4
Cognitive Feedback	15	0.70 (0.04)	0.80 (0.05)	0.89 (0.05)	0.95 (0.04)
No Cognitive Feedback	15	0.67 (0.05)	0.74 (0.04)	0.81 (0.06)	0.91 (0.07)

4b. Multivariate Analysis of Variance for Dependent Variable: Strategy Convergence (n = 30)

Source of Variation	SS	Degrees of Freedom	F-Value	*p*
Between Subjects				
Cognitive Feedback	0.092	1	1.64	0.2113
Subjects Within Cells	1.581	28		
Within Subjects				
Block	0.388	3, 26	13.68	0.0001
Block*Cognitive Feedback	0.990	3, 26	0.08	0.9682

post-decisional conflict (−0.45) and between the degree of collective control and post-decisional conflict (−0.40). These results are consistent with the relationship predicated in Figure 2 between collective control and post-decisional conflict.

Discussion and Conclusion

The objective of this paper was to study the impact of computer-based cognitive feedback on the individual, interpersonal, and collective levels of decision-making activity. Building on social judgment theory (Hammond, et al., 1980), it explains how cognitive feedback enhances an individual's cognitive control and facilitates strategy convergence between group members. Both types of impact reduce cognitive conflict. Using the social decision schemes theory (Davis, 1973), the paper also examines how cognitive feedback enhances a group's control over group decision rules. These relationships were then tested in a laboratory experiment.

Summary of findings

Groups of three worked on a personnel screening task. Group members rated the applicants individually and then reached a unified group rating. The results of the experiment show that the impact of cognitive feedback on cognitive control was statistically significant. Furthermore, cognitive feedback was hypothesized to maintain a high level of cognitive control over time, despite the adoption of new decision strategies in the process of strategy convergence. This was also confirmed. The impact of cognitive feedback on strategy convergence, although positive, was not statistically significant. The predicted negative associations between cognitive control and cognitive conflict and between strategy convergence and cognitive conflict were supported.

At the collective level, it was hypothesized that cognitive feedback would increase the degree and level of collective control. As predicted, groups that received cognitive feedback formulated group decision rules more frequently than groups that did not, and this difference was statistically significant. Moreover, the decision rules that cognitive feedback groups formulated specified the creation of collective decision strategies, as opposed to the combination of decision outcomes (ratings), which was more typical of the groups that did not receive cognitive feedback. Furthermore, the predicted negative association between collective control and post-decisional conflict was supported.

Limitations of the results

The generalizability of the results is constrained primarily by the nature of the task and subjects. The personnel screening task was relatively structured; the relevant information was pre-

Table 5. Effect of Cognitive Feedback on Collective Control

5a. Groups' Formulation of Decision Rule

	Decision Strategy Formulated?	
	Yes	**No**
Cognitive Feedback	12	3
No Cognitive Feedback	7	9

Note: This table indicates the number of groups that formulated a decision strategy in the course of the experiment. Thus, 12 groups in the cognitive feedback condition formulated a decision strategy. Chi-Square = 3.59; d.f. = 1; p = 0.058.

5b. Time of Initial Formulation of Decision Rule

	Block 1	**Block 2**	**Block 3**	**Block 4**
Cognitive Feedback	9	2	1	0
No Cognitive Feedback	2	1	4	0

Note: This table indicates the block in which a group first formulated its decision strategy. Thus, nine groups in the cognitive feedback condition formulated their initial decision strategy in block 1. Chi-Square = 5.664; d.f. = 2; p = 0.059.

Table 6. Use of Cognitive Feedback by Groups

	Block 1	**Block 2**	**Block 3**	**Block 4**
Cognitive Feedback Used	14	12	12	13
Cognitive Feedback Not Used	1	3	3	2

Note: This table indicates the number of groups that used cognitive feedback in a particular block. Thus, 14 groups used cognitive feedback during Block 1.

sented in the same format and the same strategy could be applied to new cases. Many such tasks exist and are supported by computerized systems, e.g., student screening, loan evaluation, investment portfolio, and technical ratings of vendor proposals for government contracts. Providing timely information on the process of decision making should be helpful in unstructured tasks as well. This may be difficult to investigate empirically, but on the basis of our preliminary findings, it may prove to be a fruitful challenge.

The second limitation was the sample population. The subjects were students with no personal stakes in the outcome of their deliberations. The analysis of the post-experimental debriefing, together with the experimenters' observations, indicated that the subjects were interested in the experiment and devoted the time and effort needed for serious deliberations. Nevertheless, replication with "real" and experienced stake holders is clearly needed.

Implications for the design of systems

How can these findings be translated to practical use? Figure 1 depicts three levels of information processing found in many situations of group decision making. We believe that our discussion points to two guidelines for the design and implementation of GDSS: (1) include cognitive feedback as an integral part of the GDSS at every level; and (2) design the human-computer interaction so there is an intuitive and effective transition across the components of feedback at all levels. To date, there is no formal methodology for developing GDSSs, but we believe that these guidelines should be part of any future methodology.

This approach has been used successfully in the development of SPIDER, a computer-based system for supporting business planning that is distributed across organizational functions (Boland, et al., forthcoming). At the individual level, the user engages in a private, self-reflective planning process that concentrates on an analysis based on the viewpoint of one particular organizational function. At the interpersonal level, users engage in dialogue to incorporate viewpoints of other functions into their own thinking processes. It would have been a mistake to assume that the interpersonal level can be supported by simply adding a mailing facility to the individual level system. A dedicated task analysis at the interpersonal level suggested a set of techniques that help assimilate new viewpoints into the old ones, techniques that had no place at the individual level. One such technique is a comparison between old and new cognitive maps. Conversely, typical GDSSs cannot be expected to support work at the individual level by simply adapting GDSS facilities to individual decision support.

It is not enough, however, to support each level of information processing separately by providing appropriate modes of human-computer interaction. The different modes must be designed concurrently to facilitate an easy and effective transition between interaction modes. One cannot build these modes in isolation and then hope for a smooth integration. Having satisfied the information requirements for each level, it is important to strive for consistency across levels without sacrificing functionality. Such consistency, both in terms of the format and the content of information, facilitates an easier transition between levels. This approach to system design is commonplace whenever the same user is expected to work in several interaction modes (Shneiderman, 1992). This study has shown that this approach is especially important in the transition between the individual, interpersonal, and collective levels because of the loss of cognitive control that the transition causes.

This study has shown that feedback about the decision-making process is an effective technique for helping the user regain control during the transition between levels. It is expected that less structured tasks will require even more feedback to balance the loss of control (Te'eni, 1992). Designers should look for additional techniques to facilitate an easier transition, such as techniques for translating the new information from other collaborators into familiar structures. A relatively easy example is an automatic translation of formats, say, from tables to graphs. This would make it possible to convert the incoming messages (at the interpersonal level) into the same format used by the receiver at the individual level. More complex translations of the content of incoming messages that make the message more comparable to the receiver's existing knowledge may also be helpful in facilitating an easier transition. Advances in data modeling are making such translations increasingly feasible.

Directions for future research

This study demonstrates that computer-generated feedback is an effective decision aid for dealing with cognitive conflict tasks. This conclusion is in line with DeSanctis and Gallupe's (1987) analysis of the possible roles of GDSS in a model of group tasks based on McGrath (1984). The model classifies group tasks according to the group's purpose in decision-related meetings: generating ideas, choosing alternatives, and negotiating solutions. In relating our study to McGrath's model, cognitive conflict tasks constitute a sub-class of negotiation tasks. It is important to limit our conclusions to the negotiating aspect of group decision making. Indeed, to the extent that control inhibits creativity, providing cognitive feedback too early in the phase of generating ideas may actually be counterproductive (Hogarth, 1982). Moreover, because this study adopted a linear model view of decision making, the conclusions should be limited to tasks where a similar perspective is appropriate. Future research should attempt to extend these concepts to other models of conflict that deal with ill-structured decisions (Hogarth, 1987; Janis and Mann, 1977).

This study also suggests the need to carefully examine the impact of cognitive feedback over time. As Figure 5 indicates, subjects not receiving cognitive feedback gradually recovered their cognitive control over time (albeit to a level lower than those that received cognitive feedback). Also, a few groups stopped using cognitive feedback after the first block (Table 6). This is perhaps indicative of over-confidence, a bias commonly observed in situations involving repetitive decisions (Hogarth, 1987). Thus, the results highlight a design dilemma of whether to try to correct users' biases by directing their attention to feedback over time. Future research should focus on the effect of time in determining the relative usefulness of different forms of feedback.

From a methodological perspective, this study demonstrates the utility of a multi-level framework for studying the use of GDSS (Figure 2). It facilitates the investigation of behavior at multiple levels, thereby bringing us closer to a realistic understanding of the behavior of GDSS users. In addition, this study has made an attempt at studying the process of computer-aided decision making. Future studies may benefit by adopting a more intensive method of process tracing, such as think aloud protocols, especially for more complex models of decision making where it is difficult to infer decision strategies from outcomes. Protocol analyses may also reveal how and why the use of feedback changes over time.

More research is also needed to understand how the technology should be designed so as to capitalize on the advantages of both interpersonal decision making and collective decision making (Te'eni, 1992). In particular, future research should examine the unresolved questions of the timing and format of feedback. Immediate feedback, while more effective than delayed feedback, also imposes greater cognitive load on decision makers (Jacoby, et al., 1984). Thus, the trade-offs between effort and accuracy entailed in presenting immediate versus delayed feedback need to be understood. Additionally, because the format of presentation of information affects decision behavior (Payne, 1982), future research should investigate the differential effectiveness of multiple formats of presentation of feedback. Guidelines are also needed on general GDSS design issues, such as the frequency of information refreshes, the exchange of interpersonal information (cf. Ellis, et al., 1991), and the manner in which cognitive feedback mechanisms should be incorporated within the overall architecture of GDSS. We hope these questions will trigger future research.

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Appendix

Social Judgment Theory—A Regression Formulation

This appendix provides a regression formulation of group decision making based on social judgment theory.[2] We begin with a two-system view of the theory and extend it to capture interpersonal decision making in tasks where there are no optimal solutions.

A Two-System View

Figure A1 presents a regression formulation of the social judgment theory (Dudycha and Naylor, 1966). The formulation has three components: the task structure, the decision maker, and the environment. The task structure is constituted by a set of cues ($X_1, X_2, ..., X_n$). In the personnel selection task described earlier, the cues constituting the task are: work experience, test scores, and education. The decision maker's decision, Y_s, is defined in the right hand side of the model. The *consistency score* for each decision indicates the score that would be given by a decision maker if the person had been entirely consistent with his or her decision strategy. Consistency scores are calculated by computing beta weights from a multiple regression of cue values and the decision maker's estimates, and then multiplying the beta weights with the cue values. Thus, we get:

$$\hat{Y}_s = \beta_{e,1}X_1 + \beta_{e,2}X_2 + \beta_{e,n}X_n$$

and

$$Y_s = \hat{Y}_s + Z_s, \text{ where}$$

$\hat{Y}_s$ denotes the consistency score for a decision Y_s, and Z_s is the residual.

The cognitive control exercised by a decision maker is measured by the *index of cognitive control* (R_s), and is operationalized as the multiple correlation between the cues and judgments (Hursch, et al., 1964). From the propositions of multiple regression theory (Tucker, 1964), we get:

$$\text{variance } (\hat{Y}_s) = R_s^2 \text{ and}$$

$$\text{variance } (Z_s) = 1 - R_s^2.$$

Analogously, the left hand side of the model in Figure A1 denotes the environment (represented by the actual event, Y_e). The extent to which the actual event is similar to the model of the environment is known as task predictability (R_s), similarly operationalized as the multiple correlation between the cues and actual events. The predictability of a task depends on the nature of the task. Some tasks (such as credit risk of a loan applicant) are more predictable than others (such as stock prices).

The relationship between the decision maker and the task is captured through two measures: *accuracy* and *knowledge*. A decision maker's performance in a task is summarized through the accuracy index (r_a), which indicates the correspondence between the subject's response and the environmental event. Tucker (1964) has shown that:

$$r_a = \text{Covariance } (Y_e Y_s) = \text{Covariance } (\hat{Y}_e \hat{Y}_s) + \text{Covariance } (Z_e Z_s)$$

[2] The formulations described here are derived from Hammond and Summers (1972), Hursch, et al. (1964), and Tucker (1964).

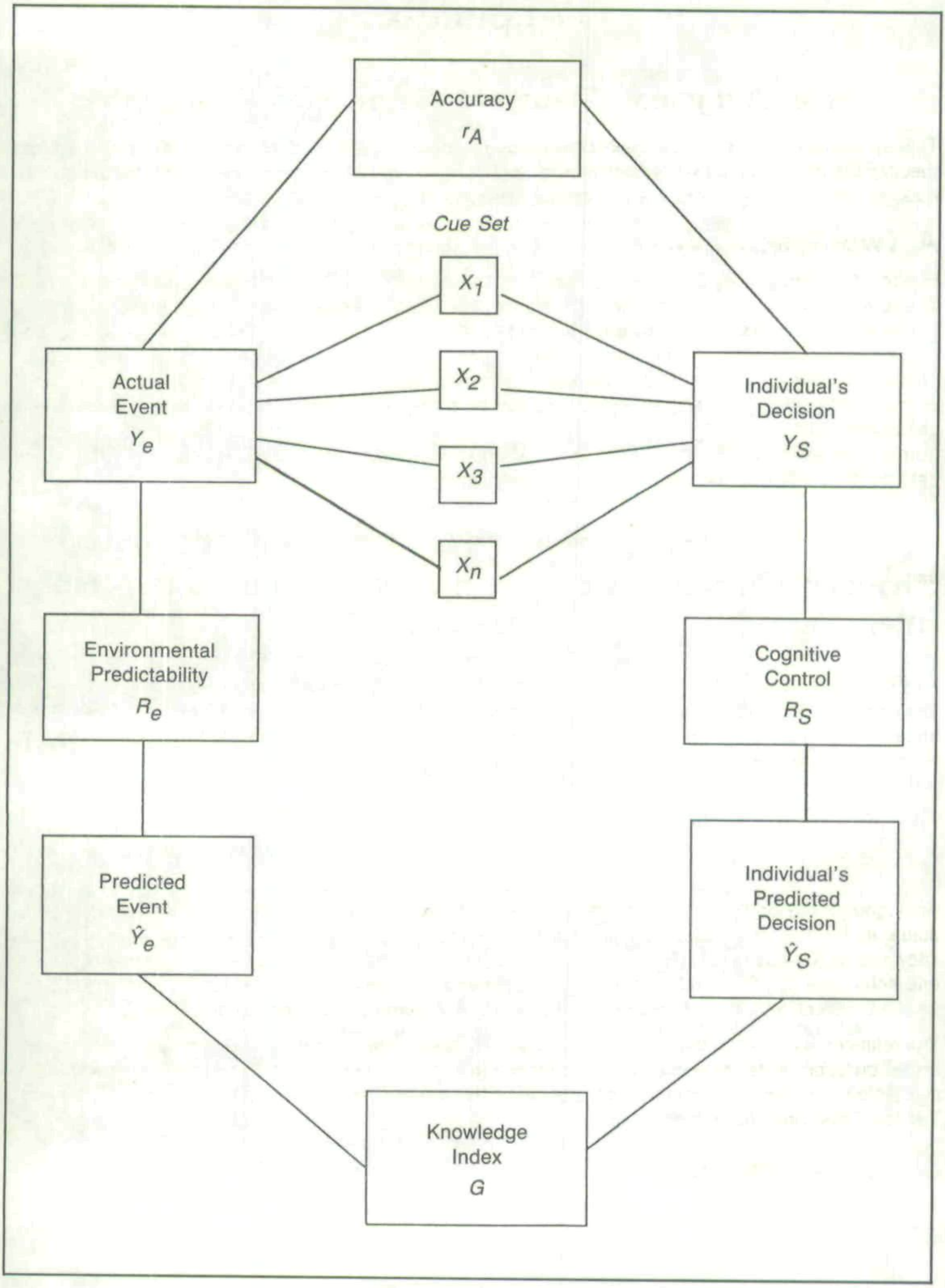

Figure A1. Lens Model: A Two-System View

Now, if the correlation of $(\hat{Y}_e \hat{Y}_s)$ is denoted by G, and the correlation of $(Z_e Z_s)$ is denoted by C, then the above can be written as:

$$r_a = GR_eR_s + C\,[(1 - R_s^2)\,(1 - R_e^2)] \tag{1}$$

G is known as the knowledge index and represents the similarity of the decision maker's use of cues with the environmental relationships. The knowledge index is interpreted as the extent to which a model of the decision maker's strategy is similar to that of the model of the environment. C is the correlation between the variance in the task system and the subject's judgmental system that is unaccounted for by G. When the systematic variance in the criterion can be accounted for by a linear function of the cue values, then the contribution of the second term on the right-hand side of Equation 1 is negligible (Hammond and Summers, 1972). Thus, Equation 1 can now be written as:

$$r_a = G\,R_e\,R_s \tag{2}$$

where:

r_a, or accuracy, is the correlation between the judgment and the actual event;

G, or knowledge, is the correlation between the linearly predictable variance in the judgment and the event;

R_s, or cognitive control, is the multiple correlation between the cues and judgments; and

R_e, or task predictability, is the multiple correlation between the cues and actual events.

An Extension of the Two-System View to Capture Interpersonal Interaction

The two-system view can be modified to capture interaction between multiple decision makers in group settings (Brehmer, 1979). We use the extended view to operationalize *cognitive conflict* and *strategy convergence*. To do this, we substitute the environment on the left hand side with another decision maker (illustrated in Figure A2). With this substitution, Equation 2 can be written as:

$$\overline{r_A} = 1 - G\,R_{S1}\,R_{S2} \tag{3}$$

where

$\overline{r_A}$, or cognitive conflict, is (1 - the correlation between the judgments made by person *S1* and those made by person *S2*).

G, or strategy convergence, is the correlation between the linearly predictable variance in *S1*'s judgment and *S2*'s judgment.

R_{S1} and R_{S2} (cognitive control of the respective decision makers) are the multiple correlations between the cues and judgments made by *S1* and *S2*, respectively.

The index of strategy convergence is interpreted as the extent to which the decision strategies of two decision makers are similar. Equation 3 can be extended to represent situations of three or more decision makers (Cvetkovich, 1973).

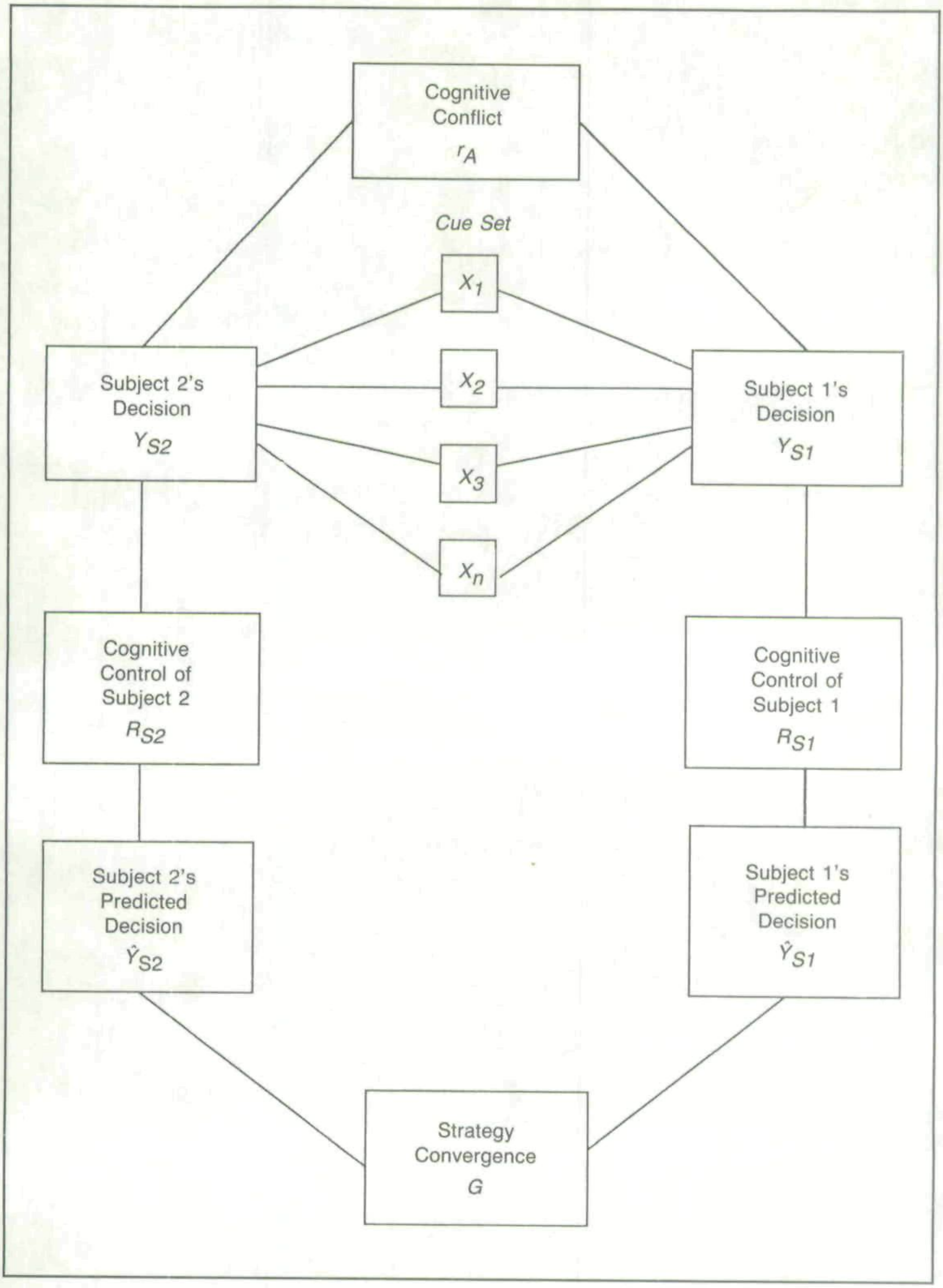

Figure A2. Lens Model: A Modified View