Spring 1999

The Ideal Free Distribution of Group Choice: A social psychology of human behavior

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THE IDEAL FREE DISTRIBUTION OF GROUP CHOICE:

A SOCIAL PSYCHOLOGY OF HUMAN BEHAVIOR

BY

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DISSERTATION

Submitted to the University of New Hampshire

in Partial Fulfillment of

the Requirements for the Degree of

Doctor of Philosophy
in
Psychology

May, 1999

UMI Number: 9926022

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Ann Arbor, MI 48103

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DEDICATION

I dedicate this dissertation, my proudest accomplishment yet, to the most important people in my life.

To my parents, Marie and Robert Kraft, your support and love made this dissertation possible. I am proud to be your son.

To my wife, Elizabethe Gail Effertz Plante, your love and wisdom helped me though the most difficult moments. I am proud to be your husband.

To my mentor, Professor William (Billy) M. Baum, your behavior inspired me. I am proud to call you my academic father.

ACKNOWLEDGEMENTS

I wish to acknowledge all the people who helped me complete this dissertation. My dissertation co-chairs, Professor William Baum and Professor Victor Benassi guided me well. Without their direct guidance, I would not be the psychologist I am today. My dissertation committee members, Professor Rebecca Warner, Professor Ellen Cohn, Professor Lawrence Hamilton, Assistant Professor B. Cliff Brown, and Assistant Professor Suzanne Mitchell, all served on my committee admirably and partook in an adventure of behavior analysis, social psychology, and sociology. Many graduate students shared their insights at our lab meetings and many thoughtful comments were incorporated into this dissertation. The Graduate School supported my research with Research Enhancement Awards and Travel Awards for conference presentations. My dearest wife, Elizabethe, endured many impromptu lectures on the IFD of Group Choice, listened to all my ranting, and helped me pursue my dreams. She made me feel intelligent even when I felt obtuse.

I thank you one and all.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

THE IDEAL FREE DISTRIBUTION OF HUMAN BEHAVIOR: A SOCIAL PSYCHOLOGY OF GROUP CHOICE

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JOHN R. KRAFT

University of New Hampshire, May, 1999

This dissertation presents an experimental analysis of social behavior. The behavior is called Group Choice (Baum & Kraft, 1998) and the analysis is a social foraging model called the Ideal Free Distribution (IFD; Fretwell & Lucas, 1970). The IFD is a social foraging model that describes the distribution of a group of foragers in a patchy environment. Group Choice describes group members engaging in two behaviors. The IFD suggests that group members engage in two behaviors in the same relative relation to the consequences obtained from those behaviors. The IFD of Group Choice is analogous to the Matching Law analysis of individual choice (Baum, 1974; Herrnstein, 1961, 1970; Kennedy & Gray, 1993).

The seven experiments of this dissertation used an IFD analysis of Group Choice. The experiments required small groups of humans (Ns = 12 -18) to engage in two behavioral alternatives. In Experiment 1, the group members sat in Row A and Row B chairs. In the remaining six experiments, the members of the groups chose blue and red cards. Different amounts of points were distributed to participants who chose each behavioral alternative. Each participant obtained points and the three highest point winners in each experiment won cash prizes (i.e., $50, $20, and $10). In Experiments 1,

2, 7a, and 7b, different amounts of points were shared among all subgroup members on each trial. In Experiment 3 and 4, unequal amounts of points were awarded probabilistically to one member of each subgroup on each trial. In Experiments 5 and 6, equal amounts of points were distributed to one subgroup member on every trial and only on some trials to a member of the other subgroup. The primary independent variable in each experiment was the ratio of points obtained from behavioral alternatives and the primary dependent variable was ratio of the average number of group members engaged in the two behaviors. Other comparisons included the effects of different behavioral alternatives, different competitive weights, different methods of point allocation, the opportunity for perfect and only imperfect IFD solutions, and the differences between participants uninformed choices (before-switch data) and informed choices (after-switch data). Other analyses included a detailed examination of the relations between the individuals' choices and the groups' choices.

The results showed consistent IFD matching of the groups' choices to the point distributions when unequal amounts of points were shared among subgroup members (Experiments 1, 2, 7a, and 7b). In contrast, the groups undermatched point distributions when the points were allocated probabilistically. Groups tended to match to the same degree regardless of the type of behavior alternative (i.e., sitting in chairs or choosing cards). Not being able to ideally distribute (imperfect solutions) tended to reduce group sensitivity to the distribution of points. Assigning different competitive weights to participants did not have an impact on group choice. Overall, the groups' choices before knowing what others chose were more variable, but similar to the choices made after knowing what others chose. Analyses of individuals' consistency in preferences and obtained points from block-to-block of trials failed to reveal order on the individual level that could explain the group level results. A promising analysis of individuals' choices between alternatives and obtained points from those alternatives also did not reveal a satisfactory explanation for group level results.

The analogy between an IFD analysis of Group Choice and a Matching Law analysis of individual choice may be far reaching . Whereas an individual's responses match the relative consequences, group members' behavior match the relative resources. Basic equations for both relations can be expressed in ratio form and generalized to account for deviations as a power function. Undermatching is the common result for both lines of research. Whereas the Matching Law describing individual choice became the foundation for the quantification of the Law of Effect and decades of fruitful research, it remains to be seen if the IFD of Group Choice stimulates similar progress. If the analogy between the Matching Law analysis of individual choice and the IFD of Group Choice is thoroughgoing, this research may provide the foundation for the quantification of a social level Law of Effect.

CHAPTER 1: Introduction and Literature Review

> "We are concerned here simply with the extent to which an analysis of behavior of the individual which has received substantial validation under the favorable conditions of a natural science may contribute to the understanding of social phenomena. To apply our analysis to the phenomena of the group is an excellent way to test its adequacy, and if we are able to account for the behavior of people in groups without using any new term or presupposing any new process or principle, we shall have revealed a promising simplicity in the data. This does not mean that the social sciences will then inevitably state their generalizations in terms of individual behavior, since another level of description may also be valid and may well be more convenient."
>
> B. F. Skinner (1953), Science and Human Behavior, p. 298

There are many ways to study social events. This dissertation presents an experimental analysis of social behavior. The experimental analysis of social behavior, like the experimental analysis of individual behavior, is an environment-oriented science of behavior grounded in Radical Behaviorism (Hineline, 1990). B.F. Skinner developed a science of behavior (known as the experimental analysis of behavior, behavior analysis, and operant psychology) and the philosophy of the science of behavior (known as Radical Behaviorism) to describe behavior selected by its consequences (Skinner, 1938, 1953, 1963a, 1963b, 1974). The cornerstone of Skinner's approach to behavior was the three-term contingency (i.e. antecedent, behavior, and consequence) and the majority of research employing the three-term contingency investigated the behavior of the individual. Skinner first addressed applications of the science of behavior to social behavior in Science and Human Behavior (1953), his first psychology textbook. Although a thoroughgoing account of social behavior has not developed as robustly as the analysis of individual behavior, experimental analyses of social behavior have been presented (Guerin, 1994; Lott & Lott, 1985). This dissertation presents an advancement in the experimental analysis of social behavior that is consistent with Skinner's analysis of behavior and the social psychology of human group behavior.

With this dissertation, I present a social level analysis of group behavior. The social behavior is called Group Choice, and the analysis is called the Ideal Free Distribution of Behavior. I use the phrase Group Choice because a group can be faced with the choice of what proportions of members should engage in two behaviors much the same way an individual might be faced with the choice to engage in two behaviors (Baum & Kraft, 1998, Kennedy & Gray, 1993). I borrowed from behavioral ecology the conceptual and quantitative model of the Ideal Free Distribution of foragers to describe group choice (Fretwell & Lucas, 1970, Kennedy & Gray, 1993). The analysis of Group Choice with the Ideal Free Distribution of Behavior is rooted in the behavioral ecology of social foraging behavior and the experimental analysis of individual choice behavior. This description of Group Choice is an example of the social psychology of small groups (Levine & Moreland, 1998) and is similar to Game Theory accounts of social behavior (Davis, 1970; von Neuman & Morgenstern, 1944) . To introduce the series of experiments that comprise the original work of this dissertation, I review: (1) the basic concepts of Skinner's approach to the experimental analysis of behavior, (2) the experimental analysis of social behavior, (3) the Ideal Free Distribution of foragers in the context of Optimality theory, and (4) Game Theoretic accounts of group behavior. I review also (5) the previous Ideal Free Distribution analysis of human group choice, and (6) I present my experiments. In conclusion, (7) I discuss the implications of the experimental results as an advancement in the experimental analysis of human social behavior.

The Experimental Analysis of Behavior

The Skinnerian approach to understanding behavior is different at its root from almost every other account of behavior -- hence it is known as Radical Behaviorism (Chiesa, 1994). The basic unit of analysis is the operant contingency, which consists of an antecedent stimulus, a behavior, and a consequence. The focus of the operant contingency is on two relations between the three terms. First, future occurrences of behavior are affected by the consequences produced by previous behavior. Second, antecedent stimuli associated with the behavior-consequence relation set the occasion for future behavior to be emitted by an organism. When Skinner first articulated the three-term contingency of the operant, it was more common for psychologists to discuss how stimuli produced responses. This so called stimulus-response approach (S-R Behaviorism) to understanding behavior is the foundation of cognitive psychology that dominates contemporary social psychology (Fiske & Taylor, 1991; Markus & Zajonc, 1985). Skinner's radical change was to turn the S-R relation around and investigate the selective qualities of consequences on behavior.

Skinner introduced psychology to operant behavior with Behavior of Organisms (1938). In the early 1930's, Skinner conducted research on the eating behavior of rats that required rats to press a lever to produce a food pellet (Hilgard, 1956). The rats were placed in a chamber with a single lever and a receptacle for a food pellet to be obtained by the rat. When the rat pressed the lever a food pellet was delivered and the lever press was recorded on a cumulative recorder. To conserve food pellets, Skinner required more than one lever press for a single food pellet and found that responding was sustained. This result led Skinner to describe the reinforcement of response classes rather than solitary responses. Responses formed a response class based on their common environmental effect. Soon thereafter, many researchers began operant research to determine the functional relations between responses and their consequences.

Initially, Skinner referred to the "strengthening" effect of consequences on response classes (Ferster & Skinner, 1957; Skinner, 1938), but later described the effect as "selective" (1981). This shift in terminology aligned behavior analysis with biological evolutionary theory. Evolutionary theory has become a unifying paradigm in the biological sciences and natural selection is the 'causal mode' of evolutionary theory. Skinner referred to natural selection as the first kind of selection and operant conditioning as a second kind (1981). The two types of selection correspond to historical changes in phylogenic and ontogenic events (Baum, 1994). On the phylogenic level, species exist as they do because of many events that occurred in the past. Some genetic variations within a species were more fit in a certain environment and reproduced more than less fit variations. Consider the case of the British Peppered Moth (Biston betularia) whose recent evolution was observed (Patterson, 1978). Before the industrial revolution of the 1800's, B. betularia was white with a few black specks and camouflaged well when resting on the trunks of trees during daylight. One can imagine that much lighter and much darker genetic variations of B. betularia were consumed by predators at higher rates than the lightly peppered variation. But during the industrial revolution the soot from coal burning factories and homes blackened the British landscape, especially near large cities such as Manchester. Darker genetic variations camouflaged better than lighter variations on soot-covered tree trunks. Beginning in the mid-1800's, the first black B. betularia was caught and soon became more common with each new generation. In only fifty years, the majority of B. betularia were black, especially near industrial centers. The explanation for black B. betularia was historical -- the different variations of B. betularia in past generations were met with different levels of successful reproduction (i.e., fitness more generally). The three requirements for phylogenic evolution were present in the above situation: (1) the environment favored darker moths, (2) variations in color were genetic in nature and could be passed on to subsequent generations, and (3) competition existed between lighter and darker moths. Skinner recognized that consequences selected behavior in much the same way that the environment selected characteristics of species.

Skinner embraced the causal mode of selection as a scientifically acceptable alternative to mentalist explanations of behavior. Just as some variations of genetic phenotypes may be more successful than others in some environments, some variations of behavior are more successful in some environments and occur more frequently during the lifetime of an individual. Consider the example of shaping a food-deprived pigeon's key-pecking to obtain food pellets (Ferster & Skinner, 1957). When placed in an operant chamber, the pigeon emits behavior. As the pigeon nears or orients to the key, the experimenter delivers a food pellet. Soon the behavior of orienting to the key occurs with more frequency. Eventually, the pigeon may touch the key or even peck at the key in an exploratory manner and then receives food. If the experimenter requires the pigeon to peck the key to obtain food, key-pecking increases in frequency. Like the evolution of the British Peppered Moth, changes in shaped behavior occur with selection by the environment over time. Both natural selection and selection of operant behavior are historical explanations and recognized as alternatives to metaphysical entities as causal modes. Just as Darwin's natural selection replaced an all-powerful Creator in a science of organisms, Skinner's selection by consequences replaced the mind (or personality, schema, etc.) in a science of behavior.

Richard Herrnstein (1961, 1970) quantified the selective characteristic of consequences on responses with the Matching Law. Herrnstein's original Matching Law equation described an individual's allocation of behavior to two alternatives with rates of reinforcement associated with each alternative (usually different rates). The matching law equation was originally expressed in proportional form, but it has been re-expressed equivalently in ratio form:

$$\frac{B_1}{B_2} = \frac{r_1}{r_2} \quad (1)$$

where B_1 and B_2 equal the number of responses (behavior) allocated to each alternative and r_1 and r_2 equal the measures of obtained reinforcers from each alternative. The contribution of Herrnstein's equation was that an individual's choices between two alternatives were seen as a relative function of reinforcement instead of an absolute function. Even when describing an organism's behavior on a single operandum, the organism can still be described as making a choice between the operandum and all other activities. The classic Matching Law experiment had a pigeon in an operant chamber with two keys lit with different colors and a food hopper. The schedule of reinforcement associated with key 1 might be variable-interval 15 (which delivered a food reinforcer after 15 seconds had passed, on average, if a peck occurred) and with key 2 might be variable-interval 30 (which delivered a reinforcer after 30 seconds had passed, on average, if a peck occurred). With these schedules of reinforcement, the reinforcer ratio equaled 2:1 and the pigeon was predicted to distribute its key pecking, over time, in a 2:1 ratio. In typical Matching Law research, researchers varied the reinforcement ratios and observed the corresponding changes in the behavior ratios. Initially, Herrnstein found that relative rates of responding equaled (i.e., matched) relative rates of reinforcement (Herrnstein, 1961, 1970).

Subsequent choice research found that individual organisms sometimes showed deviations from perfect matching. To account for these deviations, Baum (1974, 1979) proposed a generalized Matching Law that took the power function form of:

$$\frac{B_1}{B_2} = b\left(\frac{r_1}{r_2}\right)^a \quad (2)$$

where b equals a bias term and a equals a sensitivity parameter. When a and b equal 1, Equation 2 reduces to Equation 1. Bias (b) is the term to denote a preference for one key over the other that is independent of the effects of the relative rates of reinforcement.

Sensitivity (a) is the parameter that assesses the degree of matching. When the sensitivity parameter equals 1, then relative responding is proportional to relative reinforcement. If sensitivity is less than 1, then the behavior ratio is not as extreme as the reinforcement ratio (Baum called this undermatching) and if sensitivity is greater than 1, then the behavior ratio is greater than the response ratio (Baum called this overmatching). Another quantitatively useful feature of Equation 2, is that the logarithm of it,

$$\log\frac{B_1}{B_2} = a\log\frac{r_r}{r_2} + \log b \quad (3),$$

is a linear equation (i.e., y = mx + b), in which the sensitivity parameter is the slope of the line and log bias is the y-intercept. Contemporary Matching Law research uses this Generalized Matching Law (GML) to assess sensitivity and bias. By plotting the behavior ratio against the reinforcement ratio in double logarithmic coordinates of a scatterplot, a fitted regression line produces an accurate assessment of sensitivity (i.e., the slope) and bias (i.e., the y-intercept). Reviews of the experimental analysis of choice literature found consistent trends for undermatching (Baum, 1979, Wearden, 1982, Williams, 1988), but not enough to deem the Matching Law description inadequate. Nearly four decades after Herrnstein first published his Matching Law research, his eloquent equation still provides the fodder for innovative research.

Behavior analysts have made progress in describing and explaining how the environment selects the behavior of individual organisms in molar terms (i.e., extended period time). The Matching Law is a good example of moving away from molecular accounts of behavior. Previous to Herrnstein (1961, 1970), most behavior analysts followed Skinner's lead of using cumulative recorders to track the effects of each reinforcer on rate of behavior (Skinner, 1976). For example, on a fixed-interval schedule, a reinforcer is delivered after a certain amount of time has passed and the required behavior occurs. On a cumulative recorder, a researcher could observe the increase in behavior frequency just before reinforcer delivery, the cessation of responding just after reinforcer delivery, and increased responding again as the next reinforcer delivery neared (i.e., classic scalloped responding). Herrnstein's matching law research involved comparisons between rates of obtained reinforcers and rates of behavior over time. It is not possible with Matching Law research to observe the effects of individual reinforcers, but it can describe relatively long-term stable patterns. These stable patterns allow the quantification of behavior-environment interaction (Sidman, 1960).

The Experimental Analysis of Social Behavior

The experimental analysis of social behavior has developed more slowly than the experimental analysis of individual behavior. Behavioral approaches dominated social psychology in the early to middle 20th century, but they were S-R varieties. For example, behaviorists such as Clark Hull (1943) and Kenneth Spence (1948) proposed drive reduction models to explain social behavior, Miller and Dollard (1941) introduced imitative social behavior, and Mowrer (1947) described emotional learning with his dualistic theory, but these theorists proposed only variations of S-R behaviorism. Skinner's behaviorism was different and it is unclear if many social psychologists understood it. The experimental analysis of social behavior can be grouped into two categories: (1) social psychologists borrowing the framework of Skinner's behaviorism, and (2) behavior analysts delving into the realm of social behavior. Examples of these categories can be found in both literatures.

If the extent of social psychologists' understanding of Skinner's Behaviorism can be assessed from multiple editions of the Handbook, then it is clear that Skinner was never able to convince social psychologists that his behaviorism was different from other S-R behaviorisms. The telltale sign of misunderstanding Skinner was to call him an S-R theorist. William Lambert referred to Skinner as an S-R theorist in the 1954 edition. He was labeled similarly by Seymour Berger and W. Lambert in the 1968 edition, and by

Bernice Lott and Albert Lott in the 1985 edition. It may be due, in part, to Skinner's being misunderstood that social psychology no longer required a chapter on 'Behavioral Approaches' in the 1998 edition of the Handbook (Gilbert, Fiske, & Lindzey, 1998). Yet, there were examples of empirical research by social psychologists that did employ Skinner's experimental analysis of behavior reasonably well. Two good examples come from the social psychological literature on attitude formation and personal attraction. Insko (1965) used verbal reinforcers (i.e., the word 'good') to increase agreement with attitude statements one week after initial reinforcement (Insko, 1965). Lott and Lott (1960) demonstrated that if person A was rewarded for interacting with person B, then person A was attracted to person B on subsequent meetings. Both studies used the reinforcement of behavior to increase the frequency of subsequent behavior. Although not truly an example of the experimental analysis of social behavior, Daryl Bem (1967, 1972) used Skinner's nomenclature about verbal behavior to re-explain cognitive dissonance results as an environmental event and not an internal event. A few social psychologists have employed Skinner's behaviorism, but most social psychologists with a behavioral perspective used a mish-mash of other behaviorisms (i.e., S-R behaviorisms).

Behavior analysts experimented mostly with individual organisms, but occasionally delved into the more complex realm of social behavior. Skinner (1962) reported two social relations that resembled competitive and cooperative social interactions between two pigeons. The competitive interaction consisted of a ping-pong game between two pigeons. Playing ping-pong was maintained by reinforcing the winner when the opponent missed the ball. The cooperative interaction consisted of two pigeons pressing a set of corresponding buttons at roughly the same time. Cooperation was maintained by delivering reinforcers when both pigeons pecked the correct set of buttons at the same time. These two examples highlight the probable reason why so little experimental work on social behavior got done -- both experiments can be derived from the experimental analysis of individual behavior easily. For example, before the competitive social interaction began (i.e., the game) each pigeon received reinforcers for pecking at the ping-pong ball as it automatically rolled toward the pigeon. Then the two pigeons were introduced and the ping-pong game was formed. The behavior of each pigeon was the same regardless of whether a machine or another pigeon rolled the ball. The explanation for the behavior of the individual pigeons and the interacting pigeons was the same. For behavior analysts, especially Skinner (see the opening quote at the beginning of the introduction), the experimental analysis of social behavior was not urgent because it could be derived from the experimental analysis of individual behavior. Skinner's individualist view of social behavior was demonstrated by his bold account of verbal behavior, arguably the most complex social behavior, without any experimentation with verbally interacting people (Skinner, 1957). Skinner's position on the experimental analysis of social behavior may explain why so few behavior analysts experimented with social behavior. The behavior analytic study of cooperation and competition was the most notable exception to the scarcity of experimental analyses of social behavior (Schmitt, 1998).

Recently, Bernard Guerin proposed a comprehensive behavior analytic perspective on social behavior with his book, Analyzing Social Behavior: Behavior Analysis and the Social Sciences.(Guerin, 1994). Guerin, a trained social psychologist, adopted an explicitly Skinnerian framework to guide his analysis of social behavior. In his book, he presented an excellent introduction to contemporary behavior analysis, applied those concepts to general social behavior (including verbal and nonverbal behavior), and, concluded with applications to mainstream social psychological topics (e.g., attitudes, conformity, attributions, social constructed identities, and organizational behavior). Guerin's definition of what constitutes social behavior was inclusive. Mostly, he avoided defining what is and what is not social behavior because it is not clear how to do so. While it is convenient to say that social behavior involves the behavior of two more organisms of the same species, it is not obvious what constitutes "involving others". Others may be involved in the past, present, or future as contextual stimuli or consequences. Instead, Guerin approached the issue pragmatically and suggested that we approach any behavior as social behavior depending on the situation. Guerin's approach is to do the research and show what is useful about describing behavior as social behavior. A more important distinction divides social behavior into verbal behavior (as defined by Skinner) and nonverbal behavior. Guerin argued that verbal social behavior may have special properties, and nonverbal social behavior may be more like standard individual behavior. With nonverbal behavior, the other person acts like any other object in the environment (i.e., stimulus or consequence). Guerin's position on mainstream social psychology (even cognitive social psychology) is that the basic data assessing behavior are good and only need better explanations. Guerin argued that mainstream social psychology hid or implied the environmental consequences of social behavior. For example, one classic experimental manipulation was to suggest to subjects that they would have to meet again the persons with whom they were interacting. The implied consequence was that the person would deliver reinforcers or punishers to the subject at the next meeting. Guerin suggested that the manipulation worked because participants had experiences in the past with behaving a certain way when one must interact again with another. Other manipulations used in social psychological experiments that imply consequences include forewarning subjects that they will need to explain their behavior, responsibility for others, anonymity with others, evaluation by others, and others having control over consequences. One or more of these manipulations have been used in social psychological research topics such as conflict and cooperation, deindividuation, decision making, attitudes, attributions, negotiation, social loafing, and helping. Guerin suggested that behavior analysts could advance social psychology by making the implied consequence explicit and manipulating the consequences instead of assuming them.

Guerin's latest thinking on social behavior is based on the relation between population and resources (Guerin, in preparation). By focusing on populations and resources, Guerin takes a molar perspective (or the Big Picture perspective, as he wrote). The relation between populations and resources is sometimes immediate and easily observed, but more often the relation is not easy to observe because the relation is a correlated pattern of events that extends over long periods of time. Populations are groups of individuals who share or compete for resources and resources are events or things that can be obtained through behavior. Guerin presented several principles to guide the social psychological research of population and resources. The first principle is, "as resources increase, population usually increases all else being equal". For example, as more parking spaces are provided at an institution, more people drive their cars. This first principle relating population and resources is the cornerstone of his approach. Other principles include (2) as a population grows, the resources per person become less, (3) as resources decrease, competition increases and becomes "nastier", (4) scarce resources produce coalitions, and (5) new social behaviors emerge with coalitions. One of the main questions that Guerin seeks to answer is how social behavior changes when resources are allocated differently. Game Theory research (discussed later) has produced some answers. For example, by having individuals compete for resources, researchers can manipulate conditions that lead to more competition or more cooperation, protection against exploitation when cooperating, or retribution for being exploited. Guerin's description of the relation of population and resources is still in progress and many details still need empirical verification. One asset of Guerin's approach is its connection with many different environment-oriented social/behavioral sciences, such as ecology, evolutionary theory, demography, geography, politics, social anthropology, behavior analysis, and social psychology. Another field of study that is consistent with Guerin's approach is foraging theory of behavior ecology (Stephens & Krebs, 1986). Most foraging theories address the behavior of an individual seeking and obtaining resources, but some theories are social in nature. The Ideal Free Distribution of foragers is one such theory that quantifies the relation between a population of foragers and resources.

Ideal Free Distribution of Foragers

Behavioral ecologists have long studied foraging behavior of individual organisms, and recently behavior analysts have joined the field. The two areas have benefited mutually from collaboration. In general, behavioral ecologists contributed by describing the evolutionarily significant factors that influenced foraging, and behavior analysts contributed by measuring and quantifying those relations in operant chambers. Like most examples of the experimental analysis of behavior, experimentation by behavior ecologists mostly focused on the foraging behavior of the individual. One of the few examples of a social foraging theory is the Ideal Free Distribution of Foragers. The experimental analysis of the social behavior involved with the IFD of foragers represents a new and productive collaboration between behavioral ecology and behavior analysis.

The IFD is a theory or model that falls under the rubric of Optimal Foraging Theory. In general, optimal foraging theorists assume that animals behave so as to increase evolutionary fitness, and, given some constraints on behavior, predictions can be made about behavior (Stephens & Krebs, 1986). Nearly three decades ago, optimal foraging theorists, Stephen Fretwell and Henry Lucas (1970), made a prediction about the behavior of a group of foraging animals. They deduced that a group of foraging animals would distribute between resource sites ideally if foragers were free to sample sites and consume prey items. They referred to their prediction as the Ideal Free Distribution (IFD). In particular, Fretwell and Lucas were concerned with the habitat distribution of birds. For example, if Territory 1 was twice as suitable for habitation as Territory 2 (twice as many food resources, twice fewer predators, etc.), then twice as many birds should be distributed to Territory 1 as Territory 2. If in the last situation, birds did not distribute ideally (e.g., remained at equal numbers at each territory when twice as many resources were obtainable at one territory compared to the other), then each of the birds at the lean territory would gain less than the birds at the richer territory. The optimal choice for some of the birds in the lean territory would be to switch to the richer site until the IFD distribution was reached and all birds had equal gain. Some researchers refer to this phenomenon as habitat matching because the distribution of foragers matches the distribution of resource suitability (Pulliam & Caraco, 1984). Fretwell and Lucas based their IFD prediction on four assumptions. All foragers were assumed: (1) to maximize their net resource intake, (2) to have perfect knowledge about the obtainable resources, (3) not to differ in competitive abilities to obtain resources, and (4) to experience reduced resource intake as forager density increases at a resource site. When these assumptions have been reasonably met, the IFD of foragers has been observed. For example, Harper (1982) distributed food resources at two sites at a pond's edge (i.e., pieces of bread thrown into the water at equal or different rates) and observed the distribution of a flock of ducks. When the distribution of bread at the two sites was equal, the distribution of ducks was equal, and when twice as many pieces of bread were obtainable at one site compared to the other, then twice as many ducks foraged at the richer resource site. Fretwell and Lucas described the IFD of foragers as a fluid or dynamic event. If the group of foragers is not distributed ideally for any reason, the group is predicted to re-adjust toward an IFD. For example, if some of Harper's ducks at the rich site moved to the lean site, the group would have deviated from the IFD prediction. But, in time, some ducks would be expected to move to the rich site to re-establish the predicted IFD of foragers. The ducks that switch to the rich site might be the ducks that originally disrupted the IFD or they might be other ducks. This example highlights a remarkable quality of Fretwell and Lucas's model -- the IFD is silent about the behavior of the individual foragers (i.e., aside from the assumptions). Some of my previous research, conducted with Prof. William M. Baum, with a flock of pigeons supported a fluid description of the IFD of foragers (Baum & Kraft, 1998). In one experiment, we presented prey items (i.e., dried whole peas) at two resource sites (i.e., 1.2 m square areas separated by 1.2 m) at differing rates to a flock of pigeons. For example, at one resource site single peas were presented at a rate of 4 per minute and at the other site peas were presented at a rate 2 per minute. Overall, we found the flock of pigeons to be sensitive to the distribution of resources although they under-approximated the precise IFD prediction. During an experimental session, the total number of foragers fluctuated because other activities were available (e.g., courtship, preening, roosting) besides feeding in the two resource areas. Furthermore, we observed many pigeons switching from one site to the other. Nevertheless, the approximation to the IFD prediction of foragers remained constant despite the dynamic behavior of individual group members.

Since Fretwell and Lucas articulated the IFD, researchers have used different species and different prey items to test the predictions of the IFD. Many researchers use birds. In addition to Harper's ducks foraging for bread pieces, and Baum and Kraft's pigeons foraging for dried whole peas, other researchers used, for example, sparrows foraging for white millet (Gray, 1994), and starlings foraging for fly pupae (Imman, 1990). Fish are another common group used in IFD experiments. For example, Abrahams (1989) tested the IFD with guppies foraging for fly eggs, Croy and Hughes (1991) used sticklebacks foraging for Artemia (brine shrimp), Gillis and Kramer (1987) used Zebrafish foraging for Artemia, and Sutherland et al (1988) used goldfish foraging for tubifex worms. Some researchers used insects. Korona (1990) used flour beetles foraging for fresh flour and Jakobsen and Johnson used Daphnia (freshwater fleas) foraging for algae. One creative IFD project related 1800's sailing logs of whaling ships to independent records of whale censuses in the Galapagos and Northwest Passage (Whitehead & Hope, 1991). Although Fretwell and Lucas did not specify the IFD as species-specific, most researchers used animals that tend to forage in aggregates (i.e., birds, fish, and insects).

Fretwell and Lucas's IFD has been quantified as the matching relation in which ratio of foragers at two sites equals the ratio of resources obtained at the two sites (Kennedy & Gray, 1993). The equation may be expressed as:

$$\frac{N_1}{N_2} = \frac{R_1}{R_2} \quad (4)$$

where N_1 and N_2 equal the number of foragers at two sites, and R_1 and R_2 equal the resources obtained at those sites. Equation 1 is consistent with the above description of IFD. For example, when the ratio of obtained resources equals 2:1, then the IFD predicts a 2:1 forager ratio. Equation 4 is structurally equivalent and conceptually analogous to Richard Herrnstein's Matching Law equation (Equation 1, Herrnstein, 1961, 1970).

IFD researchers were also faced with the issue of assessing deviations from IFD matching. Until recently, measuring the degree of matching between the group distribution and the resource distribution had been idiosyncratic to the researcher. For example, some researchers used a t-test or ANOVA to determine whether the observed number of foragers at a site differed significantly from what was expected (Godin & Keenleyside, 1984; Harper, 1982). Recently, some IFD researchers used a generalized IFD equation that was analogous to GML (Fagan, 1987; Kennedy & Gray, 1993). The generalized IFD equation took the power function form:

$$\frac{N_1}{N_2} = b\left(\frac{R_1}{R_2}\right)^a \quad (5)$$

and logarithmic form:

$$\log\frac{N_1}{N_2} = a\log\frac{R_1}{R_2} + \log b \quad (6)$$

IFD bias refers to a group's preference for a resource site that is independent of the ratio of resources obtained at the sites, and sensitivity refers to the degree of matching between the forager ratios and resource ratios. Kennedy and Gray (1993) assessed the sensitivity parameter of previously conducted studies using groups of insects, fish, birds, and whaling ships. The common result was that groups of foragers were sensitive to resource distribution, but most groups tended to undermatch resources. Like reviews of GML research, Kennedy and Gray's review of IFD indicated a consistent tendency for groups of foragers to slightly undermatch obtainable resources. The mean sensitivity parameter (a) was .70. The general trend in IFD undermatching (i.e., too few foragers at a rich site and too many at a lean site) impelled researchers to amend the basic IFD model (Equation 1, and, more generally, Equations 5 and 6) to include additional parameters which might account for the deviation.

To account for deviations from IFD, four alternatives to Fretwell and Lucas's formulation have been offered by other researchers. Sutherland (1983) and Tregenza, Parker, and Thompson (1996) have produced evidence for an interference model, Parker and Sutherland (1986) and Grand (1997) argued for a competitive weights model, Abrahams (1986) and Gray and Kennedy (1994) postulated a "perceptual constraint" model, and Kennedy and Gray (1993) suggested a "travel-cost" model to explain deviations from matching. Alternative accounts of IFD-like foraging situations begin with the assumption that at least one of Fretwell and Lucas's original assumptions may be violated. For example, Sutherland (1983) and Tregenza, Parker, and Thompson (1996) suggested that deviations from IFD may occur if members of a foraging group were not completely free to move within or between resources sites (i.e., animals movements were interfered with). Interference was the result of social interaction between foragers that reduced the rate of capturing prey in such way as to produce undermatching (Tregenza, Parker, and Thompson 1996). The interference IFD equation has been expressed as:

$$\frac{N_1}{N_2} = b\left(\frac{R_1}{R_2}\right)^{\frac{1}{m}} \quad \text{Equation 7}$$

where sensitivity (a) is replaced by 1/m and m is a fitted parameter assessing degree of interference (Baum & Kraft, 1998; Kennedy & Gray, 1993). When m equals 1, Equation 7 is equivalent to equation 6. But as m increases (indicating more interference), undermatching will be observed. Some results have shown that experimentally manipulating the size of a foraging group or the size of resource areas could produce undermatching consistent with the interference model (Baum & Kraft, 1998; Gillis & Kramer, 1987). The interference model was taken a step further with a second model that assumed unequal competitive abilities of foragers (Grand 1997; Parker & Sutherland, 1986). In addition to interference, foragers with greater competitive ability could interfere with lesser foragers more than the reverse. For example, foragers with greater competitive abilities might be able to "out-forage" or "push-out" lesser foragers at a rich resource site causing more lesser foragers to compete at a lean resource site. Such a process would lead to undermatching. Grand (1997) assessed competitive weights of salmon before observing their foraging distribution between resource sites. She found that the numbers of foragers at resource sites undermatched the resources, but the proportions of competitive weights at the resource sites matched resources well. A competitive weights model can be expressed as:

$$\frac{\sum(t_{i1}c_{i1})}{\sum(t_{i2}c_{i2})} = \frac{R_1}{R_2} \quad (8)$$

where c_{i1} and c_{i2} equal the individual foragers' competitive weights and t_{i1} and t_{i2} equal the amount of time individual foragers spent at two resource sites. In a situation with unequal competitive weights, a forager with twice the competitive weight of other foragers has the effect of two foragers at a resource site. The competitive weights model makes the necessary quantitative adjustment to investigate the distribution of competitive weights. A third variation of Fretwell and Lucas's IFD model assumes that foragers may not have perfect knowledge of the resource distribution (Abrahams, 1986; Kennedy & Gray, 1993). A lack of omniscience may be the result of "perceptual limits" that hinder accurate discrimination of resource distribution. Foragers with imperfect knowledge may visit resource sites randomly, which would lead to undermatching. For example, if foragers cannot discriminate between average intake rates of less than 1 item per minute, and the difference between average intake falls below this threshold because of an increase in total foragers, then resource site foraging time could be allocated randomly and undermatching will occur. Both computer simulations (Abrahams, 1986; Kennedy & Gray, 1993) and empirical research with foraging ducks (Gray & Kennedy, 1994) showed that perceptual constraints may lead to undermatching. Finally, Kennedy and Gray (1993) suggested that Fretwell and Lucas's IFD model implicitly assumed that travel costs were negligible, and violations of this assumption may lead to undermatching. A "travel cost" model has been expressed as:

$$\frac{N_1}{N_2} = \frac{R_1 - k}{R_2 - k} \quad (9)$$

where k equals a cost of travel parameter (Kennedy & Gray, 1993). Increasing travel cost is predicted to have the effect of increasing IFD sensitivity to resources. Kennedy and Gray (1993) suggested that overmatching should occur, but Baum and Kraft (1998) only found that undermatching was reduced when travel was increased between resource sites. All four alternative models of IFD have received some support.

An Ideal Free Distribution Analysis of Human Performance

There is only one published experiment that assessed the IFD of humans in a group (Sokolowski, Tonneau, & Friexi i Baque, 1999). Sokolowski and colleagues had a group of fifteen adults sit at a table and raise either a green or a red card to receive money. The probability of winning money varied depending on how many individuals raised a green or red card and how much money was obtainable from raising each card (set by the experimenter). Sokolowski and colleagues demonstrated successfully that raising differently colored cards was equivalent to foragers residing at resource sites and money was equivalent to primary resources (i.e., food, access to reproduction) used in IFD experiments.

Sokolowski et al (1999) had participants (N = 15) sit around a large table. Each participant had a green and red card, a set of chips marked with a number to identify each participant, and a card holder on the top of the table. On a trial, each participant chose a card by placing it in the cardholder on signal. Participants were allowed to switch their choices, until no switching had occurred for 6 seconds, at which point all choices were final. The experimenter collected a chip from each participant; placing chips from participants who chose a green card in a green box and placing chips from participants who chose a red card in a red box. Ten chips, in total, were drawn from the two boxes to determine winners. At the end of each set of trials, the participants with the most winning chips won 52 French francs (about $10). The experimenter manipulated obtainable resources for choosing green and red cards by adjusting the proportion of chips chosen from the green and red box every twenty trials. For example, for the first 20 trials, 6 chips were drawn from the green box and 4 from the red box and for the next 20 trials, 1 chip was drawn from the green box and 9 from the red box. The remaining sets of 20 trials drew 8 from the green box and 2 from the red box, 3 from the green box and 7 from the red box, and 5 from the green box and 5 from the red box. This innovative procedure has the interesting property of partly sharing the winnings among those who choose a card color and probabilistically determining who in a card subgroup won and who did not. For example, in a trial in the first 20 trials, if eight participants chose a green card, then six of the participants shared the resources available for choosing green, but the six winners out of eight were determined probabilistically.

Like the non-human animal research, the IFD of human group behavior was sensitive to distribution of resources (i.e., points for money), but undermatched. Sokolowski and colleagues observed sensitivity parameters ranging from .62 to .70, but showed how an IFD analysis of human behavior was possible. The procedure used in Sokolowski et al (1999) was the model for my dissertation research.

Game Theory

The Ideal Free Distribution analysis of a group's choices is similar to Game Theoretical accounts of decision making. At its most basic level, game theory describes the choices players should make in games of strategy. In its original conceptualization, game theory answered the question of how each player should behave by assuming each player made rational decisions (von Neuman & Morgenstern, 1944). But recent developments in game theoretical accounts of foraging behavior and conflict resolution borrowed an evolutionary framework that eliminated the requirements of rational players (Axelrod, 1984, 1997; Maynard Smith, 1982). Evolutionary re-conceptualizations of game theory are amenable to the Ideal Free Distribution analysis of group choice.

John von Neuman and Oskar Morgenstern presented the first developed account of game theory with their book, Theory of Games and Economic Behavior (1944). They observed that most economic behavior involved more than one decision-maker and, instead, constituted a social exchange economy. As in the Ideal Free Distribution research, each member of the economy is assumed to maximize gain and the amount of gain an individual obtains is related to the individual's behavior and any other co-actors' behavior within the economy. In their book, von Neuman and Morgenstern described their account of rational decision-makers playing different types of basic games such as zero-sum and non-zero-sum games involving two or more individuals.

The most studied game is the two person non-zero-sum game – more colloquially known as the Prisoner's Dilemma Game. In this game, two players are faced with a choice of cooperating with each other or defecting against the other. If both players cooperate, they both get payoff R (for reward) and if both defect, they both get payoff P (for punishment). If one player defects and the other cooperates, then the defecting payer gets payoff T (for temptation) and the cooperating player gets payoff S (for sucker). In the classic Prisoner's Dilemma payoff matrix, $T > R > P > S$ and $R > (T + S)/2$. For example, in the case of two arrested prisoners who are separated during interrogation, each is faced with the choice of staying quiet or telling the police what they know. If they cooperate with each other and stay quiet, they may only be convicted of a minor crime (payoff R for both). But if they both confess on each other, they both get convicted of major crime (payoff P for both). But if one is tempted to turn on the other who is staying quiet, the police may offer the defector no jail time (payoff T) while convicting the other for the most severe crime possible (payoff S). The payoff for each player in the Prisoner's Dilemma Game depends on the choice of the other player. The useful aspect of the Prisoner's Dilemma Game is that cooperation and competition can be measured when the game is played iteratively. von Neuman and Morgenstern argued that the choices of players can be understood as rational decisions. Describing the players as rational decision-makers game theory may be possible when dealing with humans, but less likely to be accepted if applied to other animals with limited "rationality" (i.e., pigeons).

Researchers from biology re-worked game theory to expel rationality as the causal mode and include evolutionary explanations. John Maynard Smith, a biologist, used an evolutionary account of game theory to model stable patterns of species and behavior in the environment (Maynard Smith, 1982). Maynard Smith viewed evolution as a contest (or game) between animals. Consistent with previous game theory, Maynard Smith proposed that the best thing an animal can do depends on what other animals do. He applied this evolutionary account to animal behavior and to genotypes. Maynard Smith's major advancement was to include Evolutionarily Stable Strategies (ESS) as the causal mode or solution. ESS was defined as an "unbeatable strategy" or "a strategy such that, if all the members of a population adopt it, no mutant strategy can invade" (Maynard Smith, 1982). The strategy in evolutionarily stable strategies, was not a plan of action driven by the conscious efforts to optimize fitness, but rather, a pattern of optimal events extended over time. It is possible to determine whether a population exists in an evolutionary stable state by changing the environment and observing the population re-adjusting to conform to the ESS. Maynard Smith addressed the IFD as an evolutionarily stable strategy. By his definition, an IFD of foraging animals was an evolutionarily stable strategy. For example, when a flock of pigeons distributes in a 2:1 ratio and matches the 2:1 food resources, no other distribution could be better. If some pigeons from the rich site went to the lean site, then all the pigeons in the lean group would experience relative deprivation until some pigeons switched back to the rich group and reestablished the evolutionarily stable strategy. If some pigeons from the lean site went to the rich site, the reverse would be true. The IFD is the solution to the group foraging game because it is uninvadable.

Other researchers in sociology have examined game theory also without assuming rational agents. Sociologists, such as Robert Axelrod (1984, 1997), have advanced game theory significantly through computer simulations of the iterative Prisoner's Dilemma Game. Axelrod based his approach to simulated game player behavior on the "principle that what works well for a player is more likely to be used again while what turns out poorly is more likely to be discarded" (Axelrod, 1986, p. 1097). Axelrod attributed his position on the cause of successful player behavior to evolutionary theorists (e.g., Maynard Smith), but the selective nature of ESSs are not that different from the Law of

Effect in behavior analysis. Axelrod conducted computer tournaments of game strategies to determine which strategy was the most successful in the Prisoner's Dilemma Game (1980a, 1980b, 1984). Even though a variety of strategies were submitted, it was the relatively simple strategy of TIT FOR TAT that consistently won the most. TIT FOR TAT always began with a cooperative first move and then chose whatever option the opponent chose on the last turn. Axelrod suggested that TIT FOR TAT was successful, in part, because it did not defect on the first move (i.e., nice), retaliated only after one defection (i.e., provocable), and it cooperated if the other player cooperated no matter how many times the other player defected previously (i.e., forgiving). Axelrod conducted computer simulations of multi-person Prisoner's Dilemma Game (or n-person game) to investigate norm formation. Norms were defined to exist when "individuals act in a certain way and are often punished when seen not to be acting this way" (Axelrod, 1986, p 1097). In this computer simulation, players could defect and receive payoff T (i.e., boldness), but could be observed and punished by others (i.e., vengefulness). The punishment was severe, but it also incurred a slight cost to the player delivering the punishment. After playing many iterations of this type of multi-person game, vengefulness tended to increase as boldness decreased. To paraphrase Axelrod, punishing defectors was used again because it worked well for players (i.e., increased vengefulness) and defecting did not get used again because it did not work well (i.e., decreased boldness). Axelrod's research demonstrated that rational agents were not necessary for modeling complex game play.

The Ideal Free Distribution shares some characteristics of typical games of strategies, but is unique in other ways. The most obvious similarity is that the payoffs to IFD individuals depend on the choices of others just as the payoffs to game players depend on the choices of others. IFD individuals and game players are both assumed to maximize payoff. As with evolutionary-oriented game theory, the IFD does not rely on rational agencies as an explanation for causality, and instead uses a selection-by-consequences type of causality. The IFD differs from most games in what constitutes cooperation and defection. In the IFD situation, when an additional individual joins others, there is less payoff per individual and when an individual leave others, there is more for those left behind. This does not mean the IFD is not a game – it only means than it is different from the typical n-person Prisoner's Dilemma Game. The optimal solution in the IFD game is for the group distribution to match the resource distribution. Whenever the group distribution does not match resources (i.e., under- or overmatching), some individuals do not do well and, therefore, those choices are not used again as much in the future. Any deviations from matching can be invaded by closer approximations to matching. The IFD can be considered a zero-sum n-person game of strategy that does not require rational agents.

CHAPTER 2: Description of Experiments (Methods)

Experiment 1

The first group of participants experienced two two-hour sessions and had the opportunity to earn points that could lead to money by sitting in Row A and Row B chairs. The session consisted of ten blocks of 26 trials in which the ratio of points obtained for sitting in Row A and Row B chairs remained the same during each block. The procedure enabled an analysis of group choice as well as the choices of each individual. This experiment and the following ones used an IFD analysis of the group behavior based on Equation 6 and explored the individual-level events with descriptive statistics (i.e., frequency distributions, phase-space analyses, and correlations). All data analyses used the portions of data characterized as steady-state or stable.

Participants. Seventeen undergraduates from Introduction to Psychology classes at the University of New Hampshire agreed to participate and receive partial course credit for their participation. In addition, three of the participants received cash prizes awarded after the experiment was completed (see procedure). Nine women and eight men participated in this experiment.

Materials. For each session all participants received a pen and a score sheet. The participant score sheet consisted of a table of eight columns of 15 rows (see Appendix A for a sample block of trials). Each row in the score sheet had a space for the participant to mark the row of chairs chosen and the amount of points received for each trial. The experimenter had a table that described point distributions and a score sheet to record the numbers of participants who chose to sit in Row A and Row B chairs at the end of each trial (see Appendix C). Both Row A and Row B consisted of twenty chairs facing each other; separated by a distance of about 6 feet. The experimenter sat at the top of the rows of chairs and observed the participants' behavior.

Procedure. On the first day of the experiment, participants completed an informed consent form and were given an introduction to the procedure. The experimenter instructed the participants that they were to stand in between the rows of chairs at the beginning of each trial. At the beginning of a trial, the experimenter said, "Please sit in a row of chairs now," and each subject took a seat quickly. The experimenter recorded the number of participants who sat in Row A and Row B ("before-switch" data) and instructed all the participants that they could switch rows if they wished. The experimenter waited five seconds after the last person switched rows before indicating that no more switching was allowed. The experimenter recorded the number of participants who sat in Row A and Row B ("after-switch" data) and announced the number of points awarded to subgroup members. During the introduction to the experiment, the participants were told that during each block of trials, a certain number of points was allocated to all those who chose Row A and a certain number to those who chose Row B chairs, and that each subgroup shared those points. The participants were given the example of 5 people choosing a particular row that was allocated 60 points with the result that each subgroup member received 12 points. They were told that the number of points allocated to each row does not change during a block of trials, but would change from block to block. The number of points allocated to each row was not mentioned at any time during the experiment. The experimenter instructed the participants that they must record the row of chairs chosen and the points they were awarded on their score sheet at the end of each trial. They were told that dishonest reporting of earned points would lead to disqualification for the prizes. Finally, the participants were instructed that the person who earned the most points at the end of the experiment received a $50 cash prize, the second place winner received $20, and the third place winner received $10.

Participants were given the opportunity to ask questions before beginning the experiment. The participants were not allowed to talk with each other.

Two two-hour sessions were held during one week. The points allocated to Row A and Row B chairs were distributed in 5:1, 2:1, 1:2, and 1:5 ratios. For example, the 5:1 point ratio consisted of 100 points allocated to all those who chose Row A and 20 points to all those who chose Row B. And the 1:2 ratio consisted of 40 points allocated to Row A and 80 points to Row B. The point allocation did not change during a block, but varied from block to block in the following pattern: 20:100, 80:40, 100:20, 40:80, 40:80, 100:20, 80:40, and 20:100. At the end of a session, participants turned in their score sheets, and points were tallied after the end of the experiment. To promote participation, the experimenter began each day by noting that the differences between most participants in accumulated points were small and that anyone could still win the cash prizes (a truthful statement).

After the last block of trials on the second day, participants completed a form soliciting mailing addresses, demographic information (i.e., age and sex), and questions about the experimental situation (see Appendix B for a sample). Questions about the experimental situation included participants' (1) estimates of the number of points allocated to Row A and Row B during the last block of trials, (2) indications on a scale of 1 to 9 of how much effort they put into gaining the most points possible, (3) descriptions of strategies for gaining points, (4) descriptions of what the experimenter was investigating, and, finally, (5) any other comments. Checks for $50, $20, and $10 were mailed to the participants who earned them.

<u>Experiment 2</u>

The second experiment was similar to Experiment 1 except that the behavior of the group was different -- raising cards instead of sitting in chairs. Having the group choose to sit in two rows of chairs to receive money was similar to having non-human animals forage for resources at two different resource sites. By changing the choice behavior to raising one of two colored cards, subgroup membership is less like foraging experiments and more of an arbitrarily selected social behavior. Having a group choose cards to gain points and money was demonstrated by Sokolowski et al (1998) to be an effective method for producing an IFD of human behavior.

Participants. The participants in Experiment 2 were solicited and compensated in the same manner as Experiment 1. Ten women and eight men participated.

Materials. For each session all participants received both a blue and a red index card (10 cm X 18 cm), a pen, and a score sheet. The participant score sheet consisted of a table of several columns of 15 rows in which each row had a space for the participant to mark the card color they chose and points received for each trial. The experimenter had a table that described point distributions and a score sheet to record the number of participants who chose red and blue cards. The participants sat a large conference table with the experimenter at the head of the table.

Procedure. The procedure for Experiment 2 was identical to that used in Experiment 1 except that the experimenter instructed the group to choose a blue or red card instead of choosing a row of chairs. The experimenter instructed the subjects that they were to hold a card in each hand under the table at the beginning of each trial so that no one else could see them. The experimenter then said, "Please raise one card now," and each subject quickly placed either a blue or red card on top of the table in such a way that each participant could see it. The experimenter recorded the numbers of participants who chose blue and red cards ("before-switch" data) and instructed all the participants that they could switch cards. The experimenter waited five seconds after the last person switched cards before indicating that no more switching was allowed. The experimenter recorded the numbers of participants who chose blue and red cards ("after-switch" data) and announced earned points. Participants recorded their own choices/points and completed the post-experiment questionnaire.

Experiment 3

Experiment 3 was similar to Experiment 2 except that the method of distributing points was different. In the first two experiments, points were shared evenly among all participants in each subgroup. For example, if five participants chose a blue card and 80 points was allocated to all those who choose blue cards, then each of the five participants received 16 points (i.e., 80 points/5 participants = 16 points each). In Experiment 3, the points were distributed probabilistically. For example, if five participants choose a blue card and 80 points was allocated to all those who choose blue cards, then one of the five participants was randomly chosen to receive all 80 points. The participants in experiment 3 chose between raising blue and red cards.

Participants. The participants for experiment 3 were solicited in the same manner as in the previous experiments. Ten women and five men participated.

Materials. The materials for Experiment 3 were the same ones used in Experiment 2. The experimenter had a point distribution chart that enabled one member of different sized subgroups to be chosen as the winner of all the points allocated to that subgroup (see Appendix D). In that chart, for example, there was a section for subgroups with three members followed by a series of 1's, 2's, and 3's chosen at random. There was a section in this chart for all possible subgroup sizes.

Procedure. The procedures for experiments 3 were similar to experiment 2 except that the method of point allocation was different. Instead of a subgroup sharing the points, only one member of each subgroup received all the points allocated to that subgroup. At the end of each trial, the experimenter counted the number of participants in a subgroup (e.g., five) and each member was assigned a number for that trial (e.g., a number one through five). The experimenter used the point distribution chart to determine which of those subgroup members got all the points allocated to that subgroup. Participants recorded their own choices/points and completed the post-experiment questionnaire.

Experiment 4

To explore the effects of different competitive weights on the IFD of human behavior, Experiment 3 was replicated with an additional procedural change that manipulated the probability (or competitive weight) of individuals' gaining points. Parker and Sutherland (1986) and Grand (1997) speculated that violations of the equal competitive abilities assumption of the IFD may lead to undermatching. For example, foragers with greater competitive ability may be more likely to forage at the rich site and "push-out" lesser foragers who would then visit the lean site. Although participants in the present studies could not "push-out" or directly interfere with other participants, competitive weights were manipulated experimentally to determine their effect. In Experiments 3, all participants chose cards to gain points and one participant from each card subgroup won all the points probabilistically. The participants in a subgroup in Experiment 3 had an equal chance of winning the points. In Experiment 4, some individuals were assigned a higher probability of winning points than other participants. Those participants who were assigned a higher probability of winning points were able to obtain or "compete" better for points compared with those participants assigned lower probabilities.

Participants. The participants in Experiment 4 were solicited in the same manner as the previous experiments. Eleven women and four men participated.

Materials. The materials used in experiment 4 were identical to those used in experiments 3 with the addition of the lines on the cards. One third of the cards had a single diagonal line, one third of the cards had two horizontal lines, and one third of the cards had three lines (see Appendix E).

Procedure. From the participant point of view, the procedure was identical to that used in Experiment 3. The marks on the cards, however, denoted competitive weights. Unknown to the participants, one third of participants received cards with three lines to denote their three-times as great likelihood of gaining points as participants who received cards with one line and one third of participants received cards with two lines to denote their twice as great likelihood of gaining points as participants who received cards with one line. After participants stopped switching, the experimenter temporarily assigned a single number to all the participants in a subgroup with one-line cards, two numbers to the participants with two-line cards, and three numbers to those with three-line cards. For example, if five participants were in the blue card subgroup and the first three participants had one-line cards, the fourth participant had a two-line card, and the fifth participant had a three-line card, then the first three participants received the numbers 1, 2, and 3, the fourth participant received the numbers 4 and 5, and the fifth participant received the numbers 6, 7, and 8. Then the experimenter consulted the section of the point distribution chart of random numbers for an eight-member subgroup and determined who received the points. This procedure ensured different competitive weights. Otherwise, the procedures of Experiments 3 and 4 were identical. Participants recorded their own choices and points and completed the post-experiment questionnaire.

Experiment 5 & 6

Experiments 5 & 6 were similar to Experiments 3 & 4 except that points were distributed differently. In Experiments 3 & 4, different amounts of points were distributed probabilistically to members of both card subgroups on every trial. In Experiments 5 & 6, the same amount of points was distributed probabilistically to one member of one subgroup on every trial and only on some trials to one member of the other subgroup (see Appendix F). The participants in Experiment 6 were randomly assigned one of two competitive weights (see Appendix E for cards). The participants in Experiment 5 were not assigned different competitive weights.

Participants. Participants were solicited and compensated in the same manner as in previous experiments.

Materials. Each participant received blue and red cards, a score sheet, and a pen. The blue-red card pairs in Experiment 6 had either a circle or a triangle on them to denote competitive weights. The circle denoted the competitive weight of one and the triangle two.

Procedure. The major difference between Experiments 5 & 6 and Experiments 3 & 4 was the point distribution process. In Experiments 5 & 6, the same amount of points were awarded to each card subgroup, but one card subgroup received points on every trial and the other card subgroup received points intermittently. The rate of point distribution on the lean side determined the point ratio between cards. For example, to maintain a 5:1 point ratio, ten points were awarded to one member of the blue card subgroup on every trial, and ten points were awarded to one member of the red card subgroup only once every five trials in a fifteen-trial block. To maintain a 1:2 point ratio, ten points were awarded to one member of the blue card subgroup once every two trials, and awarded to the red card subgroup on every trial.

The procedure used for awarding points to a particular member of a card subgroup was similar to the procedure used in Experiments 3 & 4. In Experiment 5, if ten points were scheduled to be awarded, each member of the card subgroup was temporarily assigned a number for the trial and a chart of random numbers was consulted to determine which subgroup member received the points. In Experiment 6, if ten points were scheduled to be awarded, each member of the card subgroup was temporarily assigned a number for the trial (one number for card with circle and two numbers for a card with a triangle) and a chart of random numbers was used to determine which member received the points. Participants recorded their own choices and points and completed the post-experiment questionnaire.

Experiment 7

In Experiments 1 - 6 no attempt was made to control the number of participants in the experiments with the result that a perfect Ideal Free Distribution was only sometimes possible. In Experiment 7, perfect and imperfect solutions were made possible (see Appendix G for charts). The perfect solution in 5:1 point ratio with 18 participants, is for 15 participants to choose the first alternative and for 3 to choose the second. If there were 17 participants in the same situation, no perfect solution is possible. The group can only choose to undermatch (14:3) or overmatch (15:2). It is possible that the impossibility of a perfect solution would have no effect on the average distribution of the group if it overmatched and undermatched in the required proportions. It is also possible that imperfect solutions could bring about either systematic overmatching or undermatching. Alternating between blocks of trials that allow for perfect and imperfect solutions permitted assessment of the effects of imperfect Ideal Free Distribution solutions.

Participants. The participants in Experiment 7 were solicited and compensated in the same manner as the previous experiments. Two groups of students participated in two-hour sessions. Group A consisted of two men and ten women and group B consisted of eight men and nine women.

Materials. Each participant received blue and red cards, a score sheet, and a pen. The experimenter had several point distribution charts with perfect and imperfect solutions for groups of different sizes (including groups of 12 and 17). For group A, the perfect solution chart distributed 120 points in 5:1, 2:1, 1:2, and 1:5 ratios and the imperfect solution chart distributed 125 points in the same ratios. For group B, the perfect solution chart distributed 170 points in 4.7:1, 1.9:1, 1:1.9, and 1:4.7 ratios and the imperfect solution chart distributed 165 points in 5.6:1, 2.3:1, 1:2.3, and 1:5.6 ratios.

Procedure. The procedure was similar to Experiment 2; points were shared equally among subgroup members on every trial. For each group of participants, blocks alternated between the opportunity for perfect and imperfect solutions. Participants recorded their own choices and points and completed the post-experiment questionnaire.

CHAPTER 3: Analyses of the Groups' Choices

To determine the degree of IFD matching of the groups' choices two descriptive analyses were conducted. The first analysis presented the trial-by-trial data in a line graph. These graphs consisted of four lines. Two lines (boxes and diamonds) represented the number of participants who chose to be in a chair or card subgroup on each trial. The two dark dashed lines in each graph indicated an ideal distribution for each trial given the resources available and number of participants. These graphs permit readers to observe distribution of the groups' choices trial-by-trial, variability of choices during a session, and relatively steady state choices (e.g., usually after five or six trials in each block). The second analysis plotted subgroup ratios against corresponding point ratios for each block of trials in a double logarithmic scatterplot. To determine the degree of matching between group choices and point distributions, those points were fitted with a least-squares fit. To construct the group choice ratios, the average number of participants in the first subgroup (either Row A chairs or blue cards) was divided by the average number of participants in the second subgroup (either Row B chairs or red cards). Typically, the first block of trials in an experiment and the first few trials of the other blocks of trials were not used in these analyses because the responses had not reached relatively stable steady states. Qualitatively, most of the data points were expected to fall close to the major diagonal that indicated perfect matching and no bias. Quantitatively, the linear regression was expected to indicate that a line with a certain y-intercept (i.e., bias measure) and a certain slope (i.e., sensitivity measure) produced least-squares fit with low unaccounted variability. Together, these descriptive analyses provide a coherent account of Group Choice.

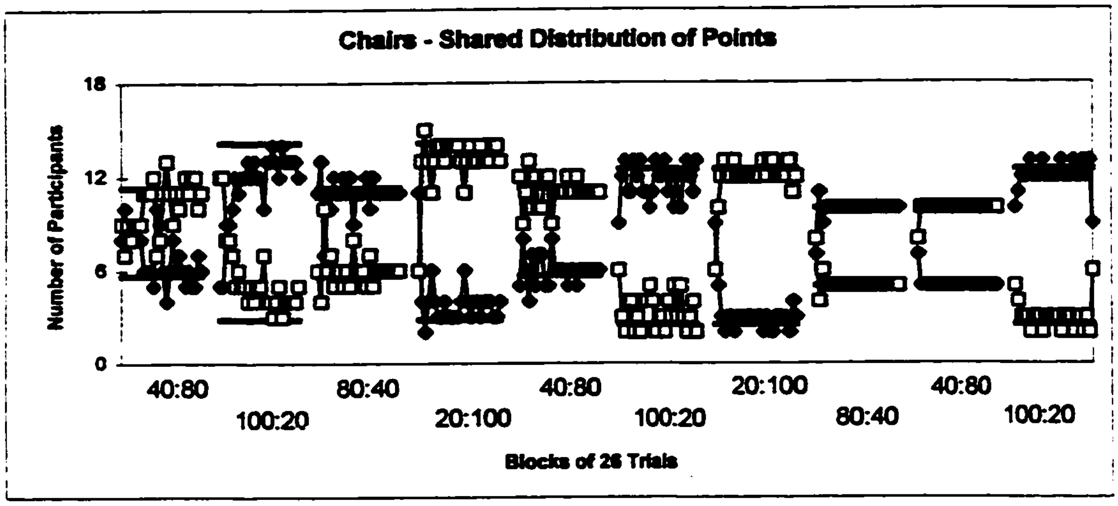
Experiment 1

The results of Experiment 1 (chairs – shared points) are presented in Figure 1. Group members chose between sitting in Row A and Row B chairs and subgroup members shared the points allocated to them. Figure 1a describes the trial-by-trial choices of the group sitting in Row A and Row B chairs. Each block consisted of 26 trials and the point ratios varied among 100:20, 80:40, 40:80, and 20:100. In general, the line graph showed the group distributing in the expected manner and reached stability after the first several trials of each block. The first block of trials was highly variable, but within-block variability was reduced in subsequent blocks. For example, the first, fifth, and ninth blocks allocated points in 40:80 ratios. The first 40:80 block of trials was highly variable, the fifth block was less variable, and the ninth block did not vary after the first few trials. The variability in the first block of trials and first several trials of each block justified their elimination from the generalized IFD analysis. The group choice ratio for a block of trials was constructed by dividing the average number of participants who chose to sit in Row A by the average number of participants who chose to sit in Row B chairs (excluding the first six trials). Those group choice ratios for Experiment 1 are presented in Figure 1b alongside their corresponding point ratios. The corresponding point ratios and choice ratios are plotted in the double-logarithmic scatterplot of Figure 1c.

Qualitatively, the data fell close to the major diagonal (representing no bias and perfect matching), but did deviate systematically. The fitted regression line indicated that the data fall on a line with a slope of slightly less than one (a = .79), y-intercept of 1 (b = 1.0), and little unaccounted variance (r^2 = .97). The results of the least squares fit indicated that the group's choices were sensitive to point distributions, the group had no preference for either blue or red cards, and the behavior of the group was orderly.

Figure 1. Group level results from Experiment 1. The group chose between sitting in Row A and Row B chairs and subgroup members shared points. Figure 1a depicts trial-by-trial data, figure 1b shows corresponding point and choice ratios, and figure 1c depicts the figure 1b data in a double logarithmic scatterplot and a least squares fit.

a.

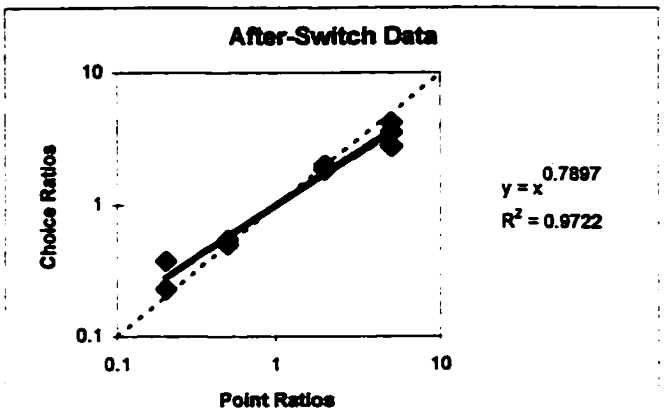


Row A = filled diamonds; Row B = empty squares

b.

Pt. Ratio	Choice Ratio
0.50	0.60
5.00	2.78
2.00	1.86
0.20	0.37
0.50	0.55
5.00	3.55
0.20	0.23
2.00	2.00
0.50	0.50
5.00	4.17

c.

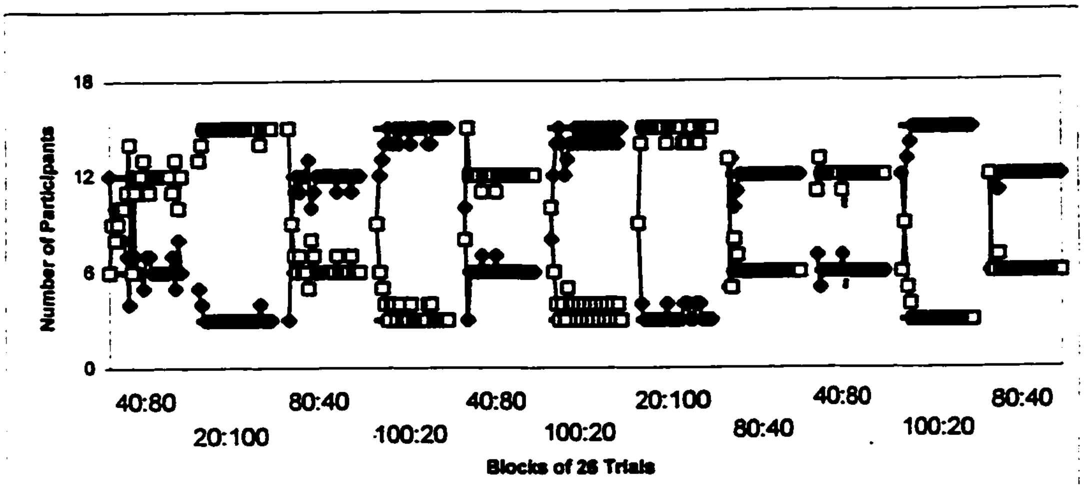


Experiment 2

The results of Experiment 2 (cards – shared points) are presented in Figure 2. Group members chose to raise blue and red cards and subgroup members shared allocated points. Figure 2a depicts the trial-by-trial choices of the group choosing blue and red cards. Each block consisted of 26 trials and the point ratios varied among 100:20, 80:40, 40:80, and 20:100. In general, the line graph shows the group distributing in the expected manner and reaching stability after the first several trials of each block. As in Experiment 1, the first block of trials was highly variable, but within-block variability was reduced in subsequent blocks. After some exposure to the experimental situation, the group's choices stabilized quickly. The variability in the first block of trials and first several trials of each block justified eliminating the these data from the generalized IFD analysis. The group choice ratio for a block of trials was constructed by dividing the average number of participants who chose blue cards by the average number of participants who chose red cards (excluding the first six trials). The group choice ratios of Experiment 2 are presented in Figure 2b with their corresponding point ratios. The corresponding point ratios and choice ratios are plotted in the double logarithmic scatter-plot of Figure 2c. Qualitatively, the data fell close to the major diagonal. The fitted regression line indicated that the data fall on a line with a slope of slightly less than 1 ($a = .95$), y-intercept of 1 ($b = 0.99$), and little unaccounted variance ($r^2 = .99$). The results of the least squares fit indicated that the group's choices matched the point distributions, had no bias for a particular card color, and were orderly.

Figure 2. Group level results from Experiment 2. The figure depicts a group's choice between choosing blue and red cards to gain points shared among subgroup members. Figure 2a depicts trial-by-trial data, figure 2b shows corresponding point and choice ratios, and figure 2c depicts the figure 2b data in a double logarithmic scatterplot and a least squares fit.

a.

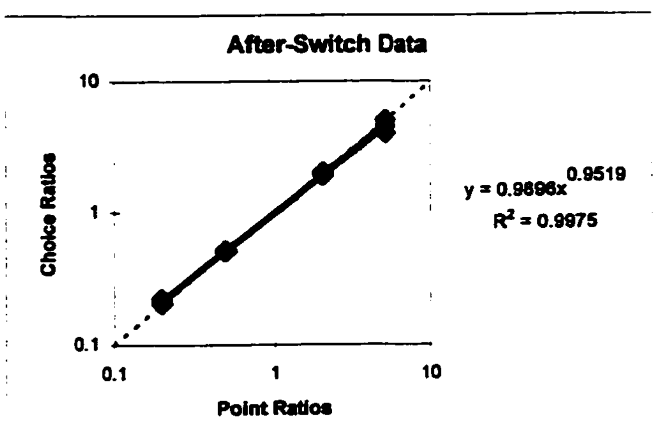


Blue Cards = filled diamonds, Red Cards = empty squares

b.

Pt. Ratio	Choice Ratio
0.50	0.56
0.20	0.20
2.00	1.90
5.00	4.54
0.50	0.51
5.00	4.00
0.20	0.22
2.00	2.00
0.50	0.51
5.00	5.00
2.00	2.00

c.

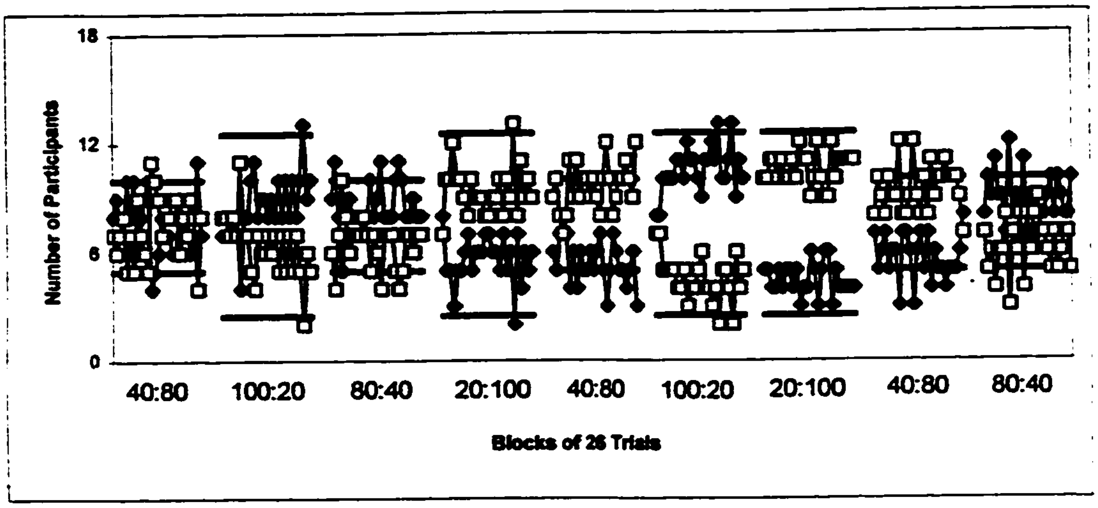


Experiment 3

The results from Experiment 3 (cards – probabilistic distribution of different amounts of points) are presented in Figure 3. The primary difference between Experiment 2 and 3 was the method of point distribution. In Experiment 3 only one member of a subgroup received the entire point allocation, whereas in Experiment 2 all members of a subgroup shared the point allocation. Each member of a subgroup had an equal chance of winning and the winner was chosen at random to receive points. In Figure 3a, the trial-by-trial data are depicted in a line graph. The data are more variable than the data of the first two experiments. For example, the 40:80 point distribution occurred on the first, fifth, and eighth block of trials and the variability decreased only a small amount across blocks. Furthermore, the group's distribution often did not match the expected distribution when the points were distributed in a 100:20 or 20:100 ratio. The choice ratios were constructed in a similar manner to the previous experiments (i.e., excluding the first block of trials and first six trials of subsequent blocks). The group's choice ratios and corresponding point ratios are presented in Figure 3b. The data in Figure 3b were plotted in a double logarithmic scatterplot and fitted with a regression line in Figure 3c. The inferences from the line graph (Figure 3a) were verified in with the least squares fit. Qualitatively, the data did not fall on the major diagonal. The overall group sensitivity was relatively low (a = 0.45) and less orderly ($r^2 = 0.88$) compared to the first two experiments.

Figure 3. Group level results from Experiment 3. The group chose blue and red cards to gain points distributed probabilistically. Figure 3a depicts trial-by-trial data, figure 3b shows corresponding point and choice ratios, and figure 3c depicts the figure 3b data in a double logarithmic scatterplot and a least squares fit.

a.

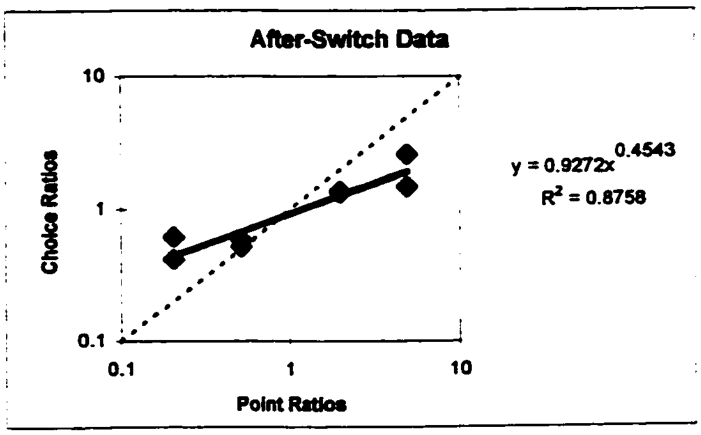


Blue Cards = filled diamonds, Red Cards = empty squares

b.

Pt. Ratio	Choice Ratio
0.50	0.97
5.00	1.48
2.00	1.37
0.20	0.62
0.50	0.52
5.00	2.58
0.20	0.42
0.50	0.58
2.00	1.33

c.

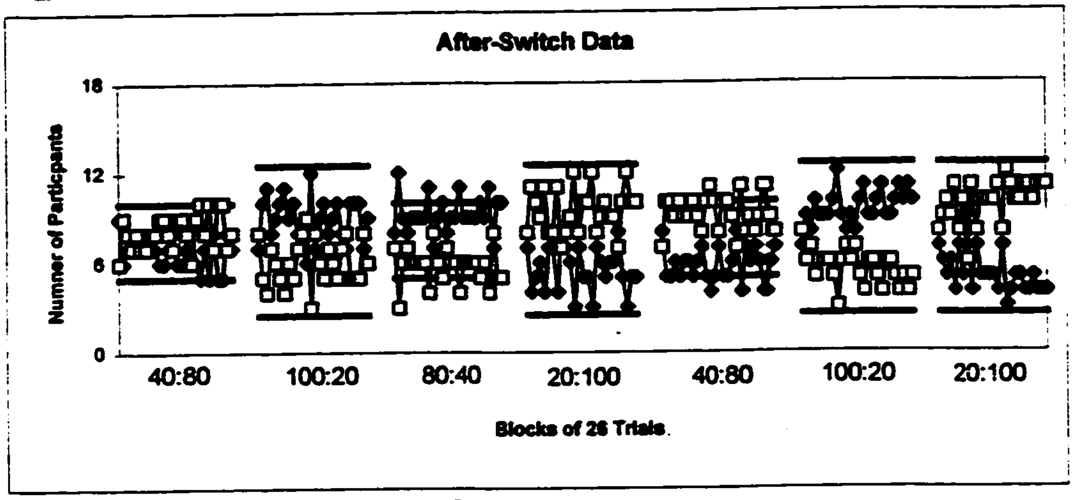


Experiment 4

The results from Experiment 4 (cards - probabilistic distribution of different amounts of points – different competitive weights) are presented in Figure 4. Experiment 4 was identical to Experiment 3 except members of the group did not have an equal chance of winning the points allocated to a subgroup. One member of each subgroup was chosen at random to receive points, but group members had one of three weights that made some members three times as likely and two times as likely to win the points as others. The distribution of the competitive weights is analyzed later. The trial-by-trial data are presented in Figure 4a. As with the data from Experiment 3, the data from Experiment 4 were variable and the group did not distribute as extremely as expected when the point ratios were 100:20 and 20:100. The choice ratios and corresponding point ratios are presented in Figure 4b. The choice ratios and point ratios are depicted in Figure 4c, the double logarithmic scatterplot, and fitted with a regression line to determine the group's overall sensitivity. As with the previous experiment, the least squares fit showed relatively little sensitivity (a = 0.37), no bias (b = 0.96), and explained variance was moderate ($r^2 = 0.91$).

Figure 4. Group level results from Experiment 4. The group chose blue and red cards to gain points distributed probabilistically. Group members had one of three competitive weights that made some members thrice or twice as likely than others to win points. Figure 4a depicts trial-by-trial data, Figure 4b shows corresponding point and choice ratios, and Figure 4c depicts the Figure 4b data in a double logarithmic scatterplot and a least squares fit.

a.

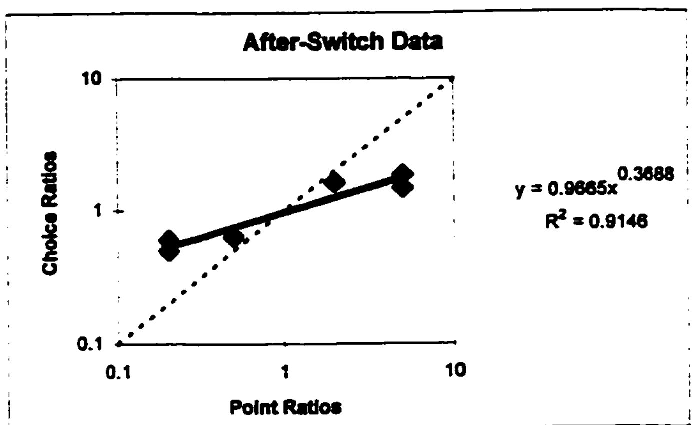


Blue Cards = filled diamonds, Red Cards = empty squares

b.

Pt. Ratios	Choice Ratio
0.50	0.81
5.00	1.46
2.00	1.60
0.20	0.60
0.50	0.63
5.00	1.84
0.20	0.50

c.

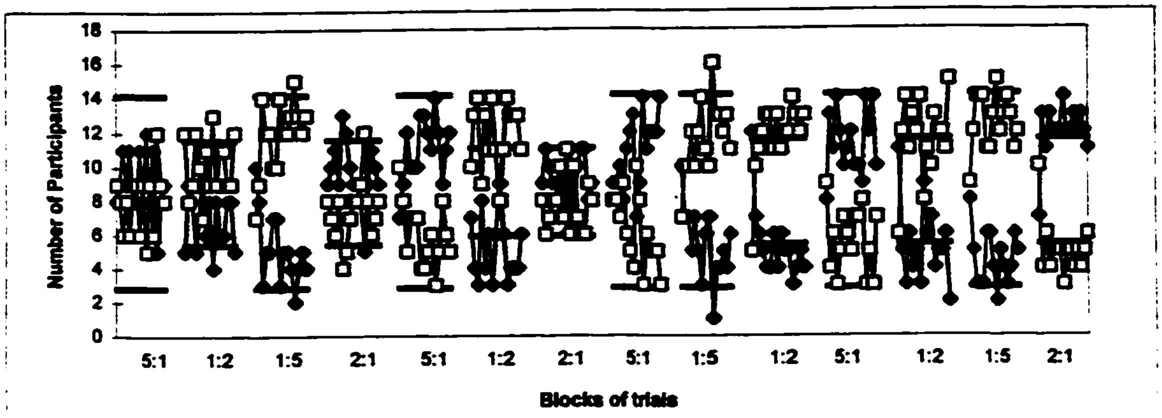


Experiment 5

The results from Experiment 5 (cards - probabilistic distribution of equal amounts of points – equal competitive weights) in Figure 5. Experiment 5 differed from previous experiments with probabilistic point distribution. In Experiment 5, the point ratios were manipulated by probabilistically allocating 10 points to one subgroup on every trial and intermittently allocating 10 points to the other subgroup. The trial-by-trial data are presented in Figure 5a. Each block consisted of only 15 trials to increase the number of blocks in the experiment. The group's choices were moderately variable and the group did not distribute as predicted by the IFD. When the point ratio was extreme (i.e., 5:1 or 1:5), the group ratio was often less extreme. In several of the 5:1 and 1:5 blocks, the group showed a slow trend toward the expected distribution. The choice ratios were constructed by averaging across the last 10 trials of the 15 trial blocks. The choice ratios and corresponding point ratios are presented in Figure 5b and plotted in the double logarithmic scatterplot of Figure 5c. The least squares fit revealed that the group's choices undermatched the point ratios ($a = 0.60$), may have been slightly biased for the red cards ($b = 0.85$), and were orderly ($r^2 = 0.89$). The same analyses were conducted on the group's choices by averaging across only the last five trials to investigate the possibility of a trend. This analysis revealed similar measures of bias ($b = 0.82$) and explained variance ($r^2 = 0.88$), but sensitivity did increase ($a = 0.67$).

Figure 5. Group level results from Experiment 5. The group chose blue and red cards to gain equal amounts of points distributed probabilistically. Group members had equal competitive weights. Figure 5a depicts trial-by-trial data, Figure 5b shows corresponding point and choice ratios, and Figure 5c depicts the Figure 5b data in a double logarithmic scatterplot and a least squares fit.

a.

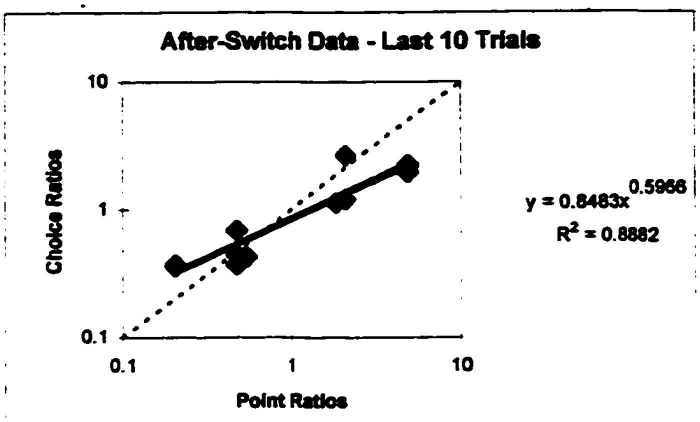


Blue Cards = filled diamonds, Red Cards = empty squares

b.

Pt. Ratio	Choice Ratio
5.00	1.07
0.47	0.68
0.20	0.37
2.14	1.21
5.00	2.21
0.53	0.43
1.88	1.13
5.00	2.15
0.20	0.36
0.47	0.37
5.00	1.93
0.47	0.44
0.20	0.36
2.14	2.62

c.

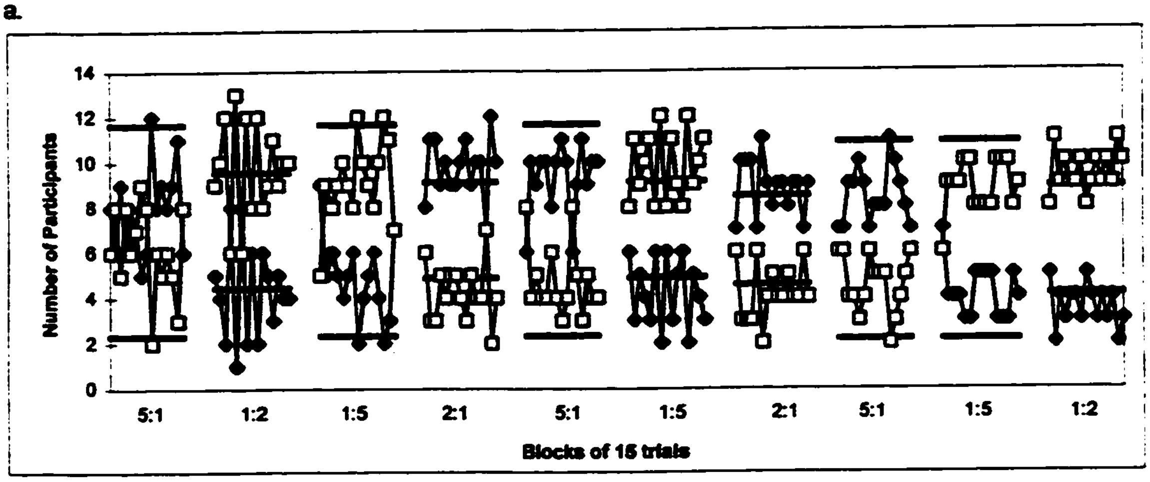


Experiment 6

The results from Experiment 6 (cards - probabilistic distribution of equal amounts of points – two different competitive weights) are presented in Figure 6. Experiment 6 was identical to experiment 5 except that half of the group members had a thrice as great a likelihood of winning points as the other half. The analysis of the competitive weights is presented later. The trial-by-trial data are presented in Figure 6a. Similar to the other experiments that distributed points probabilistically, the trial-by-trial choices were variable and not as extreme as expected with 5:1 and 1:5 point ratios. The group's choice ratios (averaged across the last 10 trials of 15 trial blocks) and corresponding point ratios are presented in Figure 6b. The group's choices in relation to point distributions are presented in the double logarithmic scatterplot and fitted with a regression line. The least squares fit revealed that the group's choices undermatched the point distributions ($a = 0.59$), no significant bias ($b = 0.92$), and a moderate measure of order ($r^2 = 0.81$). The same analysis was conducted on the group's choices constructed from the last 5 trials of each block of trials. Using the last five trials of each block did not affect the measure of bias ($b = 0.84$), increased explained variance slightly ($r^2 = 0.85$), and increased sensitivity ($a = 0.68$).

Figure 6. Group level results from Experiment 6. The group chose blue and red cards to gain equal amounts of points distributed probabilistically. Half the group members had thrice as great a likelihood of obtaining points as the other half. Figure 6a depicts trial-by-trial data, Figure 6b shows corresponding point and choice ratios, and Figure 6c depicts the Figure 6b data in a double logarithmic scatterplot and a least squares fit.

a.

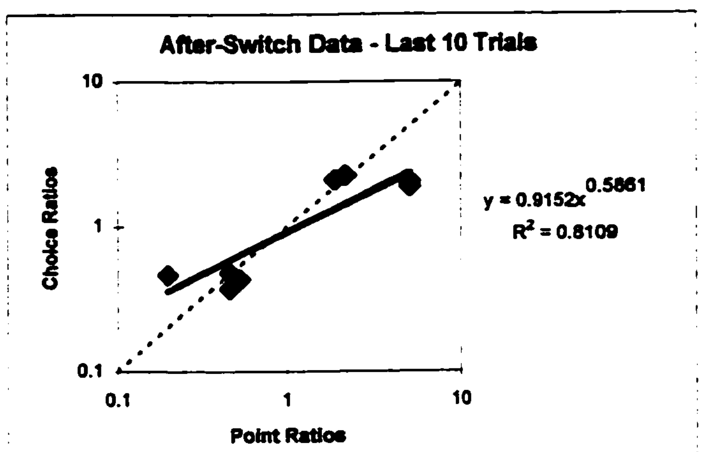


Blue Cards = filled diamonds, Red Cards = empty squares

b.

Pt. Ratio	Choice Ratio
5.00	1.37
0.47	0.47
0.20	0.46
2.14	2.26
5.00	2.04
0.53	0.43
1.88	2.10
5.00	1.89
0.20	0.46
0.47	0.37

c.



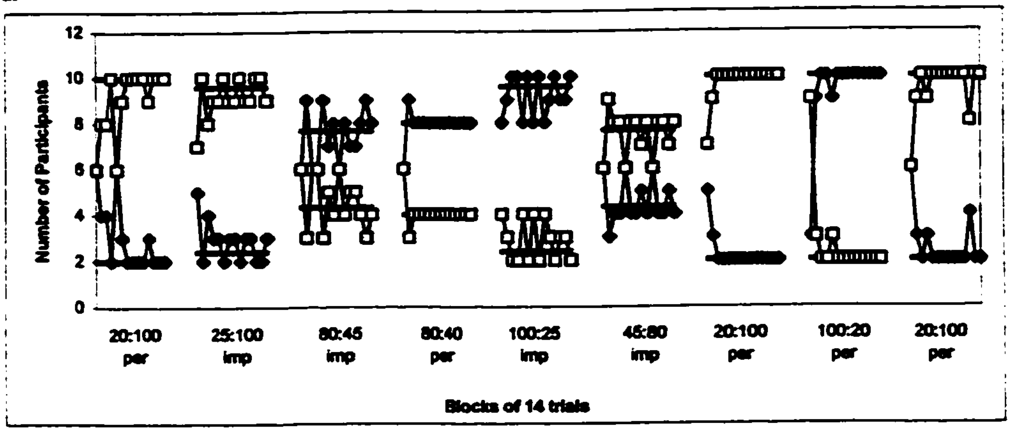
Experiment 7 (A & B)

The results from Experiment 7 (cards – shared points - perfect and imperfect solutions) are presented in Figures 7 and 8. Two groups of people participated in Experiment 7. The participants chose between raising blue and red cards and allocated points were shared among subgroup members. The procedure was nearly identical to Experiment 2 except that sometimes it was possible for the group to match the resource distribution perfectly and sometimes it was impossible. The purpose of creating resource distributions that allowed for perfect and imperfect group solutions was to determine their effect on a group's sensitivity. The results for group A are presented in Figure 7 and the results for group B are presented in Figure 8. The trial-by-trial data are presented in Figures 7a and 8a. The overall qualitative impression of the data is that both groups distributed quickly to match the resource distributions. At the beginning of a block of trials, the groups distributed evenly, but approximated the resource distribution after a few trials. The effect of imperfect solutions on the groups' choices compared to perfect solutions was increased variability. The fifth and sixth block of trials in Figure 7a provide a good example. In the fifth block a perfect solution was possible and the group made that choice on nearly every trial. In the sixth block of trials, a perfect solution was impossible and the group's choices were more variable. For group A, the choice ratios and corresponding point ratios for perfect and imperfect solutions are presented in Figures 7b and 7c and plotted separately in double logarithmic scatterplots in Figures 7d and 7e. Both least squares fits to the perfect and imperfect solutions data showed no bias

(b_{per} = 1.00; b_{imp} = 0.99) and a high degree of orderliness (r^2_{per} = 0.99; r^2_{imp} = 0.99). The measure of sensitivity was greater for the perfect solutions data (a_{per} = 0.97) than for the imperfect solutions data (a_{imp} = 0.85). For group B, the choice ratios and corresponding point ratios for perfect and imperfect solutions are presented in Figures 8b and 8c and plotted separately in double logarithmic scatterplots in Figures 8d and 8e. In a similar manner to group A, measures of bias and accounted for variance were comparable for perfect and imperfect solutions (b_{per} = 1.01, b_{imp} = 0.99, r^2_{per} = 0.99, r^2_{imp} = 0.99). The measure of sensitivity for the perfect solution data was greater than the measure of sensitivity for the imperfect solution data (a_{per} = 0.97, a_{imp} = 0.88). A least squares fit was conducted on all the combined data from both groups and both conditions. The measure of sensitivity for the combined data was high (a = 0.92), bias was low (b = 0.99), and accounted for variance was high (r^2 = 0.99).

Figure 7. Group level results from experiment 7 – group A. The group chose blue and red cards to gain points shared among subgroup members. Half the blocks of trials permitted a perfect whole number solution for the group's choices and half of the blocks did not. Figure 7a depicts trial-by-trial data, Figures 7b and 7c show corresponding point and choice ratios for perfect and imperfect solutions, and Figures 7d and 7e depict the group's choice data in a double logarithmic scatterplots and least squares fits.

a.

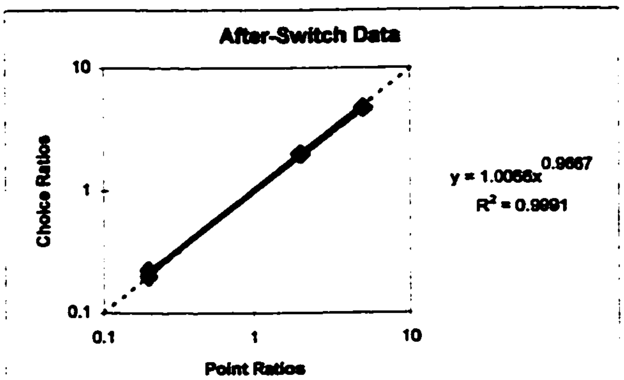


Blue Cards = filled diamonds, Red Cards = empty squares

b.
Perfect Solutions

Pt. Ratio	Choice Ratio
2.00	2.00
0.20	0.20
5.00	4.71
0.20	0.22

d.



c.
Imperfect Solutions

Pt. Ratio	Choice Ratio
0.25	0.28
1.78	1.79
4.00	3.14
0.56	0.62

e.

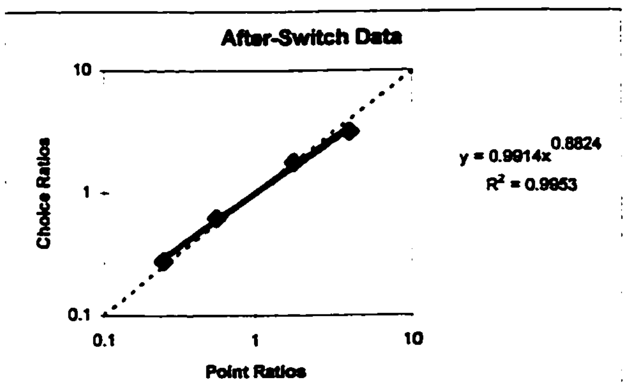
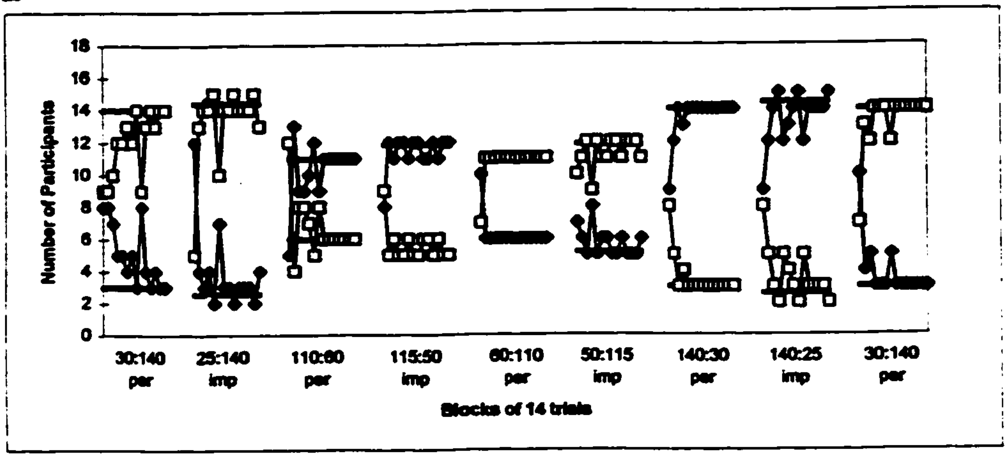


Figure 8. Group level results from Experiment 7 – group B. The group chose blue and red cards to gain points shared among subgroup members. Half the blocks of trials permitted a perfect whole number solution for the group's choices and half of the blocks did not. Figure 8a depicts trial-by-trial data, figures 8b and 8c show corresponding point and choice ratios for perfect and imperfect solutions, and figures 8d and 8e depict the group's choice data in a double logarithmic scatterplots and least squares fits.

a.



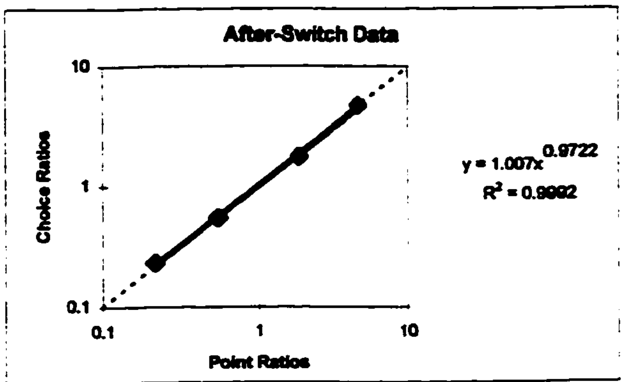
Blue Cards = filled diamonds, Red Cards = empty squares

b.

Perfect Solutions

Pt. Ratio	Choice Ratio
1.83	1.74
0.55	0.55
4.67	4.67
0.21	0.23

d.

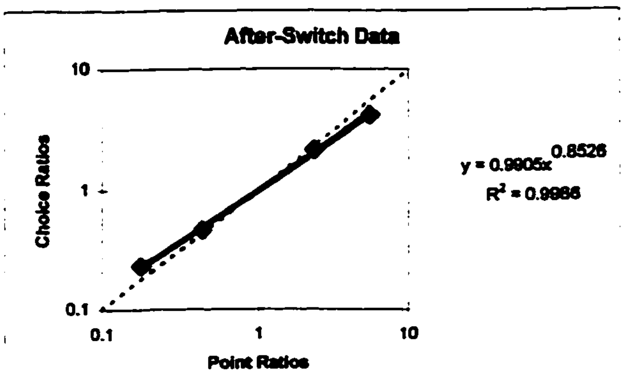


c.

Imperfect Solutions

Pt. Ratio	Choice Ratio
0.18	0.23
2.30	2.15
0.43	0.47
5.60	4.15

e.



Competitive Weights Analysis

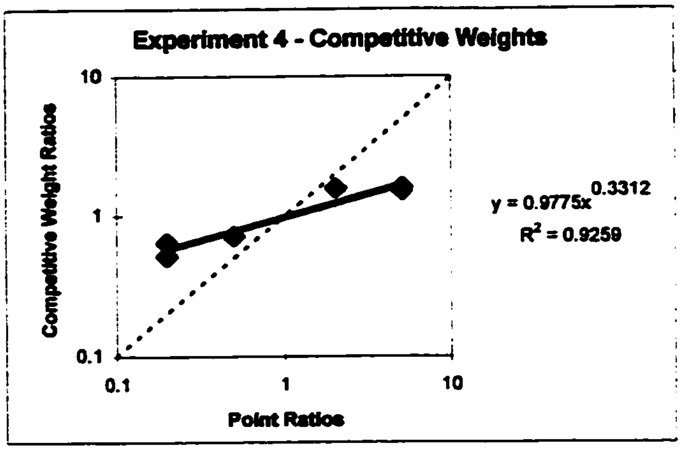
To determine the effect of point distribution on the distribution of competitive weights the average sums of competitive weights in each subgroup of Experiments 4 and 6 were analyzed in the same manner as the average number of participants in each group. The results of the competitive weights analyses are presented in figure 9. In experiment 4, participants were assigned a competitive weight of one, two, or three. The ratios of average sums of competitive weights of those who chose blue and red cards were related to their corresponding point ratios. In Experiment 6, participants were assigned competitive weights of one or three and the average sums of competitive weights were related to their corresponding point ratios. Figures 9a and 9c show the corresponding point and competitive weight ratios and Figures 9b and 9d depict the group's competitive weight data in a double logarithmic scatterplots and least squares fits for Experiments 4 and 6. For experiment 4, the least squares fit revealed a low measure of sensitivity ($a = 0.33$), no bias ($b = 0.98$), and a satisfactory measure of orderliness ($r^2 = 0.93$). For Experiment 6, the least squares fit revealed a higher sensitivity ($a = 0.58$), slight bias for the red card ($b = 0.91$), and a relatively low measure of orderliness ($r^2 = 0.81$). In the basic IFD analysis of the groups choices in Experiments 4 and 6, both groups undermatched ($a_{exp4} = 0.37$, $a_{exp6} = .58$). Comparing the distributions of competitive weights to the distributions of numbers of participants revealed no systematic differences in sensitivity measures. An additional contingency analysis verified that individuals with larger competitive weights were no more likely to choose the rich alternative than individuals with smaller competitive weights in either experiment (see Appendix H). Had individuals with larger competitive weights chosen the richer alternative relative to individuals with smaller competitive weights, then the distribution of the competitive weights would have been more sensitive to distributed resources than distributed numbers of participants.

Figure 9. Competitive weight analyses for Experiments 4 and 6. Figures 9a and 9c show the corresponding point and competitive weight ratios and Figures 9b and 9d depict the group's competitive weight data in a double logarithmic scatterplots and least squares fits for Experiments 4 and 6.

a.

Point Ratios	Competitive Weight Ratios
0.50	0.76
5.00	1.51
2.00	1.56
0.20	0.64
0.50	0.71
5.00	1.59
0.20	0.51

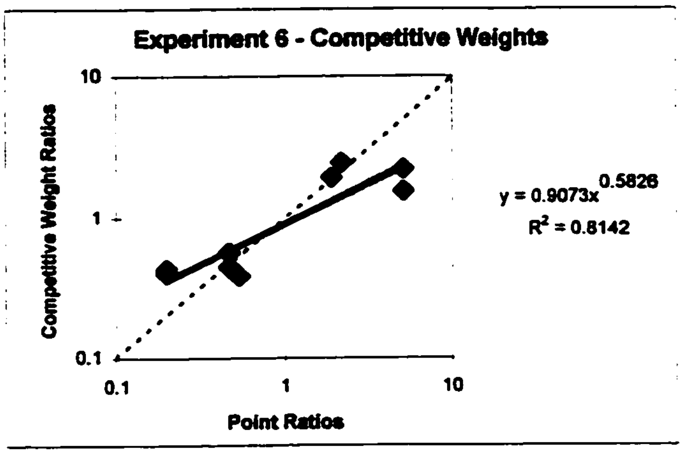
b.



c.

Point Ratios	Competitive Weight Ratios
5.00	1.20
0.47	0.56
0.20	0.43
2.14	2.46
5.00	2.22
0.53	0.38
1.88	1.93
5.00	1.55
0.20	0.40
0.47	0.44

d.



Comparing Groups' 'after-switch' Data to 'before-switch' Data

The above group level analyses used the after-switch data, but the before-switch data were collected as well. The before-switch data consisted of the groups' initial choices at the beginning of a trial and the after-switch data consisted of the groups final choices at end of the trial. Choice ratios were constructed from the before-switch data in the same manner as the after-switch data. Pilot research suggested that the groups' before-switch choices were sensitive to the distributions of points, but it was an open question as to whether before-switch sensitivity was systematically greater, less than, or equal to after-switch sensitivity. The results of the least-squares fits of before-switch and after-switch data are presented in Table 1. The sensitivity of the groups' before-switch choices was similar to the sensitivity of the groups' after-switch choices. Most of the before-switch sensitivity measures were slightly less than the after-switch sensitivity measures (e.g., experiments 1, 2, 5, 6, and 7), but sometimes slightly greater than after-switch sensitivity measures (experiments 3 and 4). Measures of bias were generally the same between before- and after-switch data, but measures of orderliness were sometimes much higher for after-switch data. The overall impression of the comparison of before- and after-switch data across all seven experiments is that the before-switch choices were more variable, but generally similar to the after-switch choices.

Table 1. Measures of sensitivity, bias, and orderliness in 'before-switch' and 'after-switch' choices of the group. The 'before-switch' data describes groups' choices before participants knew others' choices during a trial. The 'after-switch' data describes groups' choices after participants knew others' choices during a trial and had the opportunity to switch.

Experiment	before-switch data			after-switch data		
	sensitivity	bias	r^2	sensitivity	bias	r^2
1	0.77	1.02	0.98	0.79	1.00	0.97
2	0.75	0.98	0.94	0.95	0.99	0.99
3	0.50	0.95	0.82	0.45	0.93	0.88
4	0.45	0.93	0.92	0.37	0.97	0.91
5	0.57	0.89	0.82	0.60	0.85	0.89
6	0.53	0.92	0.51	0.58	0.91	0.81
7 (all)	0.61	0.90	0.85	0.92	0.99	0.99
Average	0.60	0.94	0.83	0.67	0.95	0.92

Analysis of Sensitivity and Variation Trends

Upon inspection, it appeared that successive exposures to conditions led to closer approximations to IFD matching. During the course of an experiment, participants may have been exposed to blocks of trials with the same distribution of points twice, thrice, and, occasionally four times. For example, in Experiment 1, participants experienced the 100:20 point distribution three times (i.e., in blocks 2, 6, and 10). The choices of the group in these three blocks of trials grew more extreme with each exposure. To determine if there was a general trend for more extreme Group Choice with successive exposure to point distribution conditions, the number of exposures to a point distribution were related to the ratio of the groups' distributions. Figure 10 depicts these relations for Experiments 1, 2, 3, 4, 5, and 6. Experiments 7a and 7b did not have enough multiple exposures to the same point distribution to conduct this analysis. The graphs reveal that groups did tend to distribute in more extreme ratios with successive exposures. This effect was more consistent for 2:1 point distribution ratios than the 5:1 point distribution ratios. These results suggest that the groups were still learning how to maximize their choices. Relating the Groups' Choices to the last exposures of each point distribution should show increased sensitivity. Those relations are depicted in Figure 11. The generalized IFD analyses produced orderly relations. The r-squared values are high (.79 - .99) and no biases emerged (.92 - 1.03). Differences in the sensitivity measures constructed from all exposures to conditions (except the first) and the last exposure to conditions, revealed some moderate increases in sensitivity (Experiments 1 and 3) and almost no differences (Experiments 2, 4, 5, and 6). These analyses reveal that some groups were still adjusting to the point distribution and other groups had reached their stable distributions.

Figure 10. Analysis of learning trends. These graphs show Groups' Choice ratios plotted against successive exposures to point distributions. The reciprocals of 1:2 and 1:5 conditions were combined with 2:1 and 5:1 conditions.

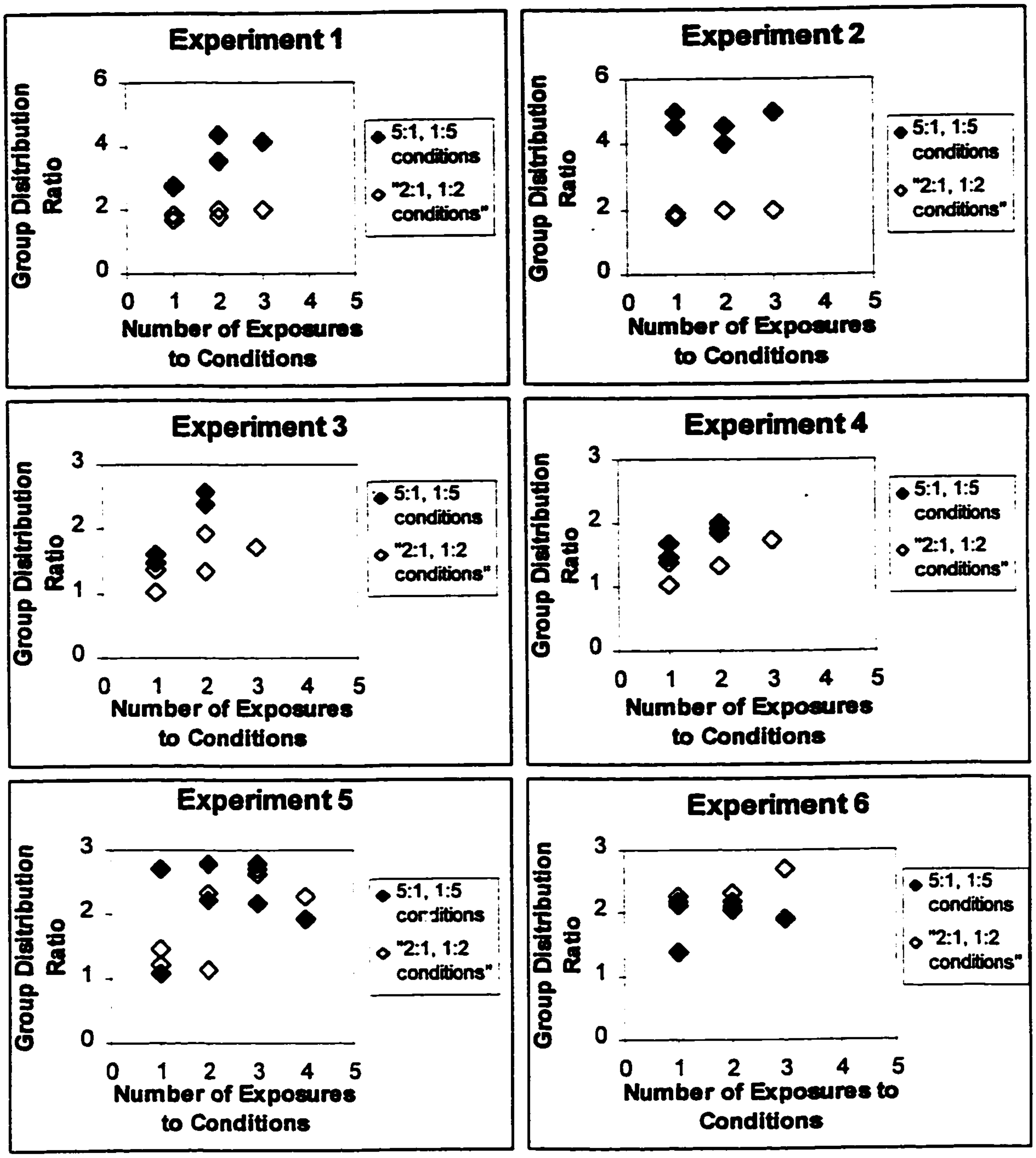
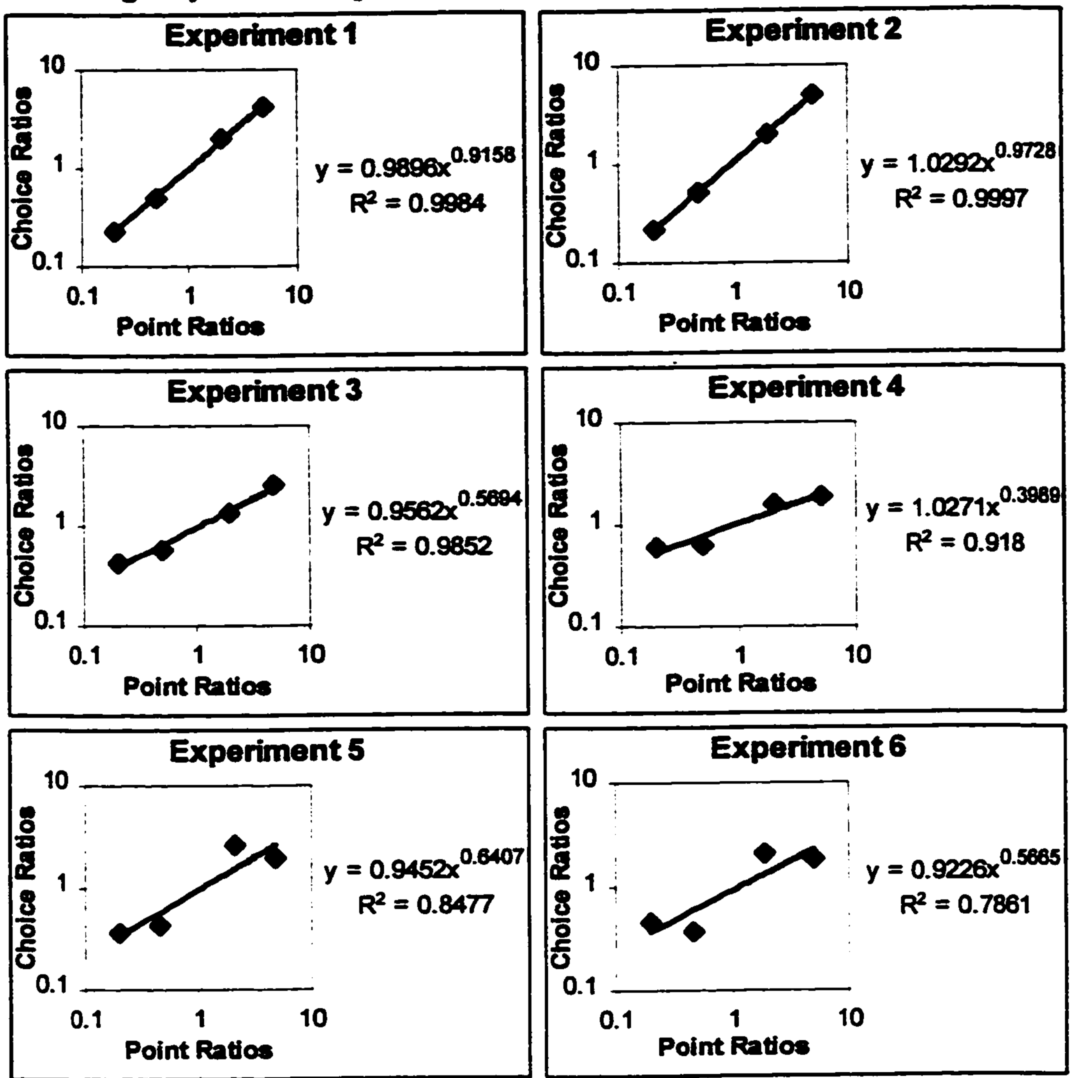


Figure 11. Groups' Choice ratios to last exposures of conditions. These double logarithmic scatterplots are identical to those depicted in Figures 1 - 6 except that only the data from the last exposures to point distribution conditions are used. The table presents the sensitivity measures using all exposures to conditions (from Figures 1 - 6), sensitivity measures using only last exposures to conditions, and the increases (if any) from using only the last exposures.



Experiment #	Sensitivity measures all exposures	Sensitivity measures only last exposures	Increases in Sensitivity measures
1	.79	.92	.13
2	.95	.97	.02
3	.45	.57	.12
4	.37	.40	.03
5	.60	.64	.04
6	.59	.57	-.02

Discussion of Analyses of Groups' Choices

From the group level analyses of the data several patterns in the results emerged. First, when points were shared equally among subgroup members, the group's choices nearly matched the point distributions. In Experiments 1 (chairs – shared points), 2 (cards – shared points), and 7 (cards, shared points, perfect/imperfect solutions), the measures of sensitivity were 0.79, 0.95, and 0.92. Second, when points were distributed probabilistically to subgroup members, the group's choices undermatched the point distributions significantly. In Experiments 3 (cards – probabilistic points), 4 (cards – probabilistic distribution of unequal points – competitive weights), 5 (cards– probabilistic distribution of equal points), and 6 (cards – probabilistic distribution of equal points – competitive weights), the measures of sensitivity were 0.45, 0.37, 0.60, and 0.58. Third, no group had a particular strong bias for either choice alternative. Bias measures ranged from 0.85 – 1.00. Fourth, the groups' after-switch choices were orderly. Measures of accounted for variance ranged from 0.81 - 0.99. Fifth, probabilistically distributing points increased overall variability in the groups' choices. The r-squared values of experiments that distributed points probabilistically ranged from 0.81 – 0.91 and the r-squared values of experiments that shared points among subgroup members ranged from 0.97 – 0.99. Sixth, the effect of probabilistically distributing equal amounts of points compared to unequal points may have been to increase sensitivity. Experiments 3 and 4 distributed unequal points probabilistically and the result was sensitivity measures of 0.45 and 0.37. Experiments 5 and 6 distributed equal amounts of points probabilistically and the result was sensitivity measures of 0.60 and 0.58. Seventh, the distributions of summed competitive weights were no more sensitive than the distribution of groups' choices ignoring competitive weights. In Experiments 4 and 6 the sensitivity measures of competitive weights (0.33 and 0.58) were no greater than the sensitivity measures of the groups' choices (0.37 and 0.59). Eighth, the before-switch data were generally similar to the after-switch data. The averages of the before- and after-switch measures of sensitivity were 0.60 and 0.67. The averages of the before- and after-switch measures of bias were 0.94 and 0.94. The averages of the before- and after-switch measures of accounted for variance were 0.83 and 0.92. These patterns constitute the results of the group level analyses of the groups' choices.

CHAPTER 4: Analyses of Individuals' Choices

The IFD model is silent about the predicted behavior of individuals. Although the IFD of foragers is based on the assumptions that all individuals maximize resource intake, know the resource distribution available to them, move freely between resource sites, and have equal competitive ability, the orderliness of individuals' choices between resource sites is not described. This chapter presents several analyses of the behavior of individuals in human group choice experiments.

The purpose of these analyses is discover any overall consistency in individuals' choices that may explain the orderliness of the Group Choice analyses in Chapter 3. Any particular individual may be consistent in his or her choices, but only consistency that may offer an explanation for Group Choice is considered. For example, it is to be expected that some individuals' choices were consistent because they "liked the card color", "wanted to be near a friend", "didn't care", "alternated just to be different", or any other number of reasons. But none of these reasons would predict orderly Group Choice.

These analyses consider individuals' behavior in relation to points obtained or available that may explain orderly Group Choice. The first set of analyses describes the relations between participants' self-reported effort and total obtained points, and self-reported estimates of point ratios and total obtained points. The second set of analyses describes the similarity of individuals' preferences for rich and lean alternatives from block-to-block of trials. The third set of analyses describes the consistency of individuals' obtained points from block-to-block of trials. The fourth set of analyses describes the matching relation between individuals' choices between alternatives and points obtained from each alternative.

<u>Individuals' Effort and Point Estimates, and Total Obtained Points</u>

To determine if effort and knowledge of the point distribution between alternatives contributed to obtaining more points, self-reports of both variables were compared to total points earned. After the completion of an experiment, participants completed post-experimental questionnaires. One question asked participants to rate the effort put into obtaining points on a scale of 1 to 9 where 1 equaled the least effort possible and 9 equaled the most effort possible. This analysis could show that increases in reported effort were related to increases in obtained points. A second question asked participants to estimate how many points were allocated to each alternative. These two amounts of points formed a point ratio that was compared to total obtained points for each participant. This analysis could show that participants had been doing mathematical calculations correctly to maximize their obtained points. If this were so, then they would be able to report the points allocated to each alternative accurately. The scatterplots depicting relations between effort and obtained points are presented in Figure 12, and the scatterplots depicting the relations between estimated reported point distribution and obtained points are presented in Figure 13. The scatterplots in Figure 12 reveal no relation between reported effort and total points earned. In most experiments, participants either earned similar amounts of points regardless of effort or earned varied amounts of points regardless of effort. The scatterplots in Figure 13 revealed no relation between accurate estimation of the point distributions and total obtained points. In general, participants who estimated the point distributions accurately were no more likely to obtain more points than inaccurate participants. In both analyses, self-reports of effort and accurate knowledge of the point distributions had no relation on obtaining points.

Figure 12. Scatterplots depicting relations between individual reported effort and total obtained points in each experiment.

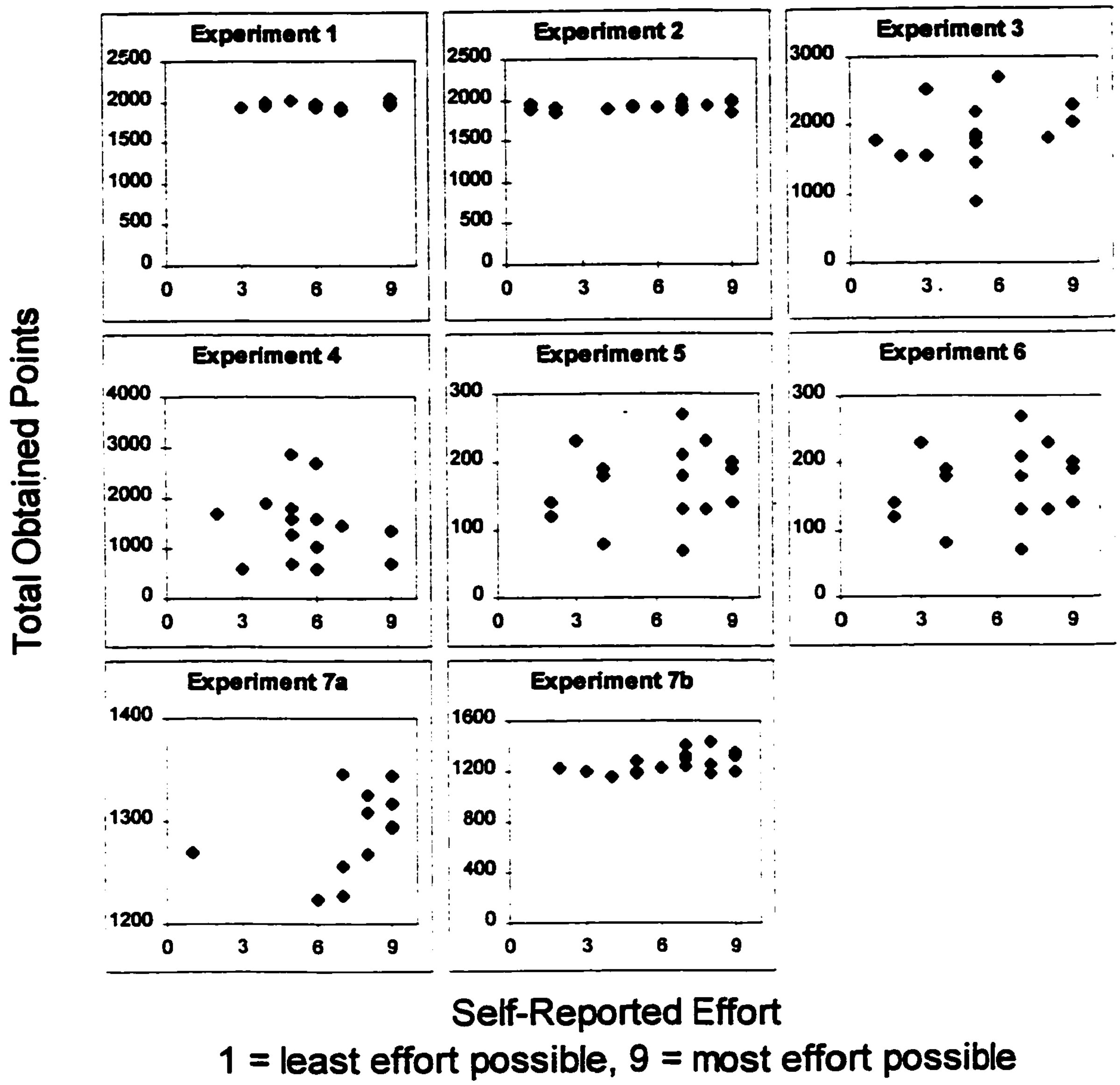
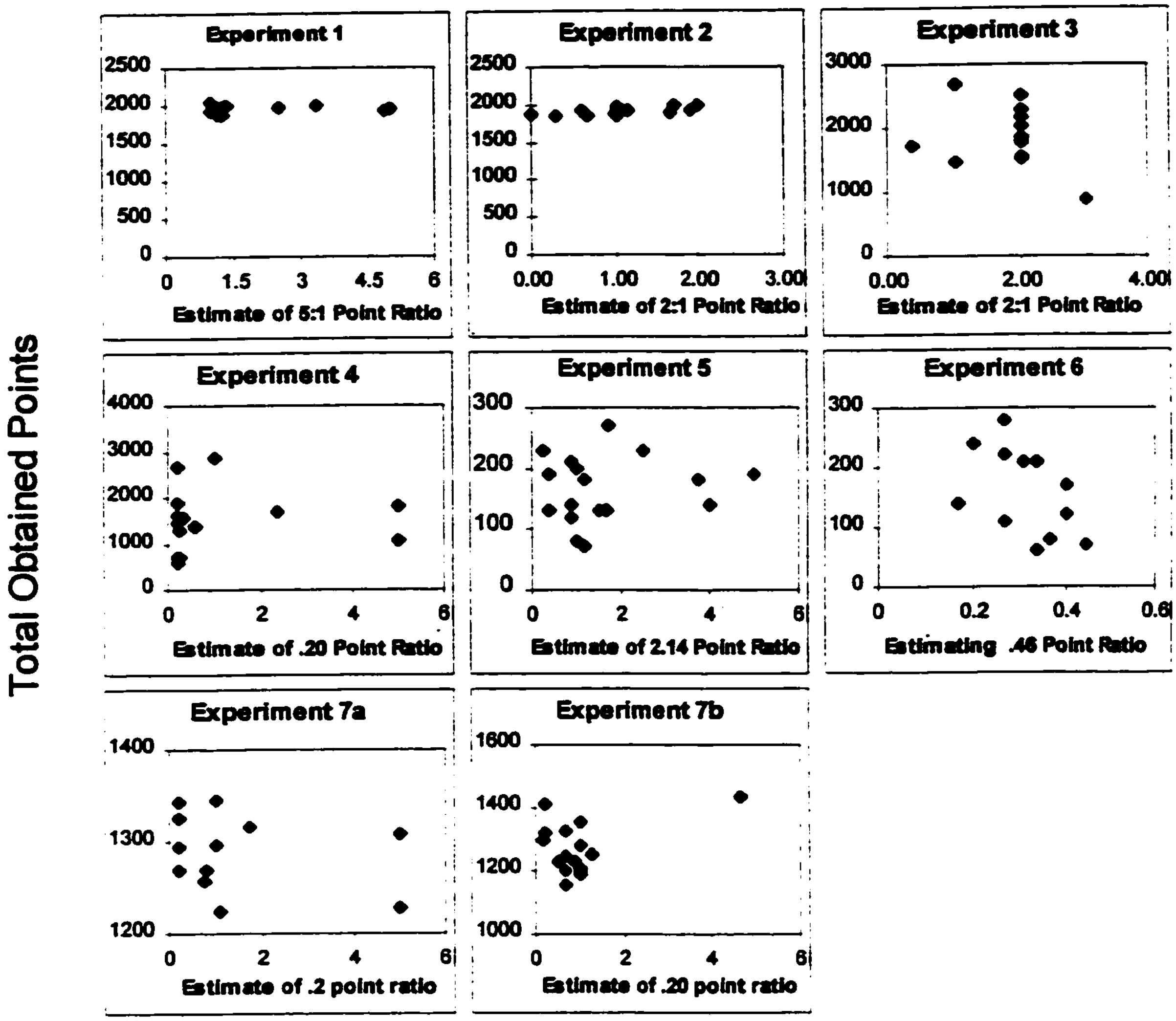


Figure 13. Scatterplots depicting relations between estimates of the points allocated to each alternative and total obtained points in each experiment.

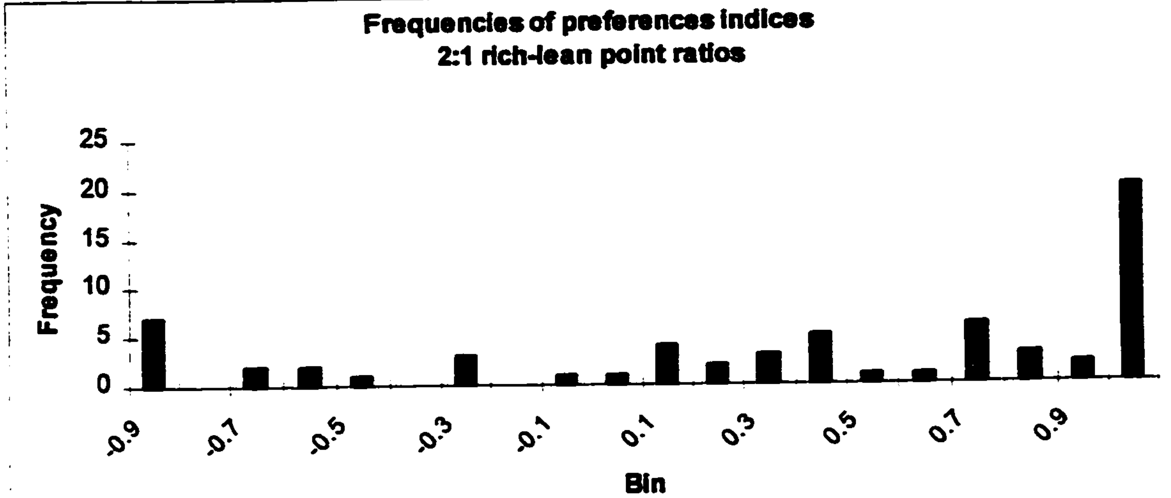


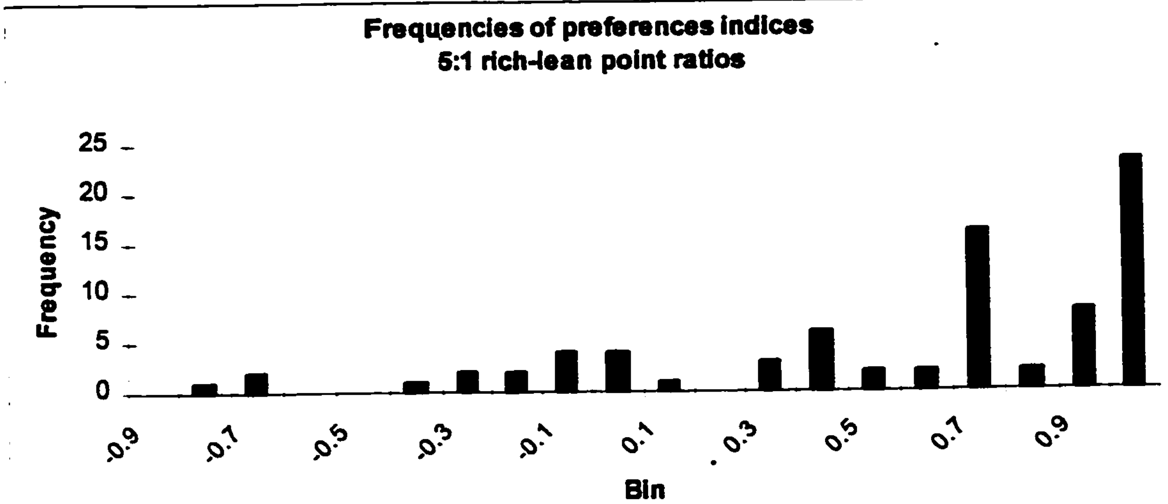
Individuals' Preferences for an Alternative

A preference index was constructed to determine the orderliness of individuals' preferences for an alternative (see Appendix I). The preference index was constructed so that it ranged from negative one to one. A preference index of negative one indicated total preference for the alternative that distributed fewer points. A preference index of one indicated total preference for the alternative that distributed more points. A preference index of zero indicated equal preference for the rich and lean alternative. Preference indices for each participant were constructed for every block of trials. This preference index is described in more detail in the Appendix.

The preference indices of each experiment were plotted in histograms to examine any general patterns that might suggest further analyses. Preference indices for each experiment were plotted in separate histograms for 2:1 and 5:1 conditions. Because the groups were sensitive to point distributions to a lesser or greater degree in all the experiments, it was expected that there would be more positive indices (indicating preference for the richer alternatives) than negative indices (indicating preference for the leaner alternatives). In general, this pattern of indices occurred. The preference histograms for all experiments are presented in Appendix J, but as an example the histograms for Experiment 1 are presented in Figure 14. As expected, most indices showed a preference for the rich alternative. Preference indices for both experiments varied across the continuum of possible preferences. The wide spectrum of preference indices indicated that individuals were not necessarily constrained in their choices. For example, a preference index of about .67 corresponds to a 5:1 choice ratio. Had all individuals chosen the richer alternative five times as often as the leaner alternative, all the preference indices would fall in the .7 bin. Although 16 out of 79 indices did fall in that bin, most did not. No obvious pattern of distributions in the histograms suggested an explanation for the group level analyses.

Figure 14. Example preference-index histograms from Experiment 1. Experiment 1 involved a group choosing to sit in Row A and Row B chairs, and subgroup members shared allocated points (i.e., chairs-shared points).

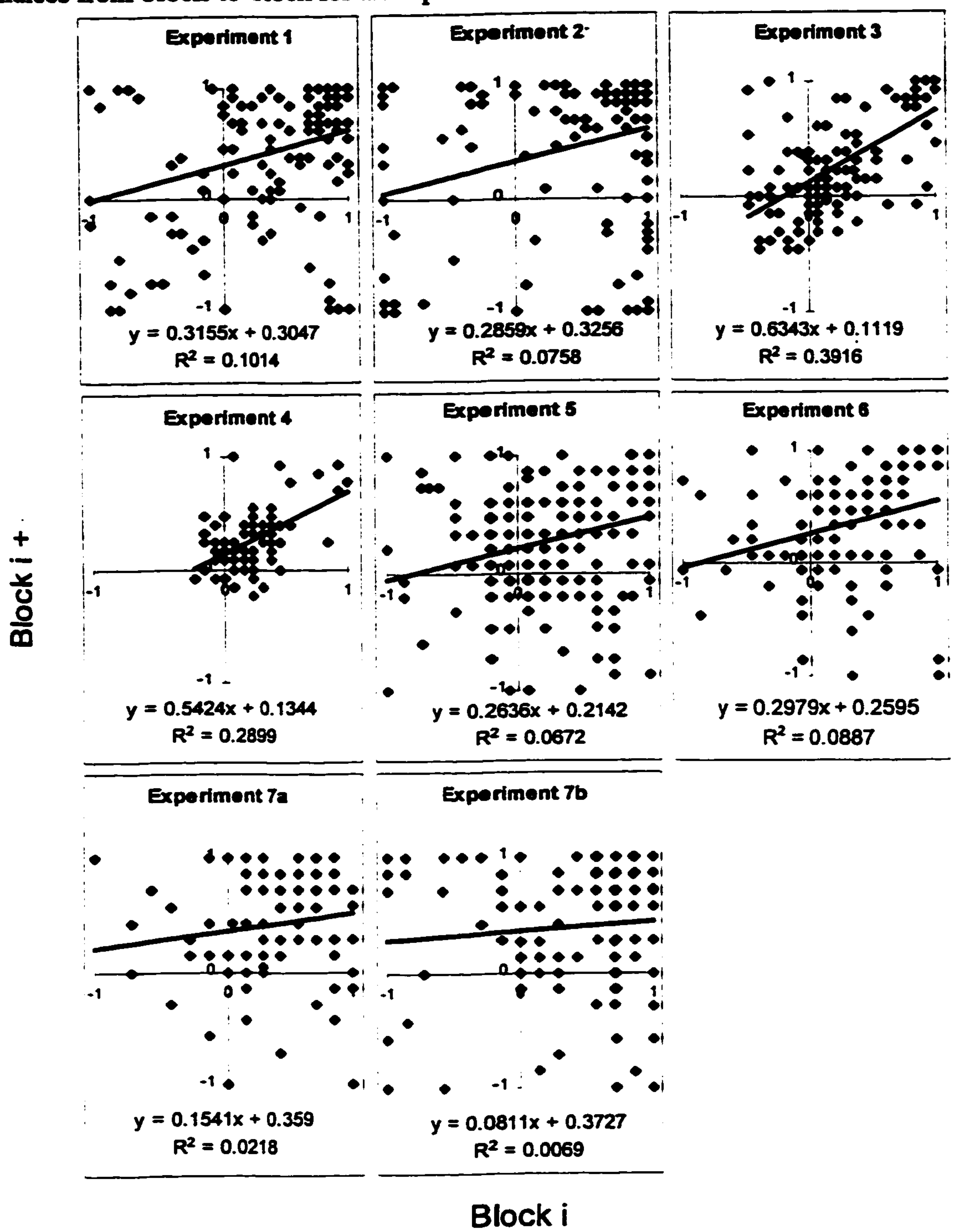




To determine if participants were consistent in the preferences from block-to-block of trials, participants' preference indices were auto-correlated with a lag of one. The histograms revealed that the preferences tended to vary, but it was possible that each individual had the same preference for rich and lean alternatives from block-to-block of trials. If a few participants consistently chose the lean alternative to the same degree from block-to-block while others consistently chose the richer alternative to the same degree from block-to-block, then it would be possible to detect this relation with an auto-correlation with a lag of one. This analysis required that participants' preference indices of the first block of trials be related the second block, the preference indices of the second block of trials to the third block, and so on. If participants were consistent from block-to-block, then positive correlations should emerge. These analyses are presented in Figure 15.

The scatterplot for each group of participants shows preferences in block i (horizontal axes) and preferences in block i + 1 (vertical axes). The first notable aspect of these scatterplots is that the data vary widely. Most data fall in the upper-right quadrant of the scatterplots. But other data points can be observed in all the other quadrants. The fitted linear regression lines have weak r-squared values (Experiments 1, 2, 5, 6, 7a, 7b) or moderate r-squared values (Experiments 3 & 4). The second notable characteristic of these scatterplots is that the fitted linear regression lines all have positive slopes whether the correlations were relatively weak or moderate. These analyses reveal that the preferences of participants were consistent from block-to-block to a weak degree.

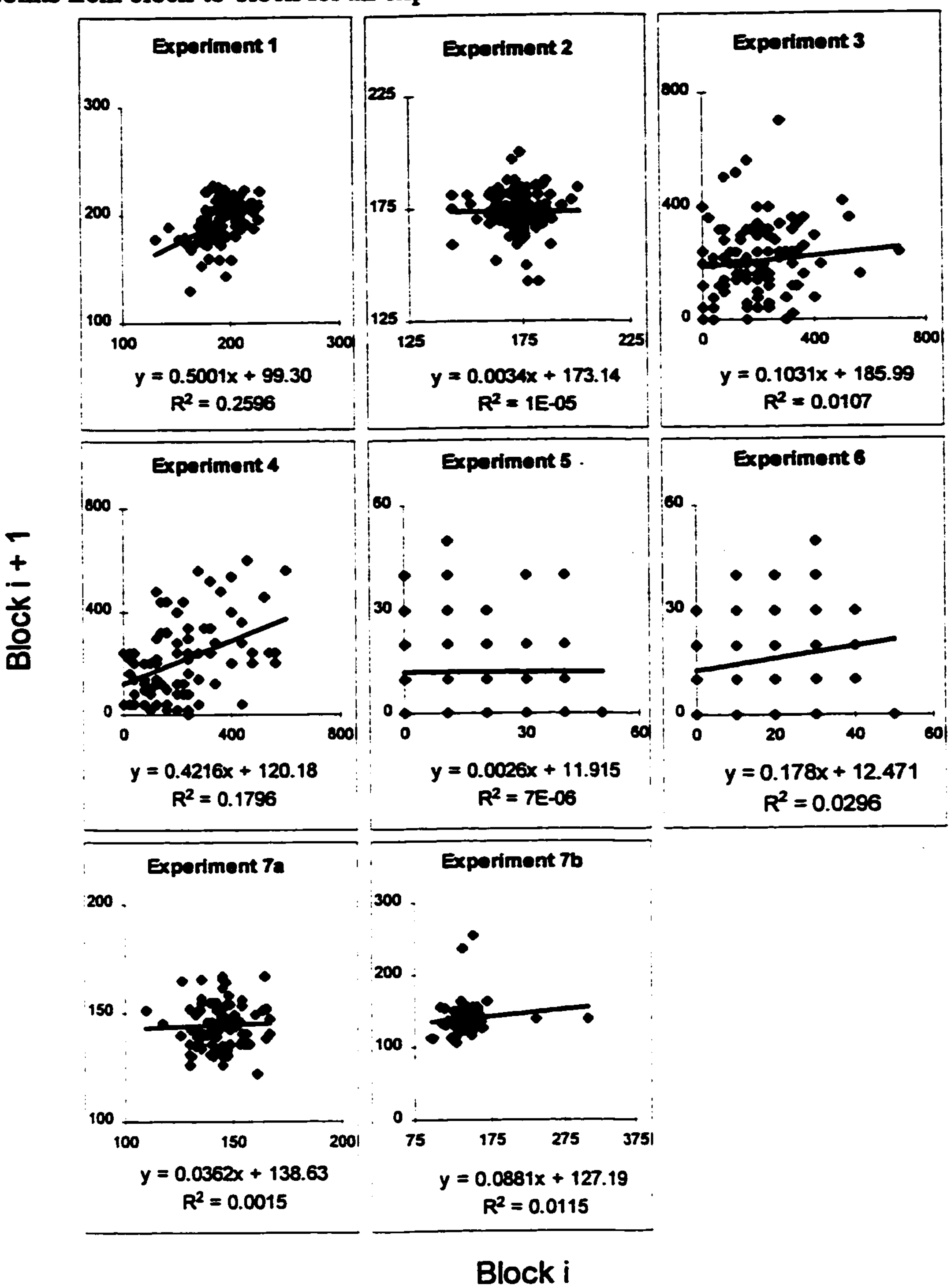
Figure 15. Scatterplots depicting the lagged auto-correlations of individuals' preference indices from block-to-block for all experiments.



Individuals' Obtained Points

To determine if participants were consistent in obtaining points from block-to-block of trials, participants' obtained points were auto-correlated with a lag of one. If a few participants obtained few points to the same degree from block-to-block while others consistently obtained more points to the same degree from block-to-block, then it would possible to detect this relation with an auto-correlation with a lag of one. This correlation requires that participants' obtained points in the first block of trials be related to those obtained in the second block, the obtained points in the second block be related to those of the third block, and so on. If participants were consistent from block-to-block, then positive correlations should emerge. These analyses are presented in Figure 16. With the exception of two experiments, there was no consistency in participants' points block-to-block. The exceptions, Experiment 1 (chairs-shared points) and Experiment 4 (card – probabilistic points – competitive weights), showed small to moderate consistency. These analyses show little consistency in participants obtaining points.

Figure 16. Scatterplots depicting the lagged auto-correlations of individuals' obtained points from block-to-block for all experiments.



Individuals' Choice Relations Between Alternatives and Obtained Points

A Generalized Matching Law analysis of individual choices may show that the choices of the individuals contribute to overall group choice. Individual double logarithmic plots were created for each individual to determine if the individuals' choices between alternatives matched the amounts of points obtained from each alternative. For example, in a block of trials an individual may have chosen one alternative twice as often as the other. If the individual obtained twice as many points from the preferred alternative as the less preferred alternative, then the individual's choices matched obtained points. By comparing the individuals' proportions of choices for one alternative with proportions of obtained points from corresponding alternatives in double logarithmic scatterplots, individual sensitivities can be assessed. Comparing the ratio of choices for alternatives with the ratio of obtained points is preferable to using proportions, but a prevalence of blocks of trials where no points were earned from either alternative (i.e., zero denominators in the ratios) required the use of arcsine proportions. In the case of no points being earned from either alternative, the arcsine of .5 was substituted because the same amount of points (i.e., 0) were obtained from each alternative. In addition, histograms depict the distribution of individual sensitivities in each experiment. These histograms may reveal consistency in individual matching in the context of group matching. For example, the histograms may show that when a group's sensitivity was .95, the majority of individuals' sensitivity measures were also .95. In contrast, the histograms may show that individual sensitivity to obtained points varied widely and inconsistently. One problem with this analysis is that when points were shared among subgroup members and the group's choices matched the point distributions, then individual matching is forced. For example, Experiment 2 (cards – shared points) had points shared among card subgroup members and the group matched the point distribution. In this situation, all individuals received the same amount of points on each trial for each block (i.e., 6.7 points) and, therefore, the proportion of choices for one alternative must equal the proportion of points obtained from that alternative. In other words, when the group matches, all individuals must match and when all individuals match, the group must match. A better test of the relation between individual sensitivities and group sensitivity occurs with the experiments that distributed points probabilistically. For example, an individual may choose one alternative twice as often as the other, but may or may not obtain points in the same proportion.

Individual matching analyses for all individuals in the experiments that shared points are presented in Figures 17, 18, 19, and 20. Experiment 1 involved participants choosing to sit in two rows of chairs and shared points. Experiment 2, 7a, and 7b involved participants choosing blue and red cards and sharing points. The histograms of individual sensitivity measures for each experiment are presented in Figure 21. With few exceptions, the individuals of all four experiments showed a strong degree of matching between choices among alternatives and obtained points from alternatives. Most sensitivity measures were in the .80 to 1.00 range. In these experiments, individuals' choices tended to match obtained points in a similar manner to the groups' sensitivities to point distributions. As noted earlier, however, when points are shared and the group sensitivity measures are close to one, then individual sensitivity is constrained and matching is forced.

Figures 17. Individual matching relations between individual choices among alternatives and obtained points from those alternatives from Experiments 1. In this experiment, points were distributed by sharing among subgroup members.

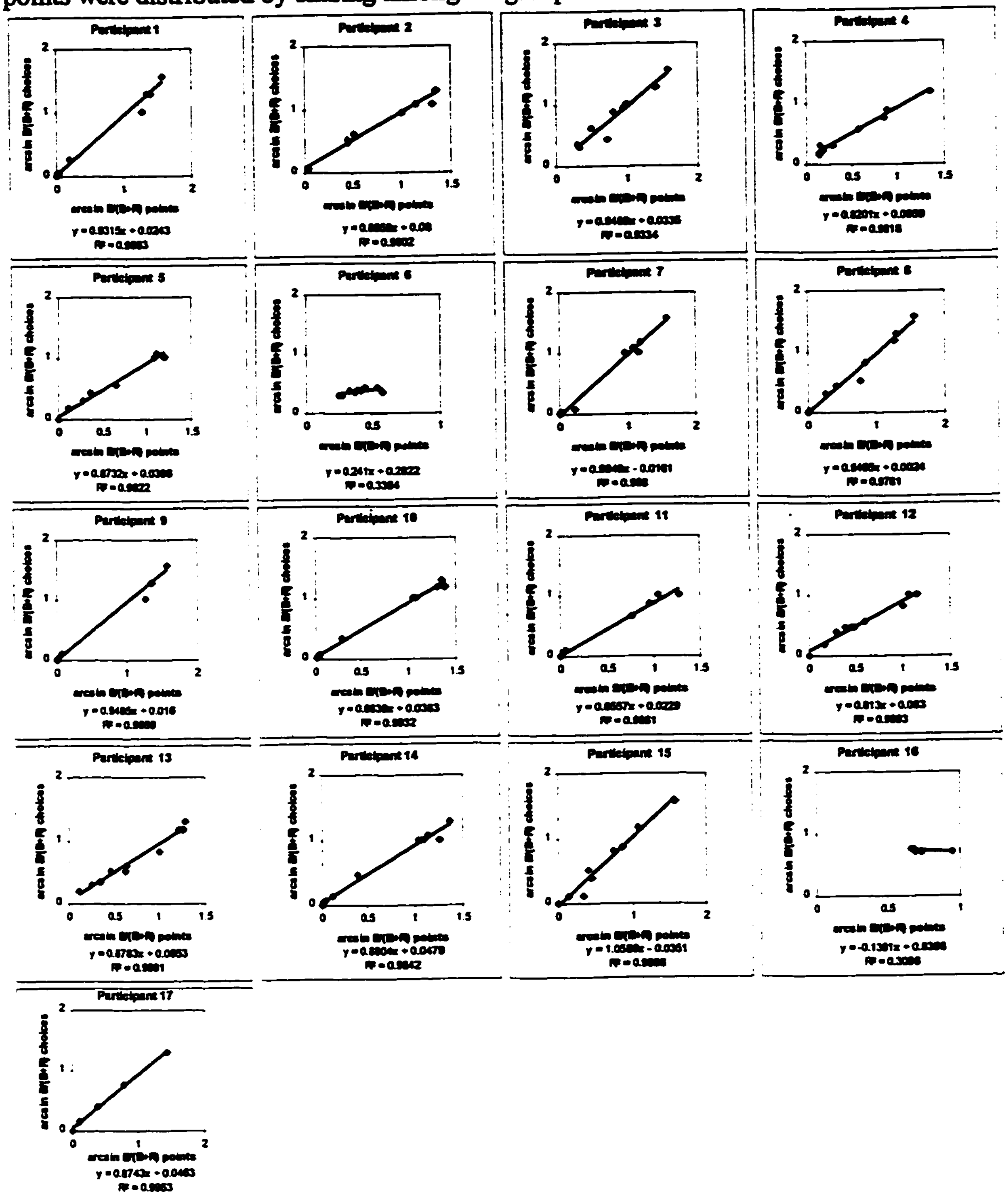


Figure 18. Individual matching relations between individual choices among alternatives and obtained points from those alternatives from Experiments 2. In this experiment, points were distributed by sharing among subgroup members.

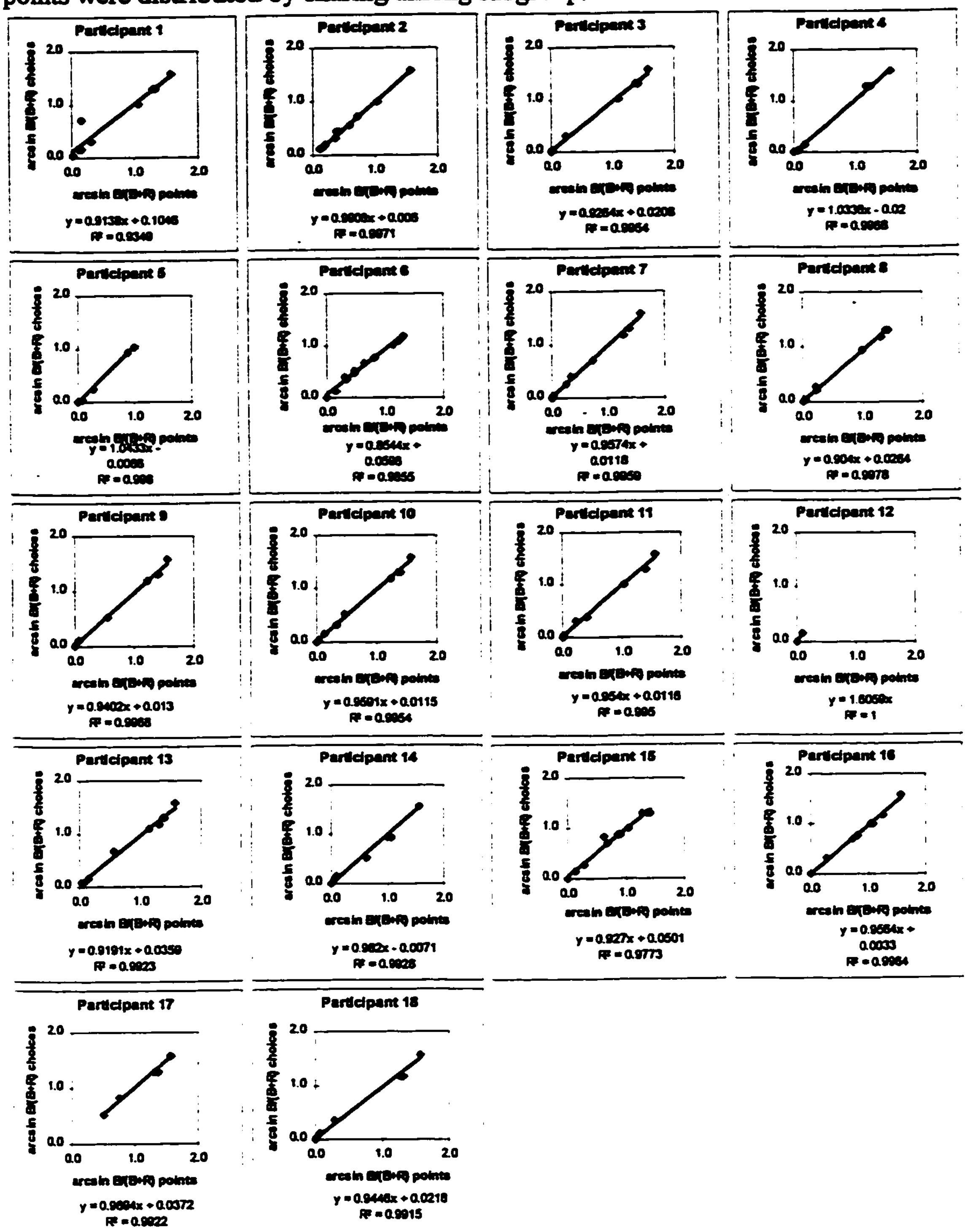


Figure 19. Individual matching relations between individual choices among alternatives and obtained points from those alternatives from Experiments 7a. In this experiment, points were distributed by sharing among subgroup members.

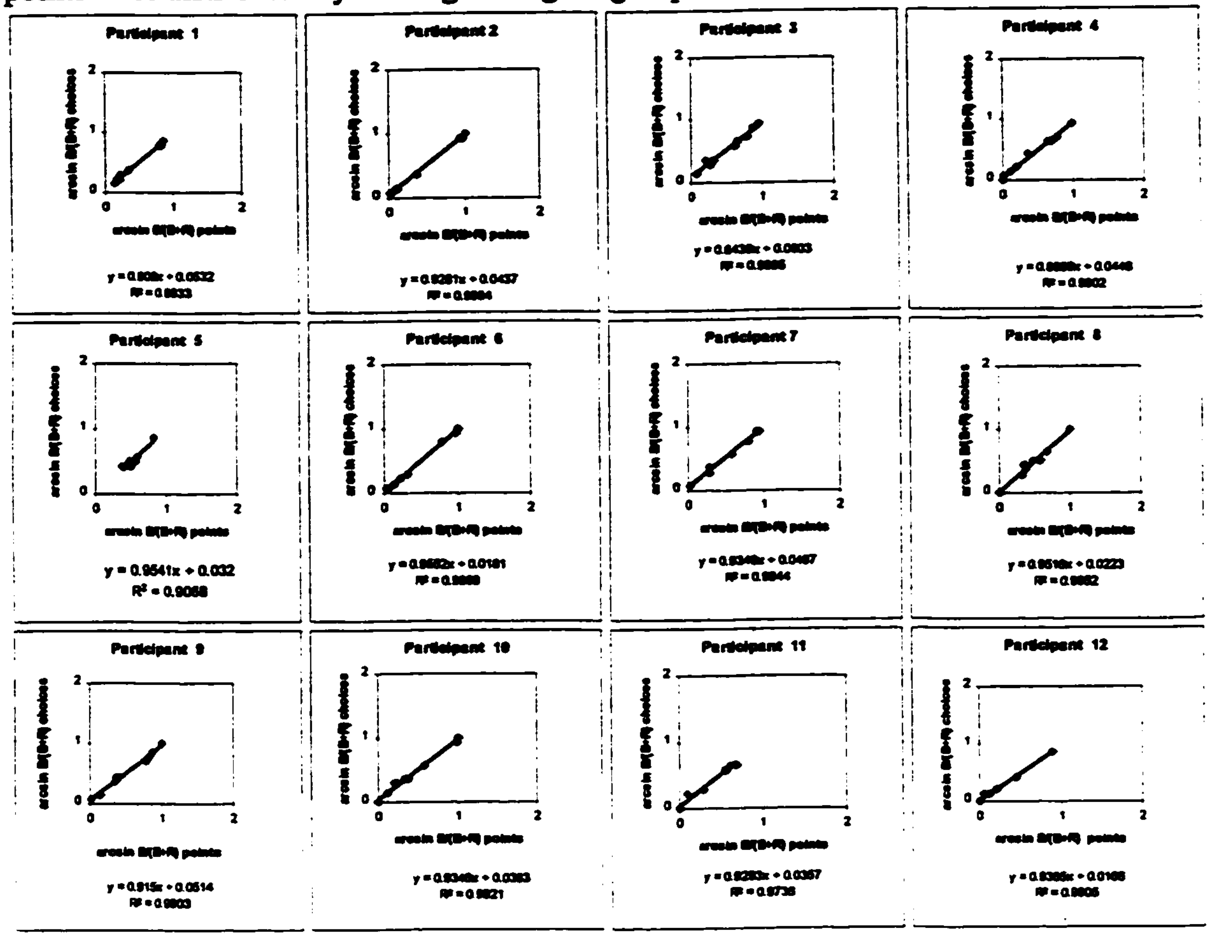


Figure 20. Individual matching relations between individual choices among alternatives and obtained points from those alternatives from Experiments 7b. In this experiment, points were distributed by sharing among subgroup members.

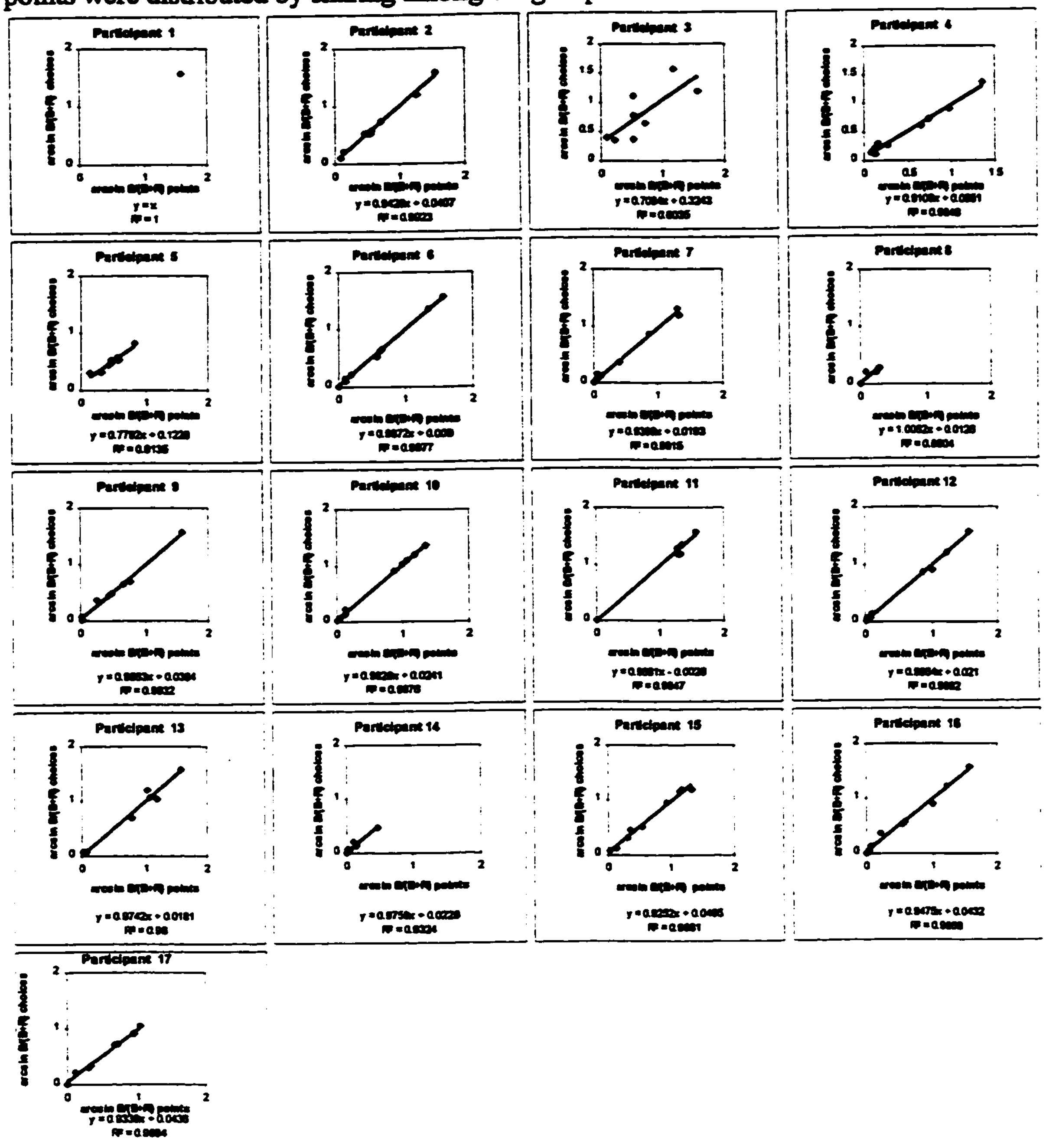
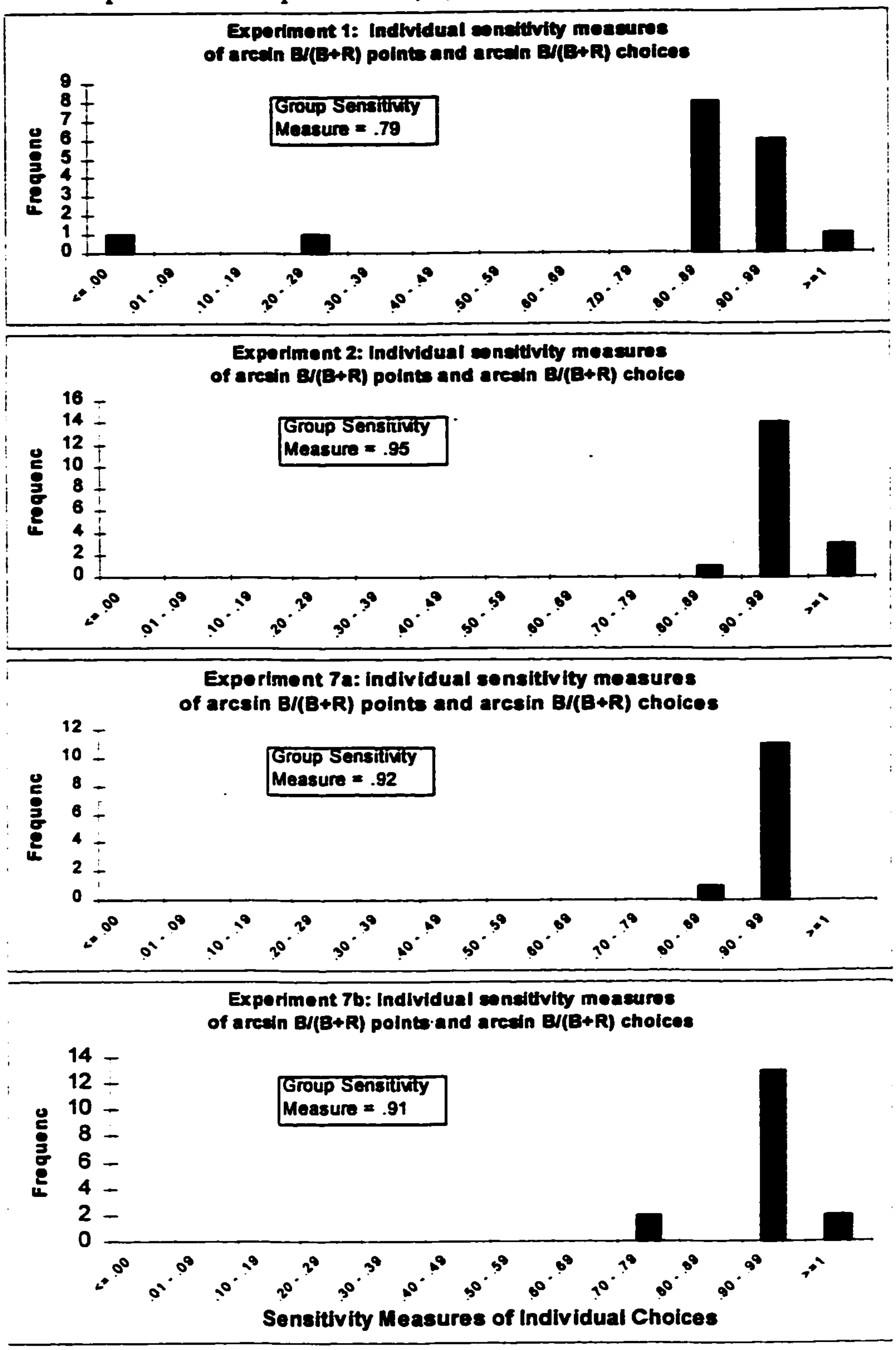


Figure 21. Histograms of individual sensitivities of choices between alternatives and obtained points from Experiments 1, 2, 7a, and 7b.



In contrast to the experiments where points were shared among subgroup members, the four experiments where points were probabilistically distributed may show different results. Experiment 3 and 4 probabilistically distributed unequal amounts of points and Experiments 5 and 6 probabilistically distributed equal amounts of points. Probabilistically distributing points permits an individual's proportion of choices to not equal the proportion of obtained points from alternatives. For example, an individual may choose a blue card once out of fifteen trials (proportional choices for blue = .07), but receive 10 points from for choosing blue once and receive none from choosing red (proportional points obtained from blue = 1.00). This result would appear as undermatching for that block of trials. Of course, an another individual might make the same proportion of choices, but receive most of their points from the preferred alternative. This individual's choices would appear to match obtained points. These experiments with probabilistically distributed points permit comparison between sensitivity of individuals' choices and the group's choices. The double logarithmic scatterplots of the arcsine of the proportion of choices and the arcsine of the proportion of obtained points for all individuals in the four experiments are presented in Figures 22 – 25. The histograms of individual sensitivity measures for the four experiment are presented in Figure 26. With few exceptions, the individual double logarithmic scatterplots show individual sensitivities to be low and to vary widely. Furthermore, the relations between individuals' choices and obtained points were more variable than observed previously (r-squared values were often below .50). The histograms in Figure

26 show a wide dispersal of sensitivity measures for each experiment. In contrast to the individual sensitivity measures from Experiments 1, 2, 7a, and 7b, there was little correspondence between the individuals' choices and the groups' choices. For example, in Experiment 3, the group's sensitivity measure was .45 and none of the individuals' choices matched obtained points in the same range. The results of Experiment 4 came closest to showing a correspondence between the group's sensitivity (i.e., .37) and individual sensitivity measures. In Experiment 4, 8 participants' choices matched obtained points to the same degree (about .40) as the group, but 8 other participants did not.

Figures 22. Individual matching relations between individuals' choices among alternatives and obtained points from those alternatives from Experiment 3 (unequal amounts of points distributed probabilistically).

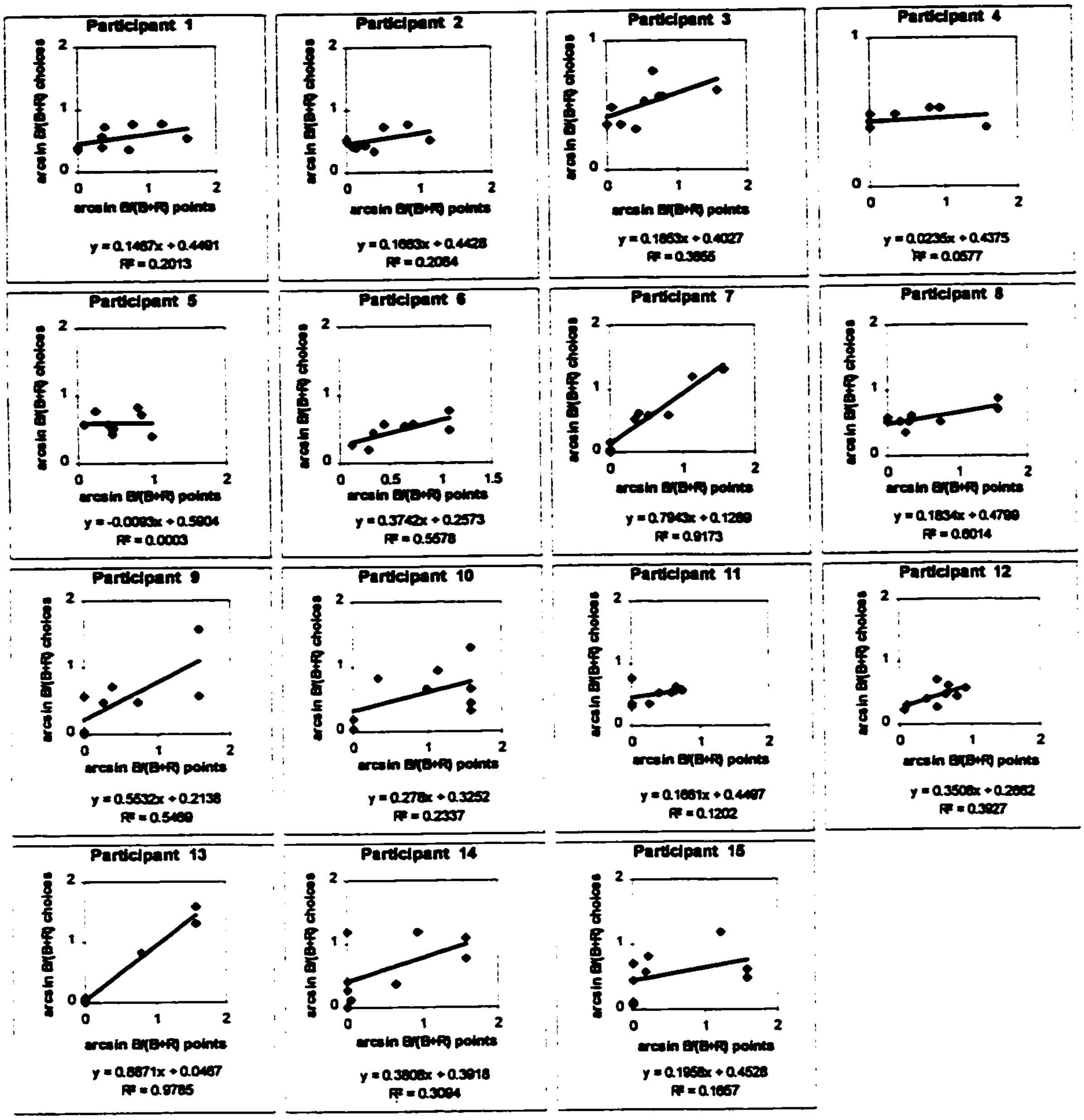


Figure 23. Individual matching relations between individuals' choices among alternatives and obtained points from those alternatives from Experiment 4 (unequal amounts of points distributed probabilistically and 3 different competitive weights).

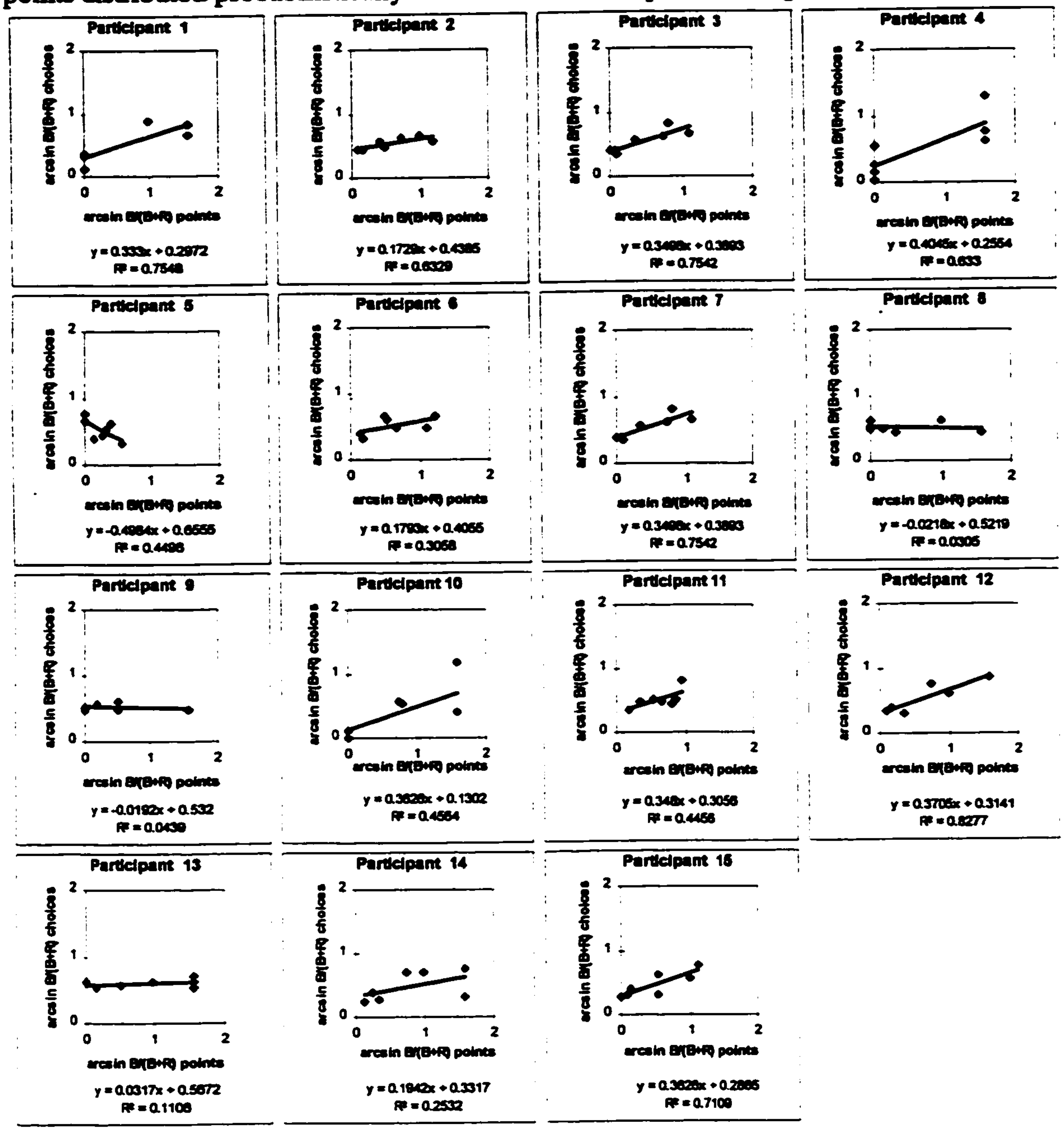


Figure 24. Individual matching relations between individuals' choices among alternatives and obtained points from those alternatives from Experiment 5 (equal amounts of points distributed probabilistically).

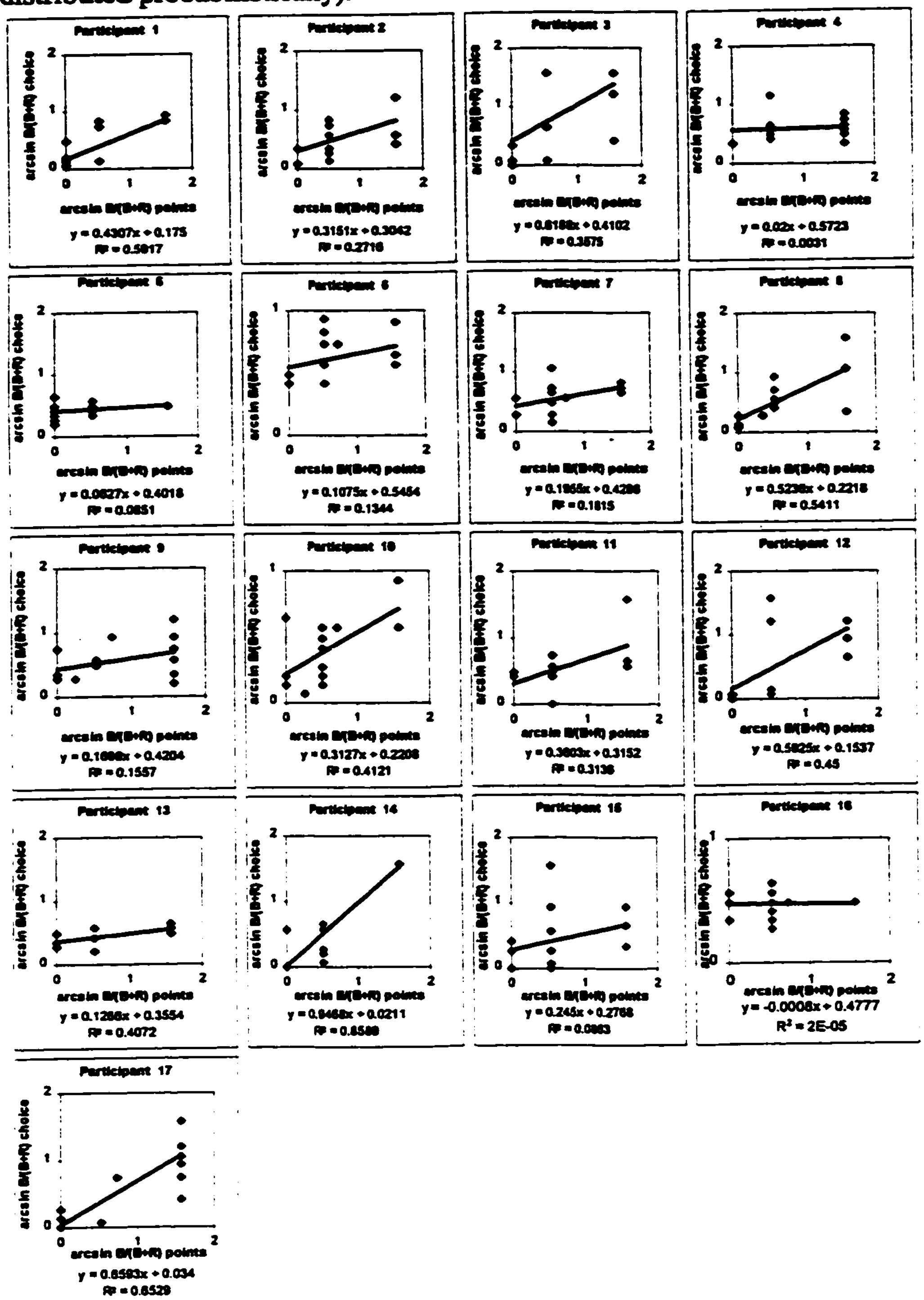


Figure 25. Individual matching relations between individuals' choices among alternatives and obtained points from those alternatives from Experiment 6 (equal amounts of points distributed probabilistically and 2 different competitive weights).

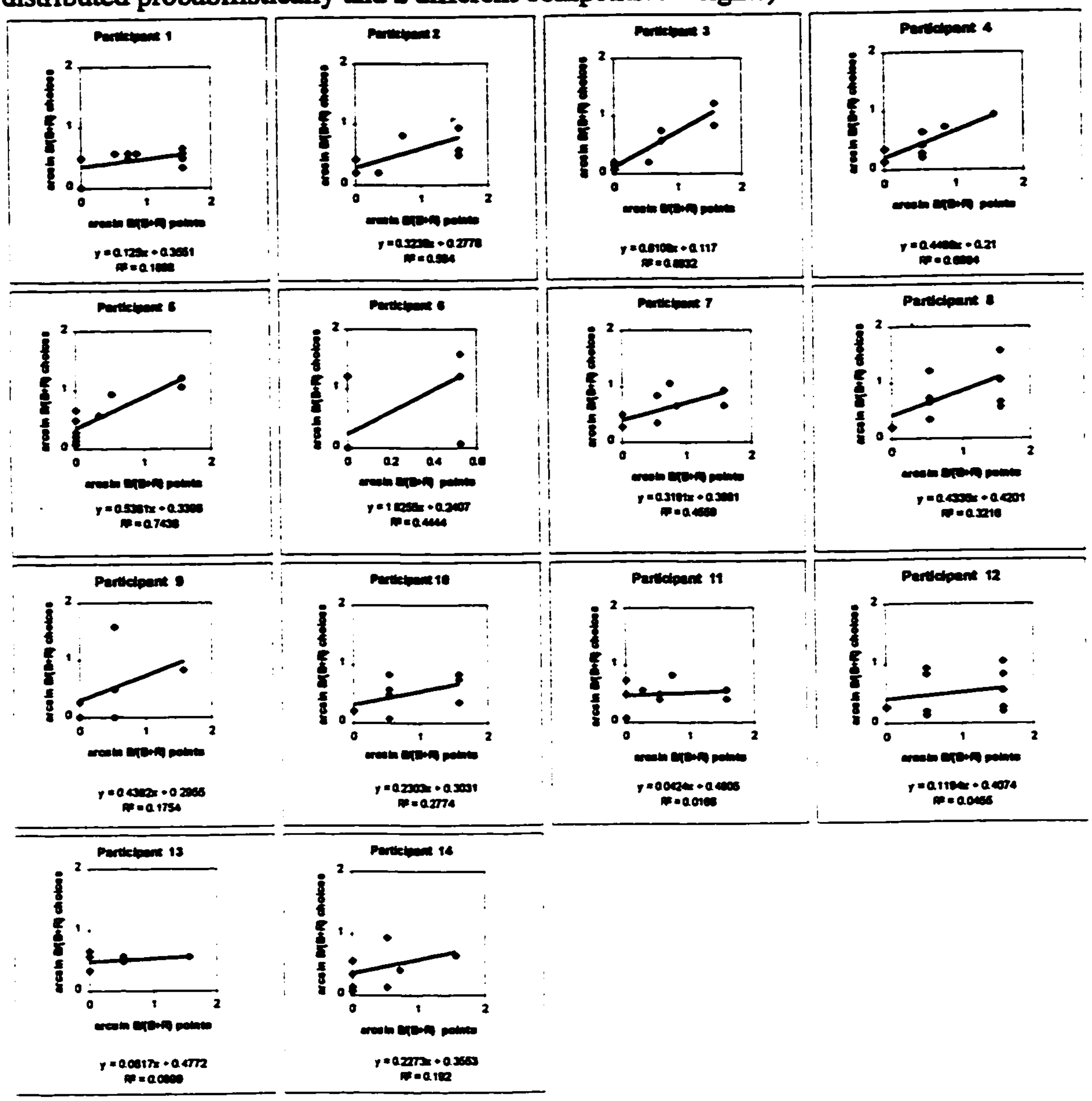
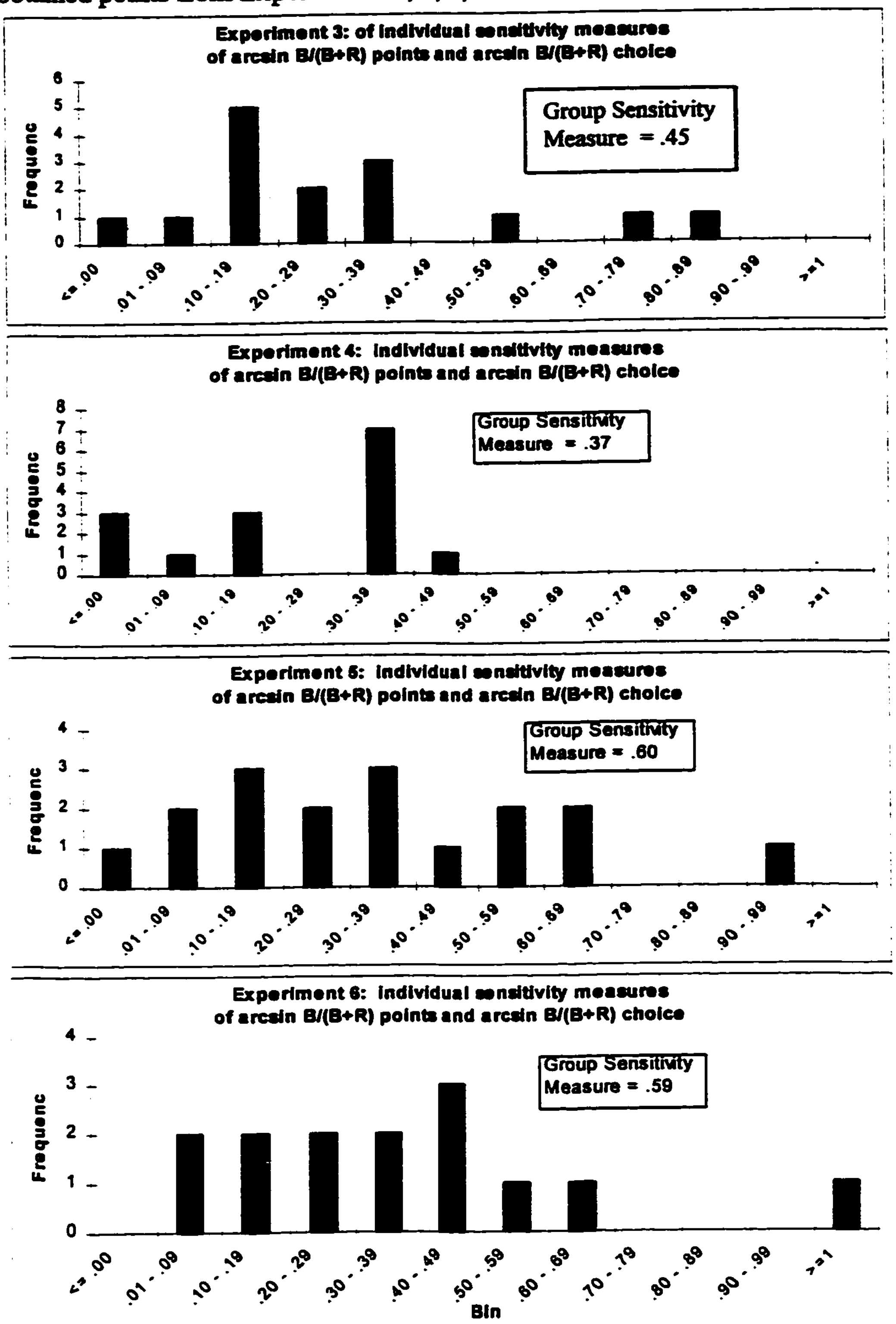


Figure 26. Histograms of individual sensitivities of choices between alternatives and obtained points from Experiments 3, 4, 5, and 6.



Discussion of Analyses of Individuals' Choices

The purpose of analyzing the choices of individual participants in the Group Choice experiments was to determine if there was any consistency on the individual level that might suggest an explanation for the group results. The overall result was there was little consistency on the individual level except when it was forced to occur.

Individual variables such as effort and accurate knowledge of the point distributions could have been related to total obtained points, but they were not. It was possible that participants who put more effort into the task would obtain more points than those who reported less effort. It was also possible that participants who performed mathematical calculations to determine the point distributions would earn more points than participants who did not. Neither self-reported effort nor knowledge of point distributions was related to participant performance.

The preference indices did not show consistent preferences of group members. For example, when points were allocated in a 2:1 rich-lean ratio, most individual preference indices did not fall into the corresponding range. Instead, preference indices ranged widely and without any particular pattern. Auto-correlations of the preference indices from block-to-block of trials were all positive, indicating that individuals' preferences for the rich card were similar from block-to-block. Those correlations, however, were mostly weak or, at best, moderate. The same auto-correlation analyses of individual obtained points showed no consistency.

The results from the generalized matching analyses of individuals' choices were complex. It was true that when a group's choices matched the distributions of points, and points were shared among subgroup members, then individuals' choices between alternatives were forced to match their obtained points. In an IFD situation, each individual gains the same amount or resources when a group's choices match the resource distributions. For example, in an experiment where 12 participants choose blue and red cards and card subgroup members share allocated points, near matching is expected to occur (given the results of Experiments 2, 7a, and 7b). If 100 points are allocated to blue cards and 20 to red cards, then over the course of time, 10 participants would choose blue and 2 would choose red. All participants, whether they chose a blue or red card, would receive 10 points on every trial. If a participant chose blue and red in a 1:14 ratio, then the individual would obtain points from blue and red cards in a 10:140 ratio. Matching on the group level forces matching on the individual level and this was observed in Experiments 1, 2, 7a, and 7b. When points were distributed probabilistically, however, no such constraint existed. For example, if participants chose blue and red cards and 10 points were allocated to a member in the blue subgroup on every trial and 10 points to a member in red card subgroup on every fifth trial, an individual may or may not obtain points in the same proportions to his or her choices. Points were distributed in this manner in Experiments 5 and 6 and in a similar probabilistic manner in Experiments 3 and 4. The results of the individual level choices showed that the individuals did not match obtain points in the same manner as the groups' choices matched point distributions. In contrast to the previous results of Experiments 1, 2, 7a, and 7b, these individuals' choices were low in sensitivity, varied, and disorderly. In Experiments 3, 4, 5, and 6, the groups' choices were relatively less sensitive to point distributions (i.e., sensitivity measures of .45, .37, .60, and .59), but not even the majority of individuals made choices like the group. In these experiments, some individuals matched, undermatched, and overmatched regardless of the orderly group choice. These results show that a group's choice between resources does not require that all the individuals make the same proportions of choices between alternatives and match obtained points.

CHAPTER 5: Discussion

This dissertation presents an experimental analysis of a social event called Group Choice. Group choice is a category of social events describing how a group of individuals engages in two behaviors and obtains corresponding consequences. The Ideal Free Distribution was the model used to understand why group members engage in two behaviors in direct relation to the consequences attached to those behaviors. By investigating the selective nature of consequences on the behavior of groups of people, this dissertation found novel results of human Group Choice that suggested explanations for the results of previous IFD research (Baum & Kraft, 1998; Kennedy and Gray, 1993; Sokolowski et al, 1999), paralleled individual choice research (Baum, 1974; Herrnstein, 1961), and offered a quantification of a new concept – a social level Law of Effect (Guerin, 1994, in preparation; Herrnstein, 1970).

The seven experiments of this dissertation demonstrated that under some conditions an IFD of human Group Choice is possible. Most previous IFD research used birds, fish, or insects to test the predictions of the IFD (Kennedy & Gray, 1993). The most common IFD research paradigm was to provide resources at different rates at two different resources sites and observe the distribution of the group of foragers. Aside from this common denominator, there is great variability in operational definitions of resource sites, resource delivery rates, and resources. For example, Harper (1982) and Kraft and Baum (1998) both investigated the IFD of a flock. Harper presented small pieces of bread to a flock of ducks by throwing them into two separate areas of a pond nearly 20 meters apart. Kraft and Baum, in contrast, dropped dried peas into two resource sites separated by 1.2 meters according to different Flesher – Hoffman variable-interval schedules. Most IFD research showed animals to be sensitive to resource distributions; albeit not perfectly in accord with IFD predictions. Until recently, an IFD of a group of humans had not been undertaken.

Sokolowski et al. (1999) conducted the first IFD study of groups of people to determine if their behavior could be distributed ideally. Two unique qualities of this research were (1) the distributed behavior of the group was raising green and red cards and not vigilance at two resource sites, and (2) the resources were obtained points that could lead to cash prizes and not appetitive reinforcers such as food. Each participant chose a green or red card and then a pre-determined number of green and red card participants received points. For example, if 5 people chose green cards and 10 people chose red cards, and the points were distributed in a 1:8 green-red ratio, then only 1 of the 5 green card participants gained a point and 8 of the 10 red card people gained a point. This example highlights a noteworthy characteristic about the method of point distribution. The points were partly shared among subgroup members when there was more than one point allocated and the points were probabilistically distributed among subgroup members when there were more people than points. The independent variable was the ratio of points made available to green and red card 'choosers' and the dependent variable was the distribution of green and red card choices across a series of trials. Sokolowski et al. found that groups were sensitive to the point distributions, but that the groups tended to undermatch (i.e., too many choose the lean card and too few chose the rich card). Generalized IFD analyses (see equations 5 and 6 in the introduction) revealed sensitivity measures between .62 and .70. Although Sokolowski et al. found the IFD analysis of the groups' choices lacking, they did demonstrate a new way to conduct research on IFD of human behavior. All the original experiments contained in this dissertation were inspired by the methodology used by Sokolowski et al. (1999).

The differences in this dissertation's experiments from those of Sokolowski et al illuminate their results. Instead of using a methodology that combined shared and probabilistic point distributions, some experiments only shared points among group members (Experiments 1, 2, 7a and 7b) and some experiments only probabilistically distributed points (Experiments 3, 4, 5, and 6). Experiment 1 shared allocated points among all those participants who sat in Row A and Row B chairs.. If 100 points and 20 points were allocated to Row A and Row B chairs, and 5 and 10 people sat in Rows A and B, then everyone in Row A received 20 points and everyone in Row B received 2 points. Experiments 2, 7a, and 7b also shared points among subgroup members, but the groups chose between raising blue and red cards instead of sitting in Row A and Row B chairs. Experiments 3 and 4 required that unequal amounts of points be distributed probabilistically to blue and red card subgroup members. For example, if 100 points and 20 points were allocated to blue and red card subgroups, and 5 and 10 people chose blue and red cards, then one randomly chosen blue subgroup member received all 100 points and one red card subgroup member received 20 points. On every trial, one member of each subgroup won the allocated points. Experiments 5 and 6 required that equal amounts of points (i.e., 10) be distributed probabilistically to blue and red card subgroup members. For example, if points were to be distributed in a 5:1 blue-red ratio, then one randomly chosen blue card subgroup member received 10 points on every trial and one red card subgroup member received 10 points on every fifth trial, on average. The four experiments that shared points equally among subgroup group members produced different results from the four experiments that distributed points probabilistically. Sharing points among subgroup members led to near IFD matching and probabilistic points led to more undermatching. The sensitivity measures of the groups' choices with probabilistic points were lower, sometimes much lower, than the sensitivity measures found by Sokolowski et al. The sensitivity measures of the groups' choices with shared points were higher, sometimes much higher, than the sensitivity measures found by Sokolowski et al. The moderate measure of IFD sensitivity found by Sokolowski et al may be due to their combined shared-probabilistic points distribution. In all likelihood, the probabilistic nature of their methodology interfered with the IFD of their groups' choices. There was, however, no reason to expect probabilistic point distribution to interfere with Group Choice.

The explanation for the interfering effects of probabilistic point distribution remains a mystery. It was expected that probabilistically distributing points would produce IFD matching in a similar manner to the first two experiments that shared points. Experiments 3 and 4 (cards – probabilistic distribution of unequal points) were conducted before the other probabilistic points experiments. The low sensitivity measures (a_{exp3} = .45; a_{exp4} = .37) were surprising, but hindsight suggested an explanation. When 100 points were allocated to the rich card and 20 to the lean, more participants chose the rich card than the lean card. Although the expected value gained from choosing the richer card was greater than the expected value gained from the lean card, there was always a better chance of winning the lesser amount of points because there were fewer people competing for it. It was as if the value of the richer alternative was discounted by participants and this made the leaner alternative preferable. Behavior analysts find analogous results with individuals' choice between reinforcers correlated with different probabilities (Rachlin, Logue, Gibbon, & Frankel, 1986; Rachlin, Castrogiovanni & Cross, 1987; Rachlin, Raineri, & Cross, 1991). As uncertainty increases, a reinforcer's value decreases, but the rate of discounting is a hyperbolic function. Compared to a certain reinforcer (e.g., p = 1.0), probabilistic reinforcers are discounted sharply when associated with small amounts of uncertainty (i.e., p = .95, .90, or .85), but are discounted less as uncertainty increases (i.e., p = .50, .40, .30, or .20). In these IFD of Group Choice experiments, probabilistic point distribution may cause reinforcers to be discounted at non-linear rates which may lead to large deviations from matching.

Experiments 5 and 6 were created to work around this effect of probabilistic unequal amounts of points. These experiments probabilistically distributed 10 points to an alternative on every trial and 10 points to the other alternative intermittently to determine the point ratio between alternatives. This type of probabilistic point distribution might have mediated the presumed discounting effects to the richer alternative by making the differences in expected value of group choices more explicit. The results showed that this procedure did increase sensitivity, but did not prevent undermatching. The interfering effects of probabilistic point distribution on the IFD of Group Choice remains a topic in need of more investigation.

The lack of opportunity for a group to distribute ideally in whole numbers to each alternative also interfered with IFD of Group Choice. Experiments 1 and 2 differed in behavior alternatives (sitting in rows of chairs and choosing colored cards) and in the number of participants ($N_{exp1} = 17$, $N_{exp2} = 18$). Both experiments distributed 120 points in 100:20, 80:40, 40:80, and 20:100 ratios, and these point distributions prevented Experiment 1 participants from ever attaining a whole number IFD of groups' choices. For example, with a 100:20 point distribution, the 17 group members could have divided in a 14/3 ratio or a 15/2 ratio. The first option undermatched the point ratio (14/3 = 4.67 < 5.00) and the second option overmatched the point ratio (15/2 = 7.50 > 5.00). Experiment 2 participants were able to ideally distribute in whole numbers on any trial (and they often did). There was no a priori reason to suspect that 17 participants would lead to undermatching and 18 would not. It was possible for the 17 member group to match the point distribution over a block of trials by under- and overmatching in the proper proportions to average out to IFD predictions. There was no way of knowing whether the sensitivity measure from Experiment 1 ($a_{exp1} = .79$) was lower than the sensitivity measure from Experiment 2 ($a_{exp2} = .95$) because of the different behavioral alternatives, different groups of participants, or the opportunity to distribute ideally perfectly.

To test the effects of perfect and imperfect solutions to the IFD problem of Group Choice, two groups participated in Experiments 7a and 7b. These experiments were identical to Experiment 2 except that sometimes there were perfect whole number solutions and sometimes there were only imperfect solutions to similar point ratios. In Experiment 7a, for example, 12 participants distributed between a 100:20 point ratio and a 100:25 point ratio. There was a perfect solution to the 100:20 point ratio and only imperfect solutions to the 100:25 point ratio. In Experiment 7b, 17 participants received points ratios with a perfect solution (e.g., 140:30, 110:60) and point ratios with only imperfect solutions (e.g., 140:25, 115:50).

The results showed a small, but reliable increase in undermatching for both experiments when there were only imperfect solutions to the Group Choice problem. This may be due to a dilemma faced by group members. Consider the case where points are distributed in a 100:20 blue-red ratio and 17 participants have distributed in a 14:3 ratio. If points are shared among group members, then the 14 blue subgroup members receive 7.1 points and the 3 red card subgroup members receive 6.7 points. The 3 red card subgroup members obtain less points that than the 14 blue card subgroup members, but this is just the beginning of the dilemma. If one of the red card subgroup members moves to the blue card subgroup, then the blue card subgroup increases to 15 and each member receives 6.7 points and the two remaining red card subgroup members obtain 10 points each. The situation does not get better for the red card subgroup member, but the situation becomes considerably better for those remaining in the red subgroup. This type of dilemma may lead all members in the lean subgroup to stay in the worse situation. By staying, each individual increases the chance that it is someone else who switches to the other subgroup. If someone else switches out, then the two remaining subgroup members are far better off. However, if all stay, then each individual minimizes their relative loss. In the 100:20 blue-red card point ratio - 14:3 participant distribution example, if all 3 red subgroup members stay, then the blue card subgroup members only gain 0.4 points over the red card subgroup members. If one of the 3 subgroup members switches, then the 2 remaining red card subgroup members gain 3.3 points over the 15 blue card subgroup members. Staying in the lean subgroup with slightly too many members may be the lesser of two bad situations. This solution would lead to consistent undermatching.

It was a surprise to find that probabilistic point distribution and imperfect solutions led to undermatching, but it was also a surprise that different competitive weights appeared to have no effect on Group Choice. Previous foraging research suggested that IFD undermatching can be caused by competitors' unequal competitive abilities (Grand, 1997). Fretwell and Lucas based an IFD of foragers on all competitors being equal in ability to obtain resources. The methodology used in the human IFD experiments with probabilistic point distribution permitted an analysis of the effects of competitive weights. In Experiments 3 and 5, points were distributed probabilistically by randomly choosing one of the subgroup members with an equal probability. Experiments 4 and 6 were parallel experiments where points were distributed probabilistically by randomly choosing one of the subgroup members, but subgroup members did not have an equal chance of being chosen. In Experiment 3, subgroup members had either thrice or twice as great a likelihood of being chosen as others. In Experiment 6, half the participants had thrice as a great a chance of being chosen as the other half. The generalized IFD analyses of the groups' choices in Experiments 3 and 5 ($a_{exp3} = .45$; $a_{exp5} = .60$) showed no real difference in sensitivity measures to the groups' choices in Experiments 4 and 6 ($a_{exp4} = .37$; $a_{exp6} = .59$). This could occur if there were hidden or unknown differences in competitors' abilities to obtain points in Experiments 3 and 5 that functioned like the experimenter determined differences in competitors' abilities in Experiments 4 and 6. A better test of the effect of different competitor weights is to compare the ratios of competitor weights in each subgroup to the ratio of points allocated to each alternative (see Equation 8). If the groups' distributions of competitive weights were more sensitive to point distributions than the groups' distributions of participants, then differences in competitive weights might be the cause of IFD undermatching. In Experiments 4 and 6, the group's competitive-weight ratios were no more sensitive to point distributions than were participant ratios ($a_{exp4CW} = .33$; $a_{exp6CW} = .58$). The experimenter-manipulated competitive weights were successful in producing differences in obtained points, but these differences did not cause an increase in participant undermatching. Competitive weights either do not have the effect described in the literature, or these experiments did not manipulate competitive weights in a way that would lead to their undermatching effect. For example, there may have been too many high competitive weights in the group or the differences in competitive weights were not great enough. Future research on experimenter determined competitive weights might clarify these results.

The analyses of the individual behavior of group members provided no conclusive answers to questions about individual orderly behavior that could produce orderly group level results. These are important questions because the orderly group behavior found in human and non-human IFD research could be derivative from some type of individual level events. For example, if all individuals in a group chose alternatives in the same ratio as the ratio of points allocated to alternatives, then group level matching must occur. If this were the case, then IFD analyses of Group Choice would be less interesting. It is certain, however, that this is not the case in foraging research (Baum & Kraft, 1998) or the human Group Choice research in these experiments. Preference indices show that there was a variety of individual choices for the same point ratios. There was a small, positive relation between individuals' preference indices for consecutive blocks of trials.

This result demonstrated a small degree of consistency in preference for the rich alternatives block-to-block. No relations were found between individuals' self-reported effort and total obtained points, self-reported knowledge of point distributions and total obtained points, and obtained points from block-to-block. These analyses showed no reason to think that IFD matching of a group's choices were derivative of some individual level process.

Variation of sensitivity measures across individuals' choice relations proved the most alluring individual level analysis. Those experiments that shared points among subgroup members were the ones that showed the best IFD matching and consistent matching of individuals' choices to obtained points. For example, the group's choices in Experiment 1 were sensitive to the point ratios allocated to rows of chairs (a_{exp1} = 0.79). In addition, nearly all the individuals' choices of sitting in Row A and Row B chairs matched the proportions of points obtained from those alternatives. Most of the individual sensitivity measures ranged from 0.81 to 0.99. This was exactly the type of result from which one could use individuals' results to account for group level IFD matching. In Experiment 1 (and 2, 7a, and 7b), the individuals matched obtained points just as the groups' choices matched allocated points. There is a problem, however, in using these results to form that argument. When a group's choices matched allocated point distributions, then each member in both subgroups received the same amounts of points no matter what choices were made. This group level event forced individual matching to obtained points. Experiments 3, 4, 5, and 6 did not have this problem. Because these experiments distributed points probabilistically, forced individual matching did not occur. The individuals' choices were free to match obtained points from alternatives or not. When points were distributed probabilistically, individual sensitivity measures corresponded little to the groups' IFD sensitivity measures. For example, in Experiment 3, the majority of the individual sensitivity measures were less than the group's sensitivity measure ($a_{exp3} = .45$). A potential relation between individual and group sensitivity measures occurred in Experiment 4. In that experiment, a close replication of Experiment 3, the modal individual sensitivity measure (0.30 to 0.39) was close to the group's sensitivity measure ($a_{exp4} = .37$). However, individual sensitivity measures varied and did not correspond to group IFD sensitivity measure in Experiments 5 and 6. Because three out of the four experiments showed no relation between individual and group level matching, one can conclude that the level of group sensitivity was not derivative of individual matching to obtained points. This conclusion, however, must be tempered by the fact that IFD matching did not occur in Experiments 3, 4, 5, and 6. The groups' choices in these experiments undermatched allocated points. A stronger test of an independent relation between individual matching and group matching can occur when the group IFD matches and individuals did not. For example, the probabilistic point distribution methodology may be adjusted to produce IFD matching without forcing individual matching. Future research will have to investigate this possibility.

The conclusion that no individual level orderliness was found that could explain the group level orderliness is provocative. I qualify this conclusion by emphasizing that no individual level orderliness was found. It may exist, but was not observed because the correct analysis was not employed. As Marshal and Zimbardo wrote about not finding a result, "Obviously, there are many ways not to find an effect and few to demonstrate it."

(Marshal & Zimbardo, 1979, p. 985). Computer simulations may offer insight into the type of individual level orderliness that may explain Group Choice orderliness. For example, it may be possible to create rules for an aggregate of computer generated 'individuals' that produce an IFD of Group Choice. These successful computer simulations may offer insight into individual level orderliness of foraging people and other animals. On the other hand, it may be possible to create computer generated individual level orderliness that does not exist in the animal experiments. For example, it is possible to generate an aggregate of individuals whose choices between alternatives match obtained resources and observe IFD matching on the group level. But the experiments in this dissertation showed that this result did not occur on the individual level. Nevertheless, computer simulations that create group level IFD matching from individual level rules can offer possible avenues of investigation of actual individual behavior in Group Choice research.

The findings in this dissertation highlight the parallels between IFD research and Matching Law research. The Matching Law describes the relations between an individual's response rates and the rates of reinforcement associated with those responses. Matching Law research has generated intensive research programs, vigorous debates, and a quantitative conceptualization of E. L. Thorndike's Law of Effect.

One of the enduring questions in behavior analysis concerns the relation between rate of behavior and rate of reinforcement. A major advance in this quest came when the relative rates of responding on two alternatives matched the relative rates of reinforcement obtained from those alternatives (Herrnstein, 1961). This line of research became known as Matching Law research. One of the enduring questions in behavioral ecology concerns the number of foragers in an area and the resources obtained in the area. Fretwell and Lucas (1970) proposed that the relative number of foragers at resource sites depended on the relative amounts of resources obtained in those areas. Both behavioral relations have been expressed in ratio forms (see Equations 1 & 4). If the ratio of response rates always equaled the ratio of reinforcement rates and the ratio of foragers always equaled the ratio of obtained resources, then Equations 1 and 4 would be sufficient descriptions of the Matching Law and IFD. But empirical results confirmed consistent deviations from these simple matching relations.

In both Matching Law research and IFD research, deviations from matching are the norm. Bias is a deviation common to both types of research. In an operant chamber with two keys, for example, a pigeon may have an inexplicable bias for the key on the left that is unrelated to the ratio of reinforcement rates. Likewise, a group of pigeons may be biased toward a resource area that offers better protection from predators compared to a site in the open. Overmatching and undermatching are another type deviation from matching in both behavioral relations. In a two key operant chamber, a single pigeon may overmatch by allocating too much of its behavior to the rich key and not enough to the lean. Instead of overmatching, a single organism's behavior may undermatch relative rates of reinforcement and a group of foragers may undermatch relative amounts of resources. For example, the pigeon in a two key operant chamber could also allocate too few responses to the rich key and too many to the lean key. Analogously, a group of pigeons may allocate too few foragers to the rich site and too many to the lean. Behavior analysts adapted Equation 1 to assess both bias and under/overmatching (Baum, 1974). This Generalized Matching Law was created by adding the two free parameters (i.e., a coefficient and an exponent to the right side of equation 1). To account for deviations from matching in IFD research, behavior ecologist also adapted the simple IFD matching relation to account for bias and undermatching on the group level (Fagan, 1987; Kennedy & Gray, 1993) . Both generalized equations allow for the quantification of deviations from the basic prediction of the Matching Law and IFD. Literature reviews of IFD and Matching Law research using the generalized forms of the equations consistently found undermatching. In both lines of research, average sensitivity measures were about 0.70 (Baum, 1979; Kennedy & Gray, 1993, Williams, 1988).

This dissertation's discussion of deriving group IFD sensitivity from lower level constituents has its GML research counterpart. Soon after the Matching Law was disseminated among behavior analysts the quest to explain it was underway (Commons, Herrnstein, Rachlin, 1982; Davison & McCarthy, 1988). Some behavior analysts were convinced that the molar (long term, steady state behavior) relations described by the Matching Law could be derived from smaller units of behavior and reinforcement (e.g., Shimp, 1966; Silberberg & Ziriax, 1982). For nearly two decades molar theorists and molecular theorists disputed the best explanations for the results of the Matching Law. Likewise, there is the temptation to reinterpret IFD matching by appealing to smaller units of foraging behavior and resources. This dissertation attempted to test this possibility. As with Matching Law research, reducing the IFD group event (molar level) to the sum of individual events (molecular level) proved a complex issue with no easy resolutions. It remains to be determined if the IFD matching relation stands on its own as a behavioral relation or if it can be reduced to constituent events. If the same debate in Matching Law research is an indicator, this line of research will prove fruitful.

The debate over explaining Matching Law research and IFD research in molar and molecular terms may be fueled by what is at stake. Herrnstein's Matching Law research became the foundation for the quantification of the venerable Law of Effect (Herrnstein, 1970). Thorndike's seminal research with cats escaping from puzzle boxes led him to state that responses followed by reward were more likely to occur again and responses followed by aversive events were less likely to occur again (Thorndike, 1898). More colloquially, this relation was described as "pleasure stamps in, pain stamps out". Thorndike named this relation the Law of Effect and it became a cornerstone concept for most behavioral research. The exact nature of the relation between behavior and effects (i.e., consequences) remained elusive until Herrnstein's Matching Law proved a useful description of behavior and consequences. Even when there is only one operandum in an operant chamber, an organism always has the choice of performing the required behavior that leads to scheduled reinforcers or something else that is associated with its own consequences. An organism always has the choice between at least two behaviors and the rates of those behaviors were shown to match (or nearly match) the relative rates of reinforcement correlated with those behaviors. The vigorous debate over explaining the Matching Law may have been important to behavior analysts because the Law of Effect was at stake.

The temptation to explain the IFD of Group Choice by constituent individual level behavioral relations may come from similar concerns. Most behavior analysts are used to describing behavior on the individual level and many accept the Matching Law as the basic relation between behavior and reinforcement. Even when behavior analysts studied social behavior, they approached it as individual behavior in the context of others. The others in a social interaction were nothing more than environmental stimuli. The idea of orderly social level events that are not easily derived from orderly individual level events is a radical supposition in behavior analysis. If it is true, it may be the foundation for a social level Law of Effect.

Recent social theorists have been developing an environment-oriented social psychology (Guerin, 1994, in preparation). This new type of analysis of social behavior is consistent with behavior analysis and based on the relation between populations and resources. The relation between populations and resources is sometimes immediate and easily observed, but more often the relation is not easy to observe because they are correlated patterns of events that extend over long periods of time. Populations are groups of individuals who share or compete for resources and resources are events or things that can be obtained through behavior. Guerin presented several principles to guide the social psychological research of population and resources, but the first principle is, "as resources increase, population usually increases all else being equal". This principle is very much like Thorndike's original statement of the Law of Effect. As rewards "stamp in" increases in behavior, resources "stamp in" increases in population. The IFD of Group Choice describes the same principle quantitatively. As with Herrnstein's Matching Law, the relation between population and resources was quantified by comparing relative populations to relative resources. Evolutionary game theorists agree that the relation between population and resources can be understood with the IFD relation (Maynard Smith, 1981). Basic Game Theory describes individuals' choices in relation to consequences partly based on what other individuals do (von Neuman & Morgenstern, 1944) . Evolutionary Game Theory describes genotypes and animal behavior as 'games" with evolutionarily significant solutions. In Evolutionary Game Theory genotypes and animal behavior adjust until they reach an evolutionarily stable strategy (ESS) or the best pattern of events given the environmental situation. For example, when a population of foragers distributes between sites and matches the resource distribution, no other distribution is better for the foraging animals. If the group is already matching and an individual moves to another site, then that individual and the subgroup of foragers it joins obtain fewer resources than those in the other resource site. An IFD of foragers, and Group Choice more generally, is an unbeatable strategy and qualifies as an ESS. Given the importance of the principle of resources and population to an environment-oriented social psychology, given the quantification of that principle with the IFD model, and given the empirical verification of an IFD of foragers and human Group Choice, the IFD of Group Choice may be a social Law of Effect. A social Law of Effect would be a new starting point for future social psychological research.

This dissertation opened with a quote from B. F. Skinner's textbook, Science and Human Behavior (Skinner, 1953). Skinner was describing his approach to social behavior. His quote also describes the guiding principles of this dissertation. First, this dissertation sought to describe Group Choice with principles from behavior analysis and behavioral ecology. Second, this dissertation sought to explain Group Choice without appealing to any new terms outside of behavior analysis and behavior ecology. Third, this dissertation sought to determine whether Group Choice could be understood solely on the group level or as an aggregate of individual behavior-consequence relations. This dissertation used only common terms from behavior analysis and behavioral ecology, and demonstrated that Group Choice could be understood on the group level. It was difficult to explain Group Choice with individual level events, but explanations rooted in individual behavioral relations cannot be ruled out. However, if future research continues to find "a promising simplicity" with the IFD of Group Choice and not find an individual level explanation, then it may be a true social phenomenon.

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Appendices

Appendix A

Sample columns of trials used by the participants to record their own choices and earned points.

	Row	Points
1.	A B	
2.	A B	
3.	A B	
4.	A B	
5.	A B	
6.	A B	
7.	A B	
8.	A B	
9.	A B	
10.	A B	
11.	A B	
12.	A B	
13.	A B	
14.	A B	
15.	A B	

	Card	Points
1.	B R	
2.	B R	
3.	B R	
4.	B R	
5.	B R	
6.	B R	
7.	B R	
8.	B R	
9.	B R	
10.	B R	
11.	B R	
12.	B R	
13.	B R	
14.	B R	
15.	B R	

Appendix B

Post-experimental questionnaire.

Name:	______________________________
ID Number:	______________________________
Address:	______________________________
Address:	

Age: ____________________ Sex: ______________

1.
Please estimate the number of points that were awarded to people who chose blue cards /row A during the last block of trials. __________

Please estimate the number of points that were awarded to people who chose red cards /row B during the last block of trials. __________

2.
Please indicate on a scale of 1 to 9 the amount of effort you put into obtaining the most points possible (circle the number).
1 = the least effort possible on this task; 9 = the most effort possible on this task.

1 2 3 4 5 6 7 8 9

3. Please describe any strategies you used to obtain points.

4. Please describe the hypothesis of this study (if you can).

5. Please write on the back of this sheet any other comments you would like to experimenter to know.

Appendix C

3. Point distribution chart for experiment #1.

ROW A	40		ROW B	80
2	20.0		2	40.0
3	13.3		3	26.7
4	10.0		4	20.0
5	8.0		5	16.0
6	6.7		6	13.3
7	5.7		7	11.4
8	5.0		8	10.0
9	4.4		9	8.9
10	4.0		10	8.0
11	3.6		11	7.3
12	3.3		12	6.7
13	3.1		13	6.2
14	2.9		14	5.7
15	2.7		15	5.3
16	2.5		16	5.0
17	2.4		17	4.7
18	2.2		18	4.4
19	2.1		19	4.2
20	2.0		20	4.0

ROW A	100		ROW B	20
2	50.0		2	10.0
3	33.3		3	6.7
4	25.0		4	5.0
5	20.0		5	4.0
6	16.7		6	3.3
7	14.3		7	2.9
8	12.5		8	2.5
9	11.1		9	2.2
10	10.0		10	2.0
11	9.1		11	1.8
12	8.3		12	1.7
13	7.7		13	1.5
14	7.1		14	1.4
15	6.7		15	1.3
16	6.3		16	1.3
17	5.9		17	1.2
18	5.6		18	1.1
19	5.3		19	1.1
20	5.0		20	1.0

ROW A	20		ROW B	100
2	10.0		2	50.0
3	6.7		3	33.3
4	5.0		4	25.0
5	4.0		5	20.0
6	3.3		6	16.7
7	2.9		7	14.3
8	2.5		8	12.5
9	2.2		9	11.1
10	2.0		10	10.0
11	1.8		11	9.1
12	1.7		12	8.3
13	1.5		13	7.7
14	1.4		14	7.1
15	1.3		15	6.7
16	1.3		16	6.3
17	1.2		17	5.9
18	1.1		18	5.6
19	1.1		19	5.3
20	1.0		20	5.0

ROW A	80		ROW B	40
2	40.0		2	20.0
3	26.7		3	13.3
4	20.0		4	10.0
5	16.0		5	8.0
6	13.3		6	6.7
7	11.4		7	5.7
8	10.0		8	5.0
9	8.9		9	4.4
10	8.0		10	4.0
11	7.3		11	3.6
12	6.7		12	3.3
13	6.2		13	3.1
14	5.7		14	2.9
15	5.3		15	2.7
16	5.0		16	2.5
17	4.7		17	2.4
18	4.4		18	2.2
19	4.2		19	2.1
20	4.0		20	2.0

Point distribution chart for experiments #2 and #7a (perfect solutions).

BLUE	40		RED	80
2	20.0		2	40.0
3	13.3		3	26.7
4	10.0		4	20.0
5	8.0		5	16.0
6	6.7		6	13.3
7	5.7		7	11.4
8	5.0		8	10.0
9	4.4		9	8.9
10	4.0		10	8.0
11	3.6		11	7.3
12	3.3		12	6.7
13	3.1		13	6.2
14	2.9		14	5.7
15	2.7		15	5.3
16	2.5		16	5.0
17	2.4		17	4.7
18	2.2		18	4.4
19	2.1		19	4.2
20	2.0		20	4.0

BLUE	100		RED	20
2	50.0		2	10.0
3	33.3		3	6.7
4	25.0		4	5.0
5	20.0		5	4.0
6	16.7		6	3.3
7	14.3		7	2.9
8	12.5		8	2.5
9	11.1		9	2.2
10	10.0		10	2.0
11	9.1		11	1.8
12	8.3		12	1.7
13	7.7		13	1.5
14	7.1		14	1.4
15	6.7		15	1.3
16	6.3		16	1.3
17	5.9		17	1.2
18	5.6		18	1.1
19	5.3		19	1.1
20	5.0		20	1.0

BLUE	20		RED	100
2	10.0		2	50.0
3	6.7		3	33.3
4	5.0		4	25.0
5	4.0		5	20.0
6	3.3		6	16.7
7	2.9		7	14.3
8	2.5		8	12.5
9	2.2		9	11.1
10	2.0		10	10.0
11	1.8		11	9.1
12	1.7		12	8.3
13	1.5		13	7.7
14	1.4		14	7.1
15	1.3		15	6.7
16	1.3		16	6.3
17	1.2		17	5.9
18	1.1		18	5.6
19	1.1		19	5.3
20	1.0		20	5.0

BLUE	80		RED	40
2	40.0		2	20.0
3	26.7		3	13.3
4	20.0		4	10.0
5	16.0		5	8.0
6	13.3		6	6.7
7	11.4		7	5.7
8	10.0		8	5.0
9	8.9		9	4.4
10	8.0		10	4.0
11	7.3		11	3.6
12	6.7		12	3.3
13	6.2		13	3.1
14	5.7		14	2.9
15	5.3		15	2.7
16	5.0		16	2.5
17	4.7		17	2.4
18	4.4		18	2.2
19	4.2		19	2.1
20	4.0		20	2.0

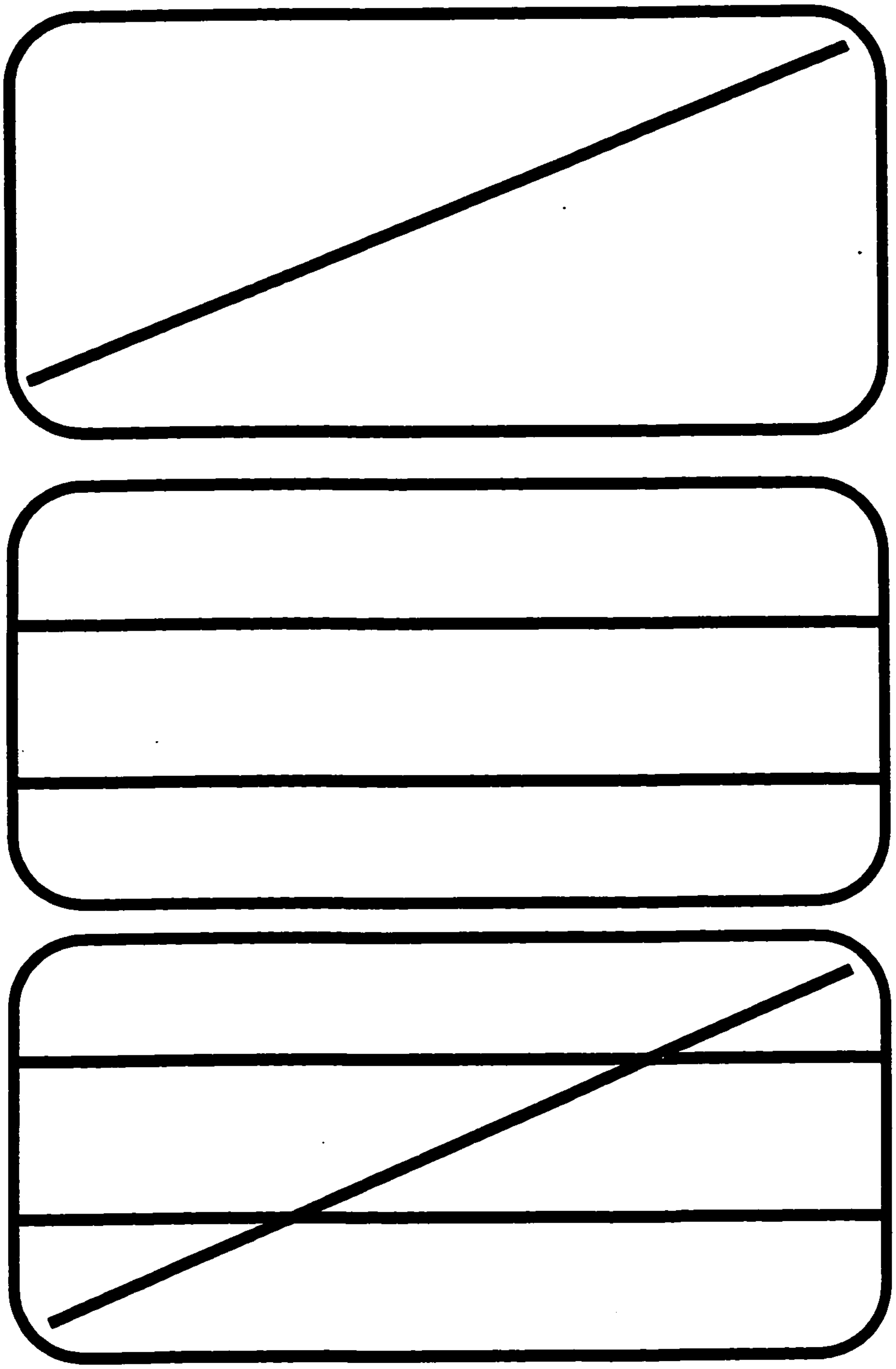
Appendix D

Random number charts used to distribute points probablisticly in experiments #3 and #4.

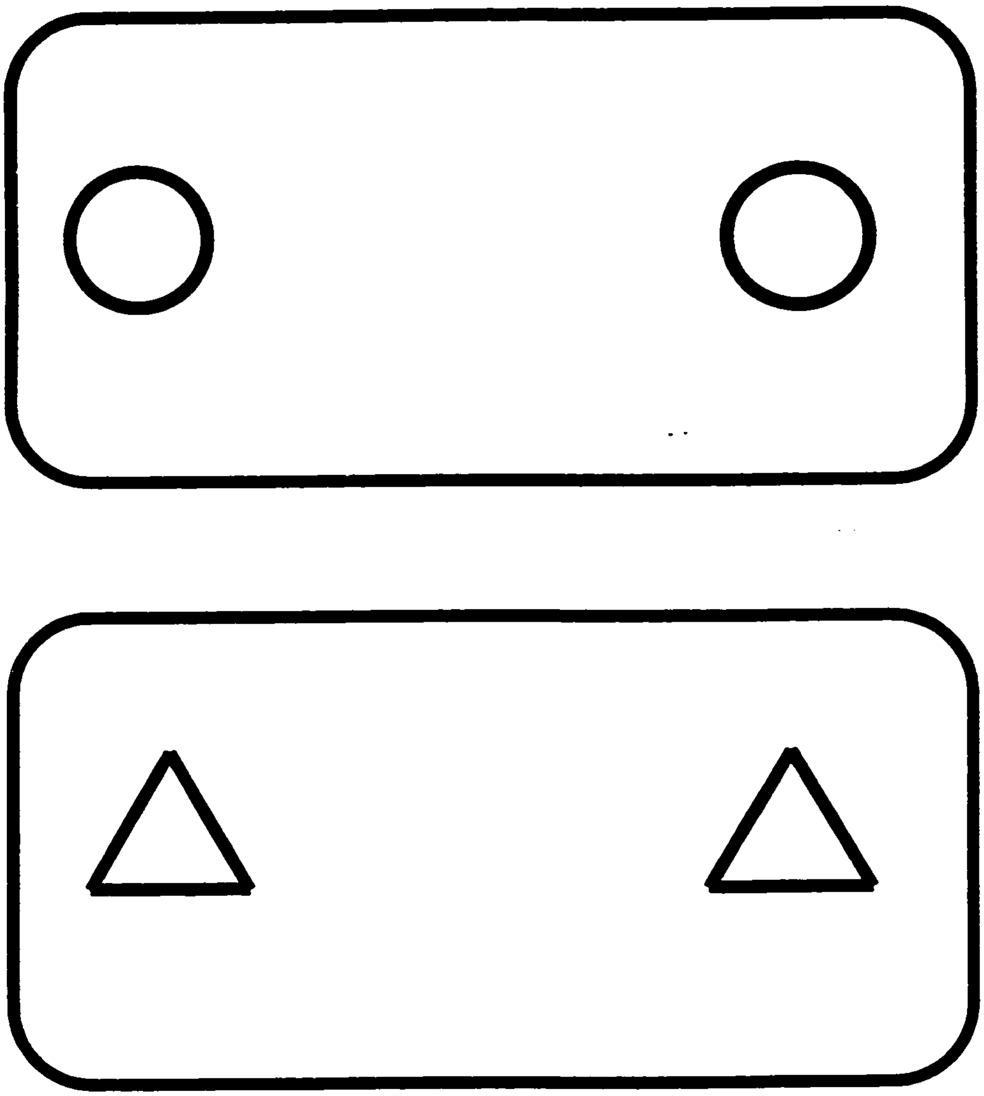
2	1	1	1	1	2	2	1	2	2	2	1	2	1	2	2	2	2	2	2	2
3	1	2	2	3	2	3	2	3	1	2	3	2	3	3	2	3	3	1	3	2
4	4	2	2	4	3	3	2	3	4	3	4	2	4	3	3	3	1	1	1	1
5	2	2	4	5	5	2	5	3	5	1	5	5	5	3	5	4	4	2	2	2
6	3	6	6	6	6	2	5	5	5	6	6	6	1	6	5	4	5	4	3	2
7	4	6	1	3	2	7	4	2	1	3	5	7	2	3	2	2	3	6	7	6
8	8	5	7	3	3	4	2	6	7	7	7	1	1	7	4	4	2	5	5	7
9	4	1	4	5	9	2	5	8	4	8	1	2	2	5	2	2	8	2	4	2
10	10	7	2	4	5	9	10	2	3	1	4	6	2	3	10	4	3	3	2	2
11	2	8	7	3	5	5	9	3	5	5	8	10	3	10	7	1	3	3	4	4
12	5	6	8	5	5	11	1	7	3	3	2	9	3	8	10	10	3	11	12	9
13	3	8	5	2	6	9	5	10	13	3	10	11	1	5	13	4	5	3	6	2
14	12	12	11	11	12	10	13	9	13	10	3	3	1	4	10	14	7	10	1	6
15	11	5	13	6	12	10	2	9	3	6	14	15	1	8	8	2	6	2	2	9
16	11	2	15	13	11	14	15	16	10	2	11	11	16	1	16	5	2	15	3	7
17	15	15	16	7	17	6	6	14	17	6	10	13	13	1	12	7	14	1	3	2
18	15	6	3	14	12	3	13	4	3	11	11	2	13	15	10	17	12	16	13	7
19	18	13	16	4	3	16	11	17	6	10	2	10	9	17	9	8	5	5	13	16
20	15	16	16	10	2	8	16	4	7	12	1	9	15	7	14	9	2	13	17	7
21	9	8	3	12	16	7	15	13	13	8	2	4	4	12	20	19	10	10	15	16
22	4	10	16	22	16	18	4	10	18	4	5	5	21	5	14	10	15	16	21	21
23	14	12	12	17	16	13	15	8	17	22	5	23	14	4	10	15	23	2	14	5
24	16	14	3	16	4	2	7	2	21	20	14	12	17	18	14	4	14	17	11	6
25	4	24	22	18	25	5	11	8	2	2	5	2	2	19	20	13	5	24	15	18
26	20	26	16	26	19	9	24	8	1	20	11	22	4	13	15	19	11	4	25	3
27	9	20	7	11	25	19	12	8	13	14	4	14	24	26	26	8	6	25	25	5
28	15	11	25	2	22	7	22	18	28	13	11	15	24	5	23	14	14	16	17	11
29	6	12	17	8	19	8	24	21	6	22	6	12	13	9	6	10	2	2	3	4
30	2	12	14	30	10	11	29	20	8	2	19	2	27	25	21	23	10	13	27	24

Appendix E

Card designs used in experiment #4



Card designs used in experiment #6.



Appendix F

Point distribution charts for experiments #5 and #6.

Block 1

2	2	1	1	1	1	2	2	1	2	2	2	1	2	2	2
3	2	3	1	2	2	1	2	3	3	2	2	3	2	3	1
4	2	4	3	1	1	2	1	3	2	4	3	1	2	4	3
5	5	3	5	3	2	2	5	3	5	3	2	4	2	4	3
6	3	5	6	2	5	2	5	2	4	3	3	4	3	5	1
7	1	7	4	2	1	1	5	5	3	5	4	7	5	6	2
8	4	6	7	7	5	5	6	7	4	6	6	2	2	5	3
9	2	6	1	9	4	8	6	5	9	9	6	9	3	7	7
10	3	10	7	1	6	7	10	7	6	8	4	9	5	7	4
11	10	7	3	2	7	9	2	8	7	5	9	6	2	5	7
12	5	9	10	5	8	9	12	11	5	10	9	3	8	5	5
13	12	9	9	6	3	13	10	7	8	8	8	10	12	13	11
14	9	14	13	1	6	9	2	12	5	7	14	8	13	12	3
15	5	2	9	15	3	15	15	12	13	11	9	1	9	11	6
16	5	8	9	4	16	10	13	6	5	4	8	16	2	9	6
17	15	13	15	14	5	1	5	9	2	17	16	15	16	12	10
18	2	6	6	18	16	7	5	13	18	9	3	4	7	1	9
19	8	3	16	13	8	11	5	14	15	5	14	10	9	9	5
20	16	3	20	17	13	11	3	17	12	1	18	17	6	16	16
21	7	14	5	5	7	10	9	15	8	11	10	15	12	2	15
22	10	19	20	18	21	13	1	17	10	14	15	6	11	18	15
23	18	5	18	12	3	20	22	17	17	15	6	5	5	20	11
24	15	20	16	1	14	12	6	10	23	11	2	8	16	12	18
25	8	22	24	12	16	20	3	7	20	23	3	24	1	21	13
26	10	19	23	19	13	8	5	9	20	8	6	7	6	25	11
27	11	20	1	10	27	2	9	23	19	19	22	6	24	5	6
28	21	23	15	3	21	21	25	18	27	15	18	28	17	20	6
29	2	24	12	15	21	17	10	28	14	22	13	21	1	19	22
30	6	19	27	10	6	26	9	13	3	15	12	25	20	21	7

Pt. Ratios

trial	5	1
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		

Block 2

2	1	1	1	1	2	2	2	2	1	2	1	1	1	2	2
3	2	3	3	3	3	2	1	2	3	2	3	2	1	3	3
4	3	3	4	1	2	1	3	2	4	4	1	3	1	3	3
5	1	4	4	2	3	5	5	3	4	5	5	5	4	2	4
6	4	5	4	3	2	6	4	1	3	3	6	2	4	2	3
7	2	6	3	7	2	5	7	1	4	1	4	4	4	1	6
8	1	6	4	8	4	2	8	6	7	3	3	6	4	8	8
9	3	7	3	9	4	2	6	5	3	6	4	2	4	5	7
10	6	7	7	2	6	6	10	6	5	9	4	4	9	10	3
11	8	11	4	8	11	5	6	10	11	11	1	4	8	8	7
12	7	4	8	10	8	9	3	10	4	4	4	11	4	1	9
13	3	12	2	9	7	5	13	8	5	8	5	10	3	5	8
14	3	10	2	5	7	6	9	11	10	11	4	8	5	3	4
15	3	9	14	14	11	13	3	10	5	5	11	13	11	14	5
16	5	3	3	12	13	11	2	1	10	8	15	6	14	16	6
17	4	6	16	7	8	10	13	16	11	6	7	11	9	17	4
18	14	1	3	3	4	12	10	11	18	14	12	14	6	10	8
19	13	17	11	2	4	8	3	6	8	18	18	18	5	6	5
20	20	16	7	6	5	14	14	11	17	14	11	10	19	5	19
21	7	12	6	17	11	10	7	16	20	7	7	4	9	17	4
22	9	20	8	5	3	9	19	16	22	22	16	7	21	13	17
23	6	4	6	11	21	21	1	9	11	6	21	20	2	14	18
24	11	20	11	14	22	11	2	23	12	24	9	14	11	16	20
25	4	24	24	4	17	13	6	11	25	5	12	2	13	3	5
26	4	18	15	11	26	15	7	26	13	12	8	22	18	16	11
27	10	24	19	17	3	23	27	12	3	2	23	25	23	4	19
28	15	3	23	20	22	7	15	14	7	27	10	4	15	27	25
29	18	5	23	2	15	8	6	18	12	25	3	29	28	18	10
30	23	21	20	17	26	10	11	26	30	16	23	7	12	7	15

Pt. Ratios

trial	1	2
16		
17		
18		
19		
20		
21		
22		
23		
24		
25		
26		
27		
28		
29		
30		

Block 3

2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	1
3	2	1	2	2	3	1	2	3	3	1	3	3	3	2	3
4	4	3	1	4	4	2	1	4	1	3	4	3	2	4	2
5	4	2	2	4	5	2	5	5	2	3	4	4	4	4	3
6	5	6	2	5	5	2	1	1	4	2	5	2	6	2	6
7	6	7	6	5	2	3	4	7	5	5	4	2	7	5	7
8	6	8	4	8	2	5	7	5	3	3	3	7	5	5	1
9	9	7	7	6	9	9	9	6	7	4	4	7	8	3	8
10	9	5	2	4	1	9	8	6	3	2	2	4	8	4	6
11	9	2	5	4	2	10	4	10	7	2	11	3	8	8	8
12	8	7	8	11	4	12	2	10	3	6	8	2	2	11	4
13	10	3	11	3	9	2	10	1	3	4	9	3	1	10	12
14	13	4	3	8	9	12	5	1	11	6	8	3	10	2	10
15	3	9	9	11	8	15	10	12	14	12	12	15	14	5	5
16	5	14	2	2	11	16	1	2	7	5	16	4	9	12	16
17	17	3	4	14	10	12	15	16	15	10	16	14	17	8	8
18	16	1	7	6	18	13	3	11	13	17	17	15	13	13	12
19	2	13	4	17	4	17	3	15	3	8	10	9	15	7	2
20	4	3	5	4	12	5	2	12	20	13	20	11	13	7	14
21	2	14	21	7	6	2	6	15	14	4	5	16	6	21	20
22	2	12	2	15	19	11	13	19	17	20	13	5	5	18	10
23	2	3	3	3	22	20	4	14	4	22	7	17	23	11	19
24	18	3	5	11	2	4	2	14	7	15	17	12	9	18	7
25	23	3	15	20	10	24	15	14	6	4	11	21	25	10	22
26	22	12	8	1	12	3	20	4	13	8	22	14	22	26	16
27	20	5	13	16	11	4	11	15	8	10	6	19	14	3	14
28	24	14	2	14	8	23	5	16	4	19	24	16	11	5	3
29	17	18	24	24	8	20	18	3	14	20	9	27	27	22	20
30	11	23	10	30	12	15	23	13	5	9	2	3	6	6	19

Pt. Ratios

trial	1	5
31		
32		
33		
34		
35		
36		
37		
38		
39		
40		
41		
42		
43		
44		
45		

Block 4

2	2	2	1	2	1	2	1	2	2	2	2	2	2	2	2
3	1	1	2	2	3	2	3	2	2	3	1	3	3	1	2
4	2	4	2	1	4	1	2	2	3	1	4	2	2	4	4
5	5	1	4	4	3	3	2	2	5	3	2	4	5	4	4
6	4	2	3	6	1	2	5	6	4	6	3	5	2	4	5
7	4	3	1	5	3	3	1	2	5	6	7	2	5	2	4
8	7	7	8	8	3	8	4	3	2	5	8	6	6	8	1
9	3	2	5	9	1	3	5	9	8	6	3	1	3	2	5
10	9	8	3	2	8	10	7	10	6	2	2	3	3	2	8
11	10	9	8	6	11	1	2	3	11	9	8	8	11	8	6
12	10	11	2	8	12	12	11	12	12	7	8	5	4	10	9
13	3	3	9	12	10	13	12	4	12	6	12	13	2	5	12
14	11	14	12	7	1	5	5	13	3	14	6	10	4	5	5
15	2	5	9	9	5	7	10	2	6	8	5	10	5	5	2
16	16	4	7	8	15	15	13	5	13	1	14	3	11	4	6
17	4	14	17	14	16	9	12	15	17	10	12	9	15	9	12
18	13	18	6	10	9	12	16	17	2	17	1	10	4	3	15
19	9	16	1	14	13	17	14	4	10	15	16	4	13	17	7
20	3	11	20	15	16	2	7	8	12	16	9	8	1	11	4
21	12	7	18	2	9	20	12	16	17	3	12	8	12	5	18
22	7	5	10	22	16	4	17	20	22	18	14	1	10	20	21
23	23	7	7	11	16	16	5	7	18	6	8	14	19	20	19
24	2	16	9	23	12	19	13	3	15	7	21	18	24	18	22
25	7	18	18	11	22	3	25	10	16	2	21	3	12	13	5
26	12	25	3	15	25	1	15	15	13	4	21	3	2	4	8
27	17	7	19	22	8	8	3	17	6	12	26	14	10	26	15
28	23	23	6	3	22	18	28	19	19	25	27	15	9	16	12
29	20	24	7	9	26	20	22	10	18	16	23	13	21	7	15
30	3	9	29	8	15	29	25	18	10	29	30	17	16	27	30

Pt. Ratios

trial	2	1
46		
47		
48		
49		
50		
51		
52		
53		
54		
55		
56		
57		
58		
59		
60		

Block 5

2	2	2	2	2	1	2	1	2	2	1	2	2	2	1	2
3	3	1	3	1	2	3	2	3	3	2	1	3	2	2	2
4	4	3	4	4	4	1	1	3	4	3	2	3	2	2	2
5	1	4	4	3	3	5	2	5	1	4	3	2	5	2	4
6	1	3	2	1	3	1	5	5	6	4	4	5	4	5	4
7	6	4	4	3	6	3	2	5	3	7	2	6	2	7	3
8	8	4	1	7	3	7	7	6	8	3	8	3	6	5	4
9	2	7	8	7	9	2	3	2	1	8	2	9	9	4	1
10	3	5	10	3	4	3	3	2	9	2	4	9	10	5	3
11	4	1	9	10	8	6	8	10	7	7	10	4	6	5	1
12	4	6	1	9	4	8	11	5	1	8	12	8	6	5	4
13	9	8	11	3	7	11	8	5	3	9	9	13	8	1	13
14	11	9	6	2	5	7	9	10	2	6	2	11	12	5	2
15	7	11	13	6	4	10	10	10	9	13	3	14	7	13	1
16	15	7	10	14	4	16	14	5	14	5	7	5	13	7	14
17	10	6	14	15	4	11	12	14	2	11	10	8	6	3	12
18	12	6	13	4	11	2	11	8	18	9	8	12	13	3	1
19	12	11	3	13	6	3	9	15	10	19	12	1	4	10	17
20	3	19	3	7	20	11	9	13	9	12	19	14	1	5	7
21	2	13	19	18	4	3	17	6	12	11	19	8	21	3	12
22	22	13	20	19	2	19	10	6	2	17	3	9	17	14	19
23	19	12	19	8	9	11	23	15	19	6	20	18	19	23	18
24	6	21	5	4	19	11	15	11	11	4	5	24	11	12	3
25	12	6	11	19	19	9	16	6	4	14	25	5	2	21	2
26	22	22	2	7	16	9	25	26	6	17	12	10	13	12	20
27	1	24	23	11	16	10	23	22	16	18	11	25	3	8	14
28	6	4	19	4	12	12	11	19	3	10	15	9	11	18	20
29	11	10	26	5	23	12	9	9	9	10	16	28	1	27	24
30	24	24	24	3	9	25	5	15	10	28	29	10	7	27	12

Pt. Ratios

trial	**5**	**1**
61		
62		
63		
64		
65		
66		
67		
68		
69		
70		
71		
72		
73		
74		
75		

Block 6

2	1	1	2	1	2	2	1	2	1	2	2	2	2	2	1
3	3	3	3	3	3	3	2	3	3	3	3	1	1	1	3
4	4	3	1	1	3	2	1	4	2	4	3	3	4	3	3
5	3	1	4	4	3	2	5	4	4	5	3	4	3	2	3
6	4	4	4	1	4	4	1	3	1	4	3	3	3	5	4
7	1	7	6	2	1	4	3	3	6	5	1	1	3	2	3
8	8	6	3	2	4	3	8	2	7	2	4	2	5	5	4
9	2	5	3	6	7	3	3	2	2	9	5	4	8	3	5
10	6	1	10	4	9	9	7	5	2	4	10	5	8	6	4
11	11	3	9	11	6	2	3	2	8	6	8	8	11	5	6
12	8	9	6	2	12	4	5	3	8	9	1	8	2	4	4
13	4	5	7	10	10	7	12	13	12	7	3	5	12	11	4
14	3	12	14	8	3	7	4	14	11	10	14	6	5	10	3
15	15	5	6	10	8	3	3	10	12	12	10	4	7	14	3
16	16	3	14	4	13	7	15	9	15	10	11	9	5	10	5
17	14	10	12	1	6	2	2	15	8	13	7	9	1	8	6
18	12	11	4	8	8	12	13	15	10	15	12	3	16	3	16
19	9	11	4	10	2	12	17	11	15	4	16	5	9	9	3
20	16	2	8	16	1	4	3	2	5	14	15	2	15	4	2
21	18	7	2	8	11	6	20	16	18	3	6	10	18	17	4
22	15	18	10	16	15	8	2	10	15	12	16	11	11	12	11
23	19	17	7	13	19	23	12	12	9	6	1	22	8	11	11
24	11	2	20	4	10	19	11	11	19	11	15	13	19	18	7
25	17	7	4	2	2	16	7	19	20	11	15	25	10	23	6
26	7	14	13	15	7	26	15	18	20	12	10	10	8	12	20
27	3	19	8	12	22	21	22	2	26	9	22	21	8	9	21
28	3	10	16	7	2	7	16	14	8	16	28	4	25	28	4
29	20	27	25	5	28	21	17	3	5	22	7	11	7	26	5
30	7	6	3	15	13	24	3	20	18	27	15	29	23	11	27

Pt. Ratios

trial	1	2
76		
77		
78		
79		
80		
81		
82		
83		
84		
85		
86		
87		
88		
89		
90		

Block 7

2	2	1	1	2	2	2	2	2	1	1	2	2	1	2	2
3	3	2	3	1	2	1	3	3	2	3	3	3	2	3	3
4	1	2	2	3	2	2	2	1	1	3	4	3	4	3	1
5	4	2	3	2	1	3	5	5	4	4	3	2	5	2	3
6	3	3	4	3	4	6	2	1	4	3	1	2	4	5	6
7	4	5	4	1	3	6	4	6	5	3	4	3	1	7	2
8	5	6	5	2	4	4	8	5	3	2	3	7	5	5	8
9	6	3	1	7	2	1	9	6	4	9	3	9	4	8	2
10	10	8	5	3	6	8	2	6	2	8	4	5	6	3	2
11	3	10	9	11	7	10	6	9	9	4	11	2	2	5	11
12	8	9	4	11	12	6	11	5	1	10	12	7	6	2	11
13	3	4	4	8	5	5	8	3	9	2	9	10	6	8	4
14	3	4	13	12	3	4	14	9	3	12	5	8	4	7	7
15	9	9	14	15	11	10	12	12	15	13	7	3	3	6	8
16	4	4	5	12	12	9	10	3	13	8	10	11	14	7	8
17	15	15	14	5	12	5	4	16	14	9	16	6	3	9	11
18	16	14	14	16	8	17	9	3	18	10	13	8	18	15	12
19	16	14	14	9	6	12	12	15	15	19	6	8	10	5	16
20	10	18	12	16	10	18	3	20	9	6	14	9	19	19	1
21	6	4	3	9	19	19	11	2	9	21	14	12	4	2	18
22	13	22	14	4	19	6	21	21	18	11	13	7	5	10	21
23	16	20	22	5	7	15	13	13	9	13	3	16	1	2	5
24	23	7	9	10	20	15	12	7	15	16	13	20	9	5	14
25	11	15	4	5	19	18	7	22	11	20	19	5	24	7	21
26	21	15	16	23	13	20	14	7	19	22	10	23	13	4	25
27	17	8	19	5	22	12	22	14	9	14	9	6	18	7	2
28	18	16	10	14	9	10	26	27	13	17	26	11	5	28	5
29	26	13	13	19	20	8	21	11	10	18	29	14	16	6	16
30	17	23	27	29	17	26	7	6	22	14	22	19	9	6	9

Pt. Ratios

trial	**2**	**1**
91		
92		
93		
94		
95		
96		
97		
98		
99		
100		
101		
102		
103		
104		
105		

Block 8

2	1	1	2	2	1	1	1	2	1	2	2	2	1	2	2
3	2	1	1	3	3	3	2	3	2	2	2	2	2	3	2
4	4	4	1	3	3	2	1	2	2	3	3	2	2	2	1
5	3	2	4	4	3	4	5	3	5	5	2	4	2	1	5
6	2	4	3	5	3	4	4	3	2	4	4	1	5	5	5
7	1	2	3	4	4	1	3	7	4	5	4	5	6	4	1
8	3	3	8	8	3	8	2	5	3	3	8	6	8	8	4
9	4	2	6	9	9	6	3	9	5	5	8	3	5	3	6
10	8	2	8	9	5	7	5	3	7	2	2	8	9	10	1
11	2	4	4	1	3	11	4	5	11	1	11	8	2	4	7
12	12	10	12	7	7	5	10	10	4	1	5	10	11	12	4
13	8	3	7	12	6	11	3	3	5	2	11	2	6	2	8
14	10	9	11	8	9	7	8	8	2	10	8	9	5	5	5
15	6	14	8	10	11	10	15	7	7	3	2	12	3	9	3
16	2	3	14	9	7	4	10	10	15	3	7	16	10	13	7
17	8	10	11	16	6	4	15	12	16	14	5	5	7	4	9
18	3	18	8	16	8	4	15	11	3	3	15	5	5	3	15
19	2	1	10	12	18	2	5	4	7	12	6	3	3	5	10
20	10	4	12	10	3	8	13	7	5	1	18	2	2	7	17
21	9	19	16	19	13	17	15	20	12	17	19	18	10	5	5
22	11	4	9	15	9	7	4	3	13	20	11	7	9	3	5
23	7	17	13	2	22	21	15	23	22	11	8	21	21	18	3
24	22	10	19	17	24	16	17	13	15	3	1	19	12	4	9
25	2	20	18	11	5	10	20	15	25	11	19	5	12	19	9
26	26	25	18	6	14	26	2	12	10	14	19	8	17	17	15
27	6	20	4	3	10	2	23	15	17	19	17	4	8	16	25
28	22	27	25	9	23	12	23	28	24	9	13	3	19	19	27
29	23	23	22	7	4	12	27	9	8	3	20	11	20	26	4
30	20	10	25	10	6	7	8	14	8	21	29	10	15	17	10

Pt. Ratios

trial	5	1
106		
107		
108		
109		
110		
111		
112		
113		
114		
115		
116		
117		
118		
119		
120		

Block 9

2	1	2	2	2	2	2	2	1	2	1	2	1	1	2	2
3	3	2	3	1	2	3	2	2	3	2	3	3	2	3	2
4	4	1	4	2	3	2	4	3	3	4	3	4	3	2	4
5	2	3	1	5	1	3	5	2	5	4	2	4	3	5	4
6	3	3	4	2	3	1	2	5	1	6	6	2	4	3	4
7	2	7	2	5	2	7	6	7	1	5	7	7	5	2	7
8	5	8	8	8	8	5	6	5	6	3	8	3	6	5	4
9	5	5	4	7	4	1	9	3	2	6	6	3	9	8	8
10	8	5	3	2	3	10	6	6	9	8	1	9	5	10	1
11	4	7	8	4	2	9	10	9	6	10	3	6	6	9	6
12	7	11	7	2	1	4	5	12	5	11	3	9	10	9	2
13	9	1	8	13	2	8	13	12	6	5	8	9	8	10	5
14	1	6	11	3	3	7	2	4	4	3	2	10	10	6	7
15	3	2	14	12	12	5	15	5	6	10	14	13	6	2	3
16	1	5	16	14	5	2	10	15	14	5	4	10	1	10	15
17	5	16	8	15	16	9	13	4	10	5	16	9	11	3	17
18	14	3	16	1	17	17	2	3	5	4	14	14	4	3	11
19	19	13	8	17	13	13	2	12	14	9	5	2	12	8	3
20	16	16	14	13	12	16	6	17	15	7	9	19	13	5	18
21	14	4	20	2	12	2	11	16	7	11	8	13	8	13	8
22	22	6	17	9	9	12	15	15	3	19	20	22	17	3	17
23	9	21	15	21	23	5	18	6	10	20	11	2	15	11	4
24	24	18	23	16	20	19	4	18	11	9	12	6	8	12	9
25	19	8	18	9	21	9	17	15	6	18	3	10	16	13	13
26	7	26	17	22	23	6	5	4	25	26	14	17	3	4	16
27	17	2	14	27	25	2	23	27	12	26	24	12	13	16	15
28	17	10	1	12	2	13	25	27	19	14	6	7	10	26	23
29	16	21	18	10	12	29	13	4	27	19	14	19	10	28	24
30	27	13	7	28	20	5	22	9	4	22	6	14	17	27	10

Pt. Ratios

trial	1	5
121		
122		
123		
124		
125		
126		
127		
128		
129		
130		
131		
132		
133		
134		
135		

Block
10

2	1	1	1	2	2	1	2	2	1	2	2	2	1	2	2
3	3	2	2	2	1	2	3	3	2	3	2	2	2	1	1
4	2	3	2	2	3	4	1	2	3	4	1	4	1	3	2
5	3	3	3	3	5	3	4	5	2	2	3	3	5	3	4
6	3	3	3	1	1	6	3	5	6	1	3	6	1	1	3
7	3	7	4	5	3	1	7	7	4	3	1	7	6	3	6
8	7	5	2	4	2	5	4	4	8	4	7	2	2	8	3
9	5	8	5	6	8	5	7	5	4	6	9	2	5	3	5
10	8	8	8	9	9	2	9	8	8	1	2	9	10	5	3
11	10	4	9	5	1	10	5	7	7	7	2	1	11	4	8
12	4	12	7	7	3	11	12	10	7	11	9	10	5	5	6
13	5	10	2	7	2	3	7	3	9	7	12	9	13	5	10
14	14	13	10	14	3	3	11	10	5	9	9	1	8	4	8
15	3	11	10	7	13	14	10	7	9	11	7	5	5	12	15
16	10	9	8	8	3	9	3	12	7	9	6	6	3	4	15
17	6	9	7	10	14	14	7	2	15	17	3	17	10	4	17
18	1	16	15	12	14	6	6	12	7	8	6	1	1	17	16
19	14	7	12	4	7	3	19	3	16	8	19	15	5	17	14
20	14	2	15	19	4	3	12	2	8	16	4	10	10	18	9
21	3	11	21	4	10	18	18	1	21	8	11	20	6	8	11
22	1	7	8	5	22	11	14	7	9	17	5	15	2	5	17
23	3	14	5	6	21	15	12	21	10	15	17	17	21	6	16
24	13	11	21	18	23	14	8	9	15	23	2	1	6	14	6
25	7	9	11	25	16	19	11	2	1	3	2	13	17	17	17
26	17	14	14	19	24	26	12	20	3	11	23	10	19	6	6
27	3	7	14	25	21	4	9	22	5	24	4	4	8	26	13
28	10	6	24	9	28	21	25	5	23	23	6	5	1	9	5
29	28	22	25	29	1	18	2	27	29	14	20	4	15	3	13
30	8	30	21	22	16	10	2	11	19	21	1	20	3	30	7

Pt. Ratios

trial	1	2
136		
137		
138		
139		
140		
141		
142		
143		
144		
145		
146		
147		
148		
149		
150		

Appendix G

Point distribution chart used in experiment 7a (imperfect solution for N = 12).

BLUE	105		RED	20
2	52.5		2	10.0
3	35.0		3	6.7
4	26.3		4	5.0
5	21.0		5	4.0
6	17.5		6	3.3
7	15.0		7	2.9
8	13.1		8	2.5
9	11.7		9	2.2
10	10.5		10	2.0
11	9.5		11	1.8
12	8.8		12	1.7
13	8.1		13	1.5
14	7.5		14	1.4
15	7.0		15	1.3
16	6.6		16	1.3
17	6.2		17	1.2
18	5.8		18	1.1
19	5.5		19	1.1
20	5.3		20	1.0

BLUE	85		RED	40
2	42.5		2	20.0
3	28.3		3	13.3
4	21.3		4	10.0
5	17.0		5	8.0
6	14.2		6	6.7
7	12.1		7	5.7
8	10.6		8	5.0
9	9.4		9	4.4
10	8.5		10	4.0
11	7.7		11	3.6
12	7.1		12	3.3
13	6.5		13	3.1
14	6.1		14	2.9
15	5.7		15	2.7
16	5.3		16	2.5
17	5.0		17	2.4
18	4.7		18	2.2
19	4.5		19	2.1
20	4.3		20	2.0

BLUE	40		RED	85
2	20.0		2	42.5
3	13.3		3	28.3
4	10.0		4	21.3
5	8.0		5	17.0
6	6.7		6	14.2
7	5.7		7	12.1
8	5.0		8	10.6
9	4.4		9	9.4
10	4.0		10	8.5
11	3.6		11	7.7
12	3.3		12	7.1
13	3.1		13	6.5
14	2.9		14	6.1
15	2.7		15	5.7
16	2.5		16	5.3
17	2.4		17	5.0
18	2.2		18	4.7
19	2.1		19	4.5
20	2.0		20	4.3

BLUE	20		RED	105
2	10.0		2	52.5
3	6.7		3	35.0
4	5.0		4	26.3
5	4.0		5	21.0
6	3.3		6	17.5
7	2.9		7	15.0
8	2.5		8	13.1
9	2.2		9	11.7
10	2.0		10	10.5
11	1.8		11	9.5
12	1.7		12	8.8
13	1.5		13	8.1
14	1.4		14	7.5
15	1.3		15	7.0
16	1.3		16	6.6
17	1.2		17	6.2
18	1.1		18	5.8
19	1.1		19	5.5
20	1.0		20	5.3

Point distribution chart for experiment #7b (perfect solution for N = 17).

BLUE	140		RED	30
2	70.0		2	15.0
3	46.7		3	10.0
4	35.0		4	7.5
5	28.0		5	6.0
6	23.3		6	5.0
7	20.0		7	4.3
8	17.5		8	3.8
9	15.6		9	3.3
10	14.0		10	3.0
11	12.7		11	2.7
12	11.7		12	2.5
13	10.8		13	2.3
14	10.0		14	2.1
15	9.3		15	2.0
16	8.8		16	1.9
17	8.2		17	1.8
18	7.8		18	1.7
19	7.4		19	1.6
20	7.0		20	1.5

BLUE	110		RED	60
2	55.0		2	30.0
3	36.7		3	20.0
4	27.5		4	15.0
5	22.0		5	12.0
6	18.3		6	10.0
7	15.7		7	8.6
8	13.8		8	7.5
9	12.2		9	6.7
10	11.0		10	6.0
11	10.0		11	5.5
12	9.2		12	5.0
13	8.5		13	4.6
14	7.9		14	4.3
15	7.3		15	4.0
16	6.9		16	3.8
17	6.5		17	3.5
18	6.1		18	3.3
19	5.8		19	3.2
20	5.5		20	3.0

BLUE	30		RED	140
2	15.0		2	70.0
3	10.0		3	46.7
4	7.5		4	35.0
5	6.0		5	28.0
6	5.0		6	23.3
7	4.3		7	20.0
8	3.8		8	17.5
9	3.3		9	15.6
10	3.0		10	14.0
11	2.7		11	12.7
12	2.5		12	11.7
13	2.3		13	10.8
14	2.1		14	10.0
15	2.0		15	9.3
16	1.9		16	8.8
17	1.8		17	8.2
18	1.7		18	7.8
19	1.6		19	7.4
20	1.5		20	7.0

BLUE	60		RED	110
2	30.0		2	55.0
3	20.0		3	36.7
4	15.0		4	27.5
5	12.0		5	22.0
6	10.0		6	18.3
7	8.6		7	15.7
8	7.5		8	13.8
9	6.7		9	12.2
10	6.0		10	11.0
11	5.5		11	10.0
12	5.0		12	9.2
13	4.6		13	8.5
14	4.3		14	7.9
15	4.0		15	7.3
16	3.8		16	6.9
17	3.5		17	6.5
18	3.3		18	6.1
19	3.2		19	5.8
20	3.0		20	5.5

Point distribution chart for experiment #7b (imperfect solution for N = 17).

BLUE	140		RED	25
2	70.0		2	12.5
3	46.7		3	8.3
4	35.0		4	6.3
5	28.0		5	5.0
6	23.3		6	4.2
7	20.0		7	3.6
8	17.5		8	3.1
9	15.6		9	2.8
10	14.0		10	2.5
11	12.7		11	2.3
12	11.7		12	2.1
13	10.8		13	1.9
14	10.0		14	1.8
15	9.3		15	1.7
16	8.8		16	1.6
17	8.2		17	1.5
18	7.8		18	1.4
19	7.4		19	1.3
20	7.0		20	1.3

BLUE	115		RED	50
2	57.5		2	25.0
3	38.3		3	16.7
4	28.8		4	12.5
5	23.0		5	10.0
6	19.2		6	8.3
7	16.4		7	7.1
8	14.4		8	6.3
9	12.8		9	5.6
10	11.5		10	5.0
11	10.5		11	4.5
12	9.6		12	4.2
13	8.8		13	3.8
14	8.2		14	3.6
15	7.7		15	3.3
16	7.2		16	3.1
17	6.8		17	2.9
18	6.4		18	2.8
19	6.1		19	2.6
20	5.8		20	2.5

BLUE	50		RED	115
2	25.0		2	57.5
3	16.7		3	38.3
4	12.5		4	28.8
5	10.0		5	23.0
6	8.3		6	19.2
7	7.1		7	16.4
8	6.3		8	14.4
9	5.6		9	12.8
10	5.0		10	11.5
11	4.5		11	10.5
12	4.2		12	9.6
13	3.8		13	8.8
14	3.6		14	8.2
15	3.3		15	7.7
16	3.1		16	7.2
17	2.9		17	6.8
18	2.8		18	6.4
19	2.6		19	6.1
20	2.5		20	5.8

BLUE	25		RED	140
2	12.5		2	70.0
3	8.3		3	46.7
4	6.3		4	35.0
5	5.0		5	28.0
6	4.2		6	23.3
7	3.6		7	20.0
8	3.1		8	17.5
9	2.8		9	15.6
10	2.5		10	14.0
11	2.3		11	12.7
12	2.1		12	11.7
13	1.9		13	10.8
14	1.8		14	10.0
15	1.7		15	9.3
16	1.6		16	8.8
17	1.5		17	8.2
18	1.4		18	7.8
19	1.3		19	7.4
20	1.3		20	7.0

Appendix H

Experiment 4
Cards - probabilitic distribution of unequal points - three competitive weights
Each participants 26 choices for rich and lean alternatives categorizes and grouped according to competitive weights

Subjects' Competitive Weights		Choices rich	lean	
	1	426	484	910
	2	453	457	910
	3	445	465	910
		1324	1406	2730

Cell	Observed	Expected	(O - E)	(O - E)sq	[((O - E)sq)/E]
1, rich	426	441.33	-15.33	235.11	0.53
1, lean	484	468.67	15.33	235.11	0.50
2, rich	453	441.33	11.67	136.11	0.31
2, lean	457	468.67	-11.67	136.11	0.29
3, rich	445	441.33	3.67	13.44	0.03
3, lean	465	468.67	-3.67	13.44	0.03

chi-square =	1.69
df =	2.00
(.01) critical chi-square =	9.21
(.05) critical chi-square =	5.99

Experiment 6
Cards - probabilitic distribution of equal points - two competitive weights
Each participants 26 choices for rich and lean alternatives categorizes and grouped according to competitive weights

		rich choice	lean choice	
Competitive	1	684	306	990
Weight	3	677	373	1050
		1361	679	2040

percentage of row totals

0.69	0.31
0.64	0.36

Cell	Observed	Expected	(O - E)	(O - E)sq	[((O - E)sq)/E]
1, rich	684	660.49	23.51	552.94	0.84
1, lean	306	329.51	-23.51	552.94	1.68
3, rich	677	700.51	-23.51	552.94	0.79
3, lean	373	349.49	23.51	552.94	1.58

chi-square =	4.89
df =	1
(.01) critical chi-square =	6.64
(.05) critical chi-square =	3.84

Appendix I

The preference index was created to describe each participant's preference for the rich alternative across of block of trials. The following procedure was used to formulate a preference index that ranged from negative one for total preference for the lean alternative to positive one for total preference for the rich alternative.

1. Participants' choices between alternatives were recorded with a 1 (Row A, blue card) or 3 (Row B, red card).
2. The 1s and 3s were changed to -1 (Row A, blue card) and 1 (Row B, red card).
3. The average of choices (-1s and 1s) between alternatives across a block of trials was constructed.
4. The sign of the average was corrected to reflect preference for the rich and lean alternative instead of the first and second alternative.

Several examples of choices across a block of 26 trials and their corresponding preference indices are depicted below.

Point Ratio ==> 2 to 1 **-1 = altern. 1, 1 = altern. 2**

total preference for rich		total preference for lean		split preference		approximate 2:1 preference	
trial	**choice**	**trial**	**choice**	**trial**	**choice**	**trial**	**choice**
1	-1	1	1	1	1	1	-1
2	-1	2	1	2	1	2	-1
3	-1	3	1	3	1	3	-1
4	-1	4	1	4	1	4	-1
5	-1	5	1	5	1	5	-1
6	-1	6	1	6	1	6	-1
7	-1	7	1	7	1	7	-1
8	-1	8	1	8	1	8	-1
9	-1	9	1	9	1	9	-1
10	-1	10	1	10	1	10	-1
11	-1	11	1	11	1	11	-1
12	-1	12	1	12	1	12	-1
13	-1	13	1	13	1	13	-1
14	-1	14	1	14	-1	14	-1
15	-1	15	1	15	-1	15	-1
16	-1	16	1	16	-1	16	-1
17	-1	17	1	17	-1	17	-1
18	-1	18	1	18	-1	18	-1
19	-1	19	1	19	-1	19	1
20	-1	20	1	20	-1	20	1
21	-1	21	1	21	-1	21	1
22	-1	22	1	22	-1	22	1
23	-1	23	1	23	-1	23	1
24	-1	24	1	24	-1	24	1
25	-1	25	1	25	-1	25	1
26	-1	26	1	26	-1	26	1

	total preference for rich	total preference for lean	split preference	approximate 2:1 preference
Average ==>	-1	1	0	-0.38
Preference Index ==>	1	-1	0	0.38

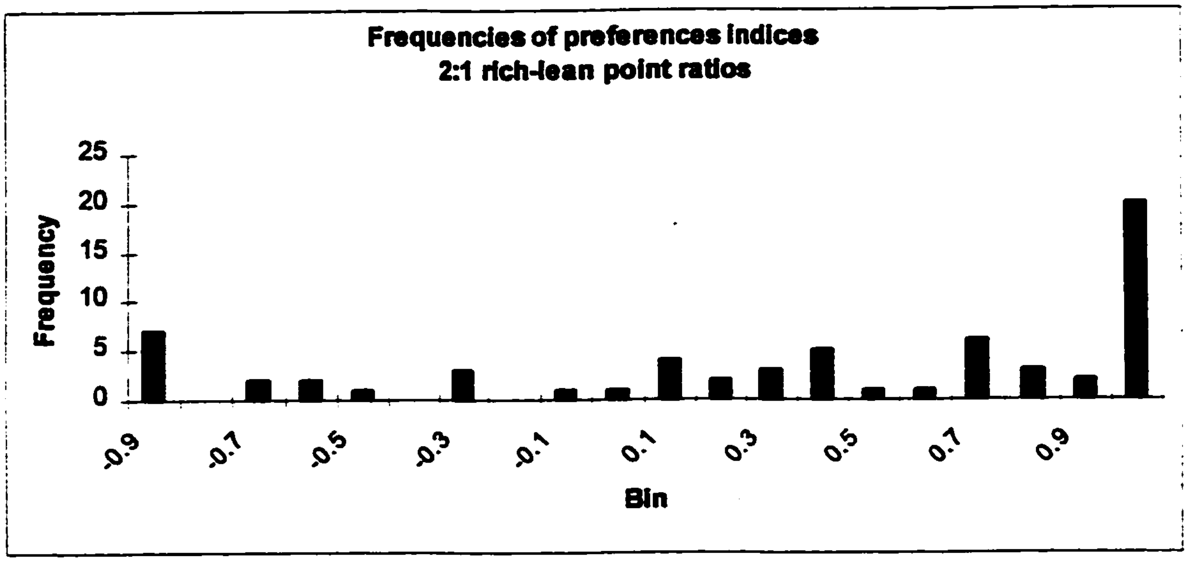
Point Ratio ==> **1 to 2** **-1 = altern. 1, 1 = altern. 2**

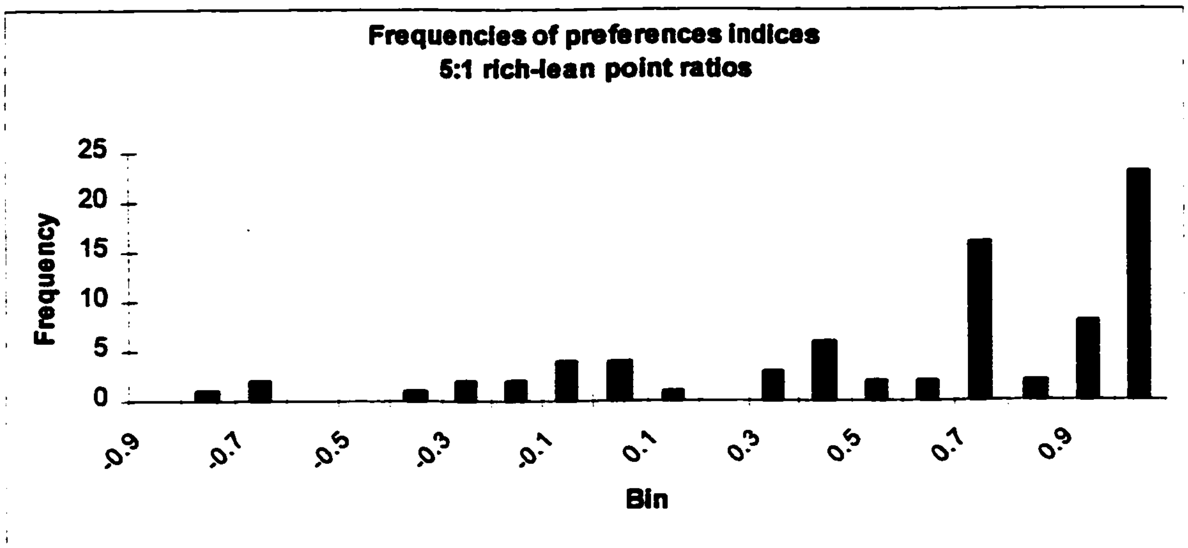
total preference for rich		total preference for lean		split preference		approximate 2:1 preference	
trial	choice	trial	choice	trial	choice	trial	choice
1	1	1	-1	1	1	1	-1
2	1	2	-1	2	1	2	-1
3	1	3	-1	3	1	3	-1
4	1	4	-1	4	1	4	-1
5	1	5	-1	5	1	5	-1
6	1	6	-1	6	1	6	-1
7	1	7	-1	7	1	7	-1
8	1	8	-1	8	1	8	-1
9	1	9	-1	9	1	9	-1
10	1	10	-1	10	1	10	-1
11	1	11	-1	11	1	11	-1
12	1	12	-1	12	1	12	-1
13	1	13	-1	13	1	13	-1
14	1	14	-1	14	-1	14	-1
15	1	15	-1	15	-1	15	-1
16	1	16	-1	16	-1	16	-1
17	1	17	-1	17	-1	17	-1
18	1	18	-1	18	-1	18	-1
19	1	19	-1	19	-1	19	1
20	1	20	-1	20	-1	20	1
21	1	21	-1	21	-1	21	1
22	1	22	-1	22	-1	22	1
23	1	23	-1	23	-1	23	1
24	1	24	-1	24	-1	24	1
25	1	25	-1	25	-1	25	1
26	1	26	-1	26	-1	26	1

Average ==>	1	-1	0	-0.38
Preference Index ==>	1	-1	0	-0.38

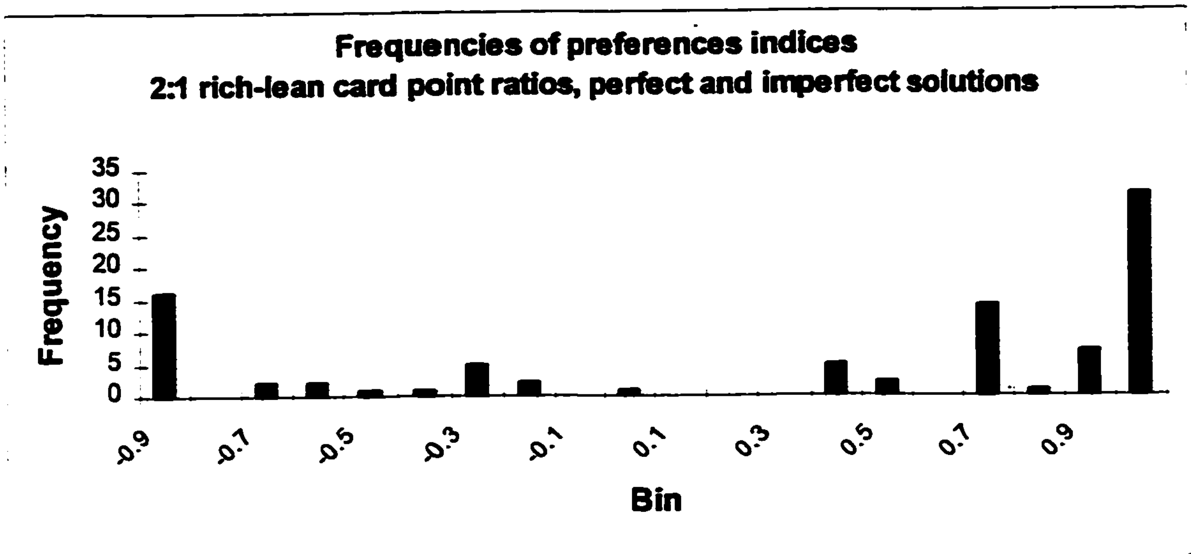
Appendix J

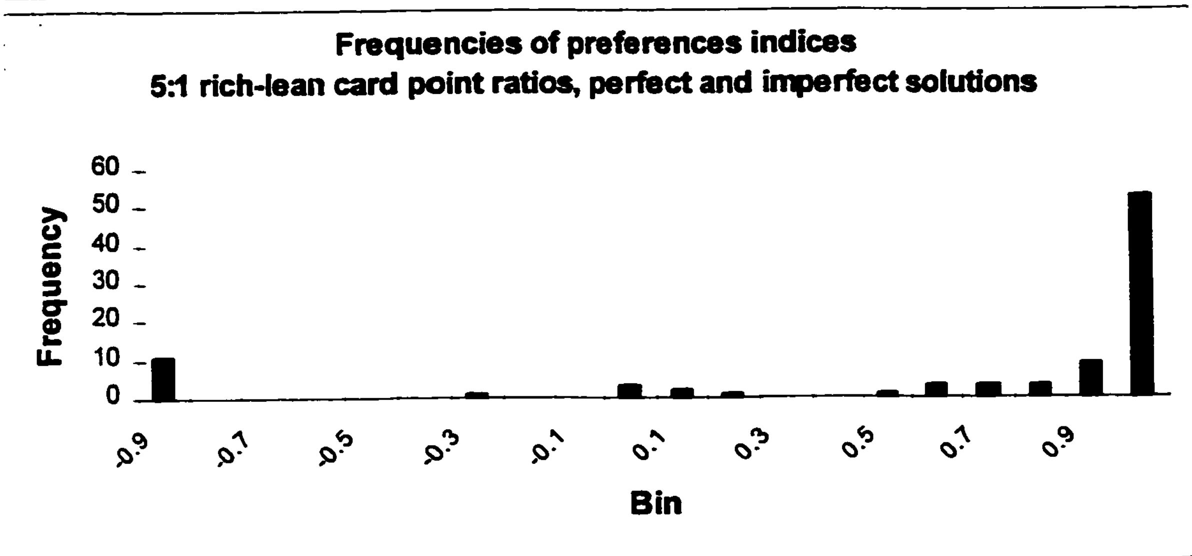
Experiment 1: Distributions of preference indices.



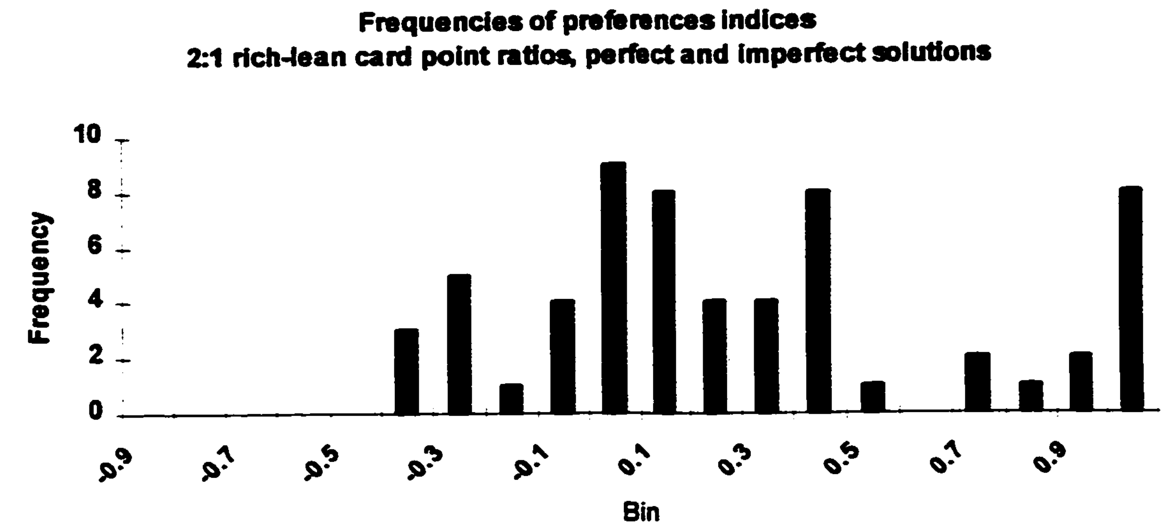


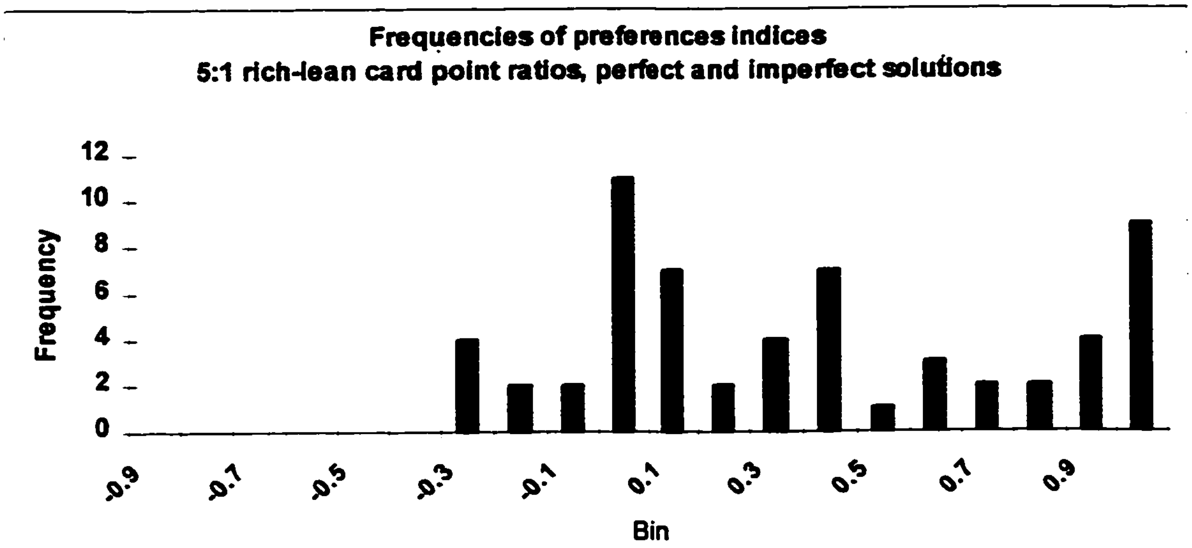
Experiment 2: Distributions of preference indices.



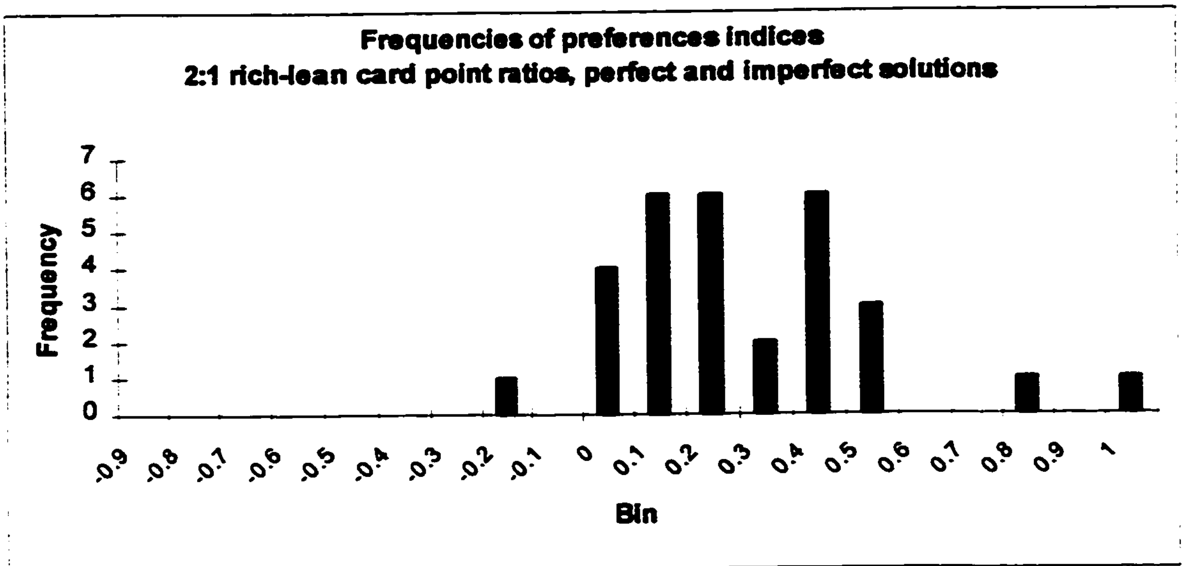


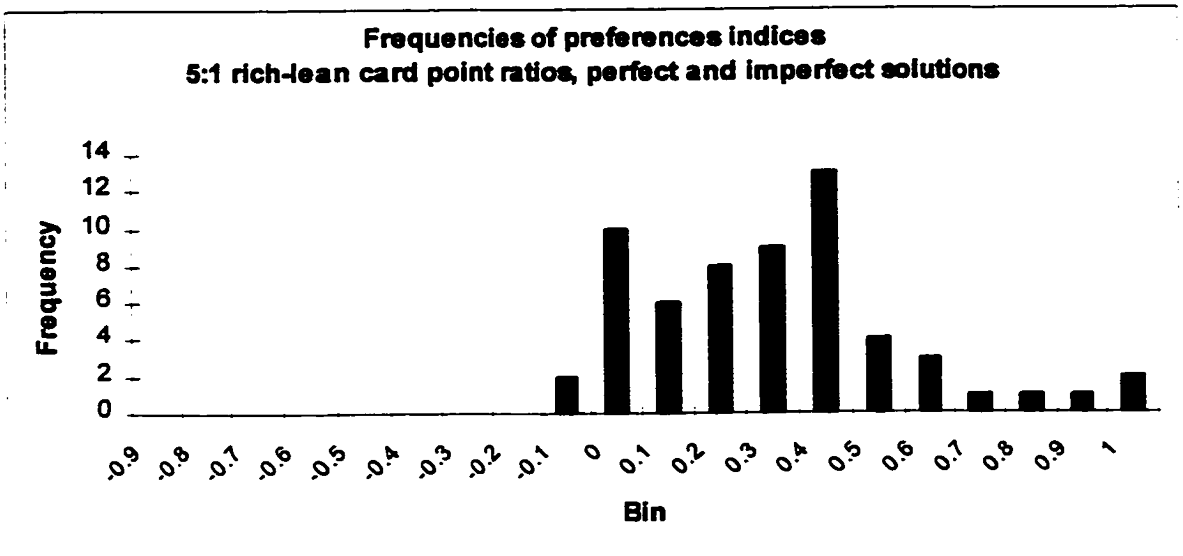
Experiment 3: Distributions of preference indices.



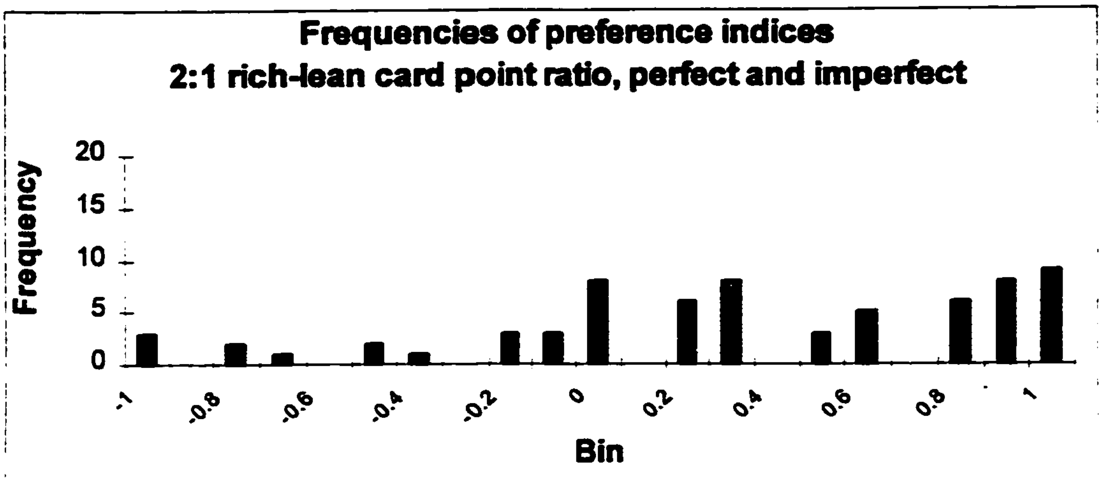


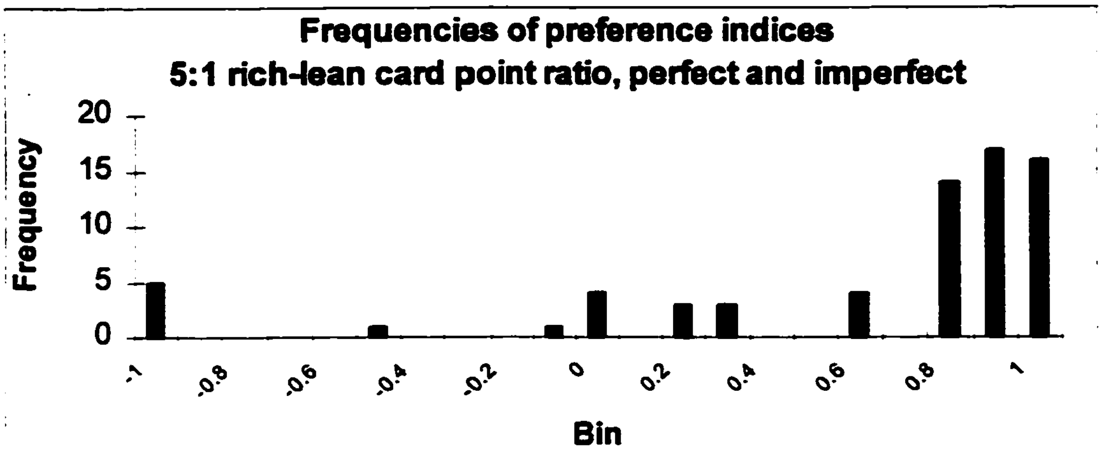
Experiment 4: Distributions of preference indices.



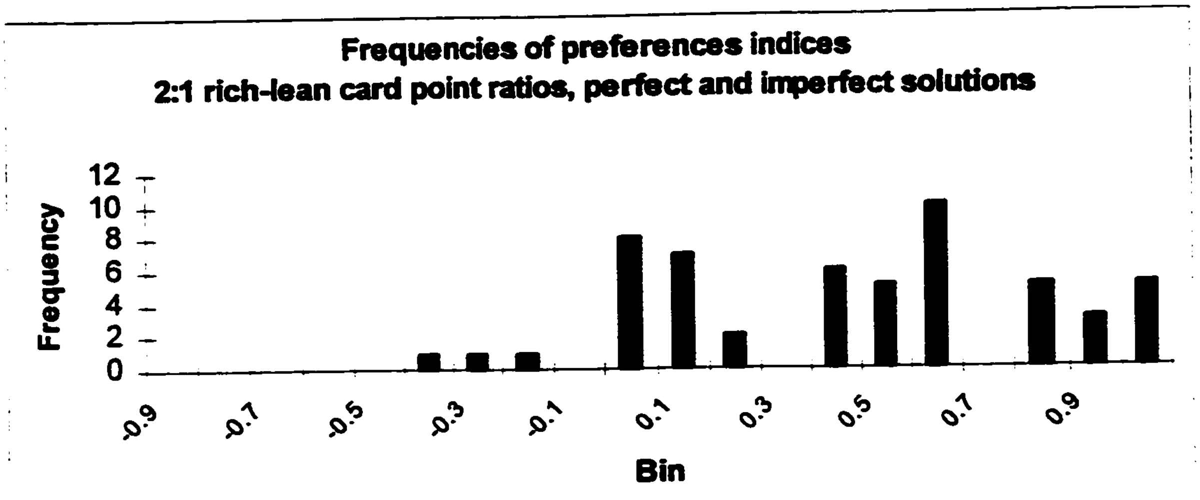


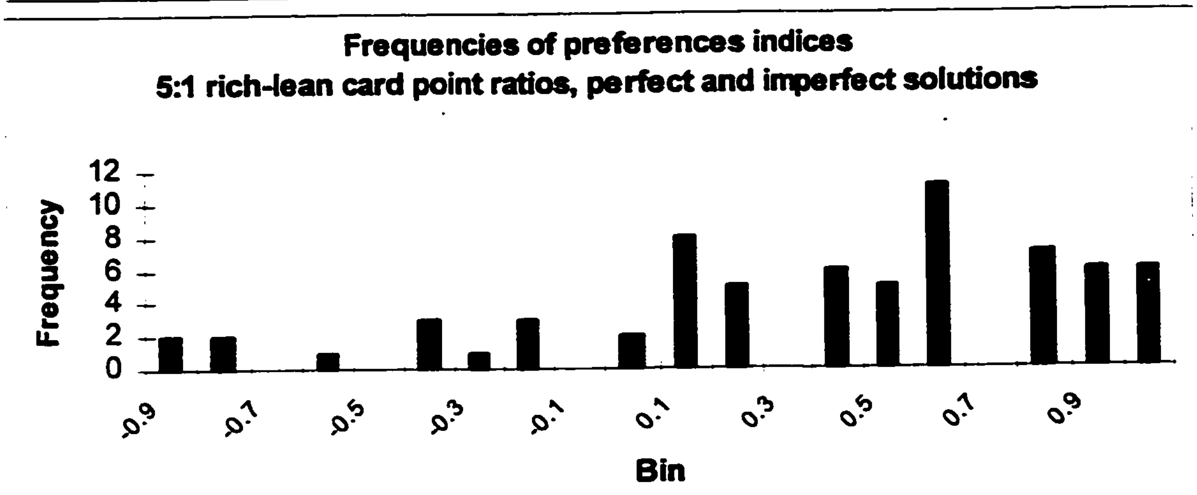
Experiment 5: Distributions of preference indices.



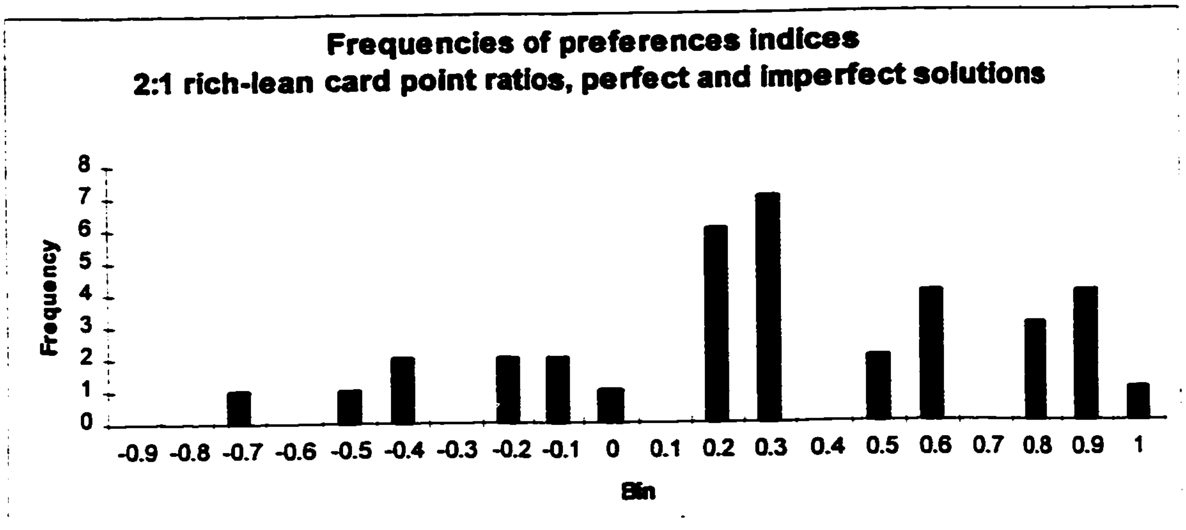


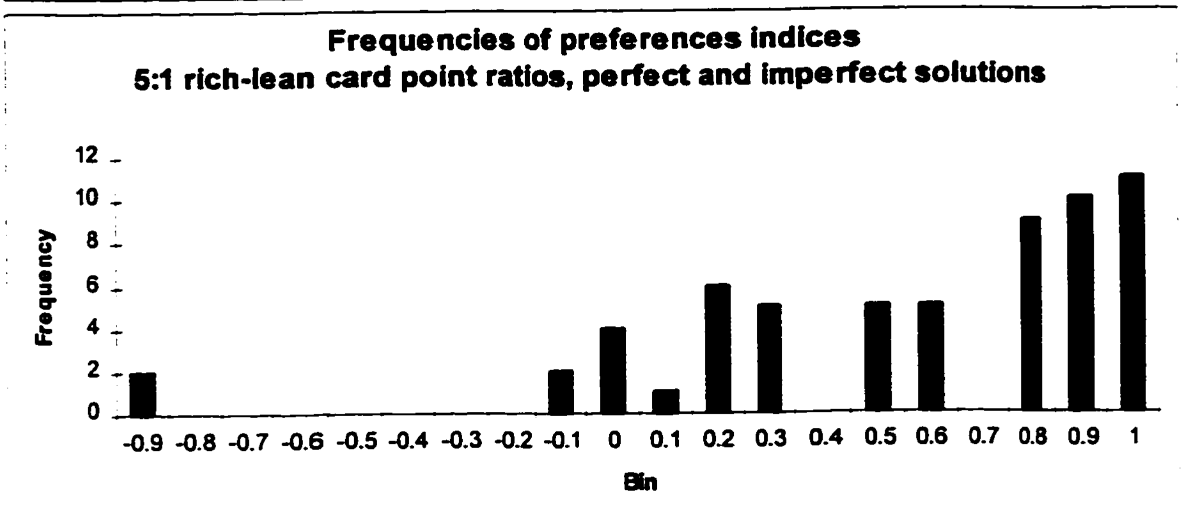
Experiment 6: Distributions of preference indices.



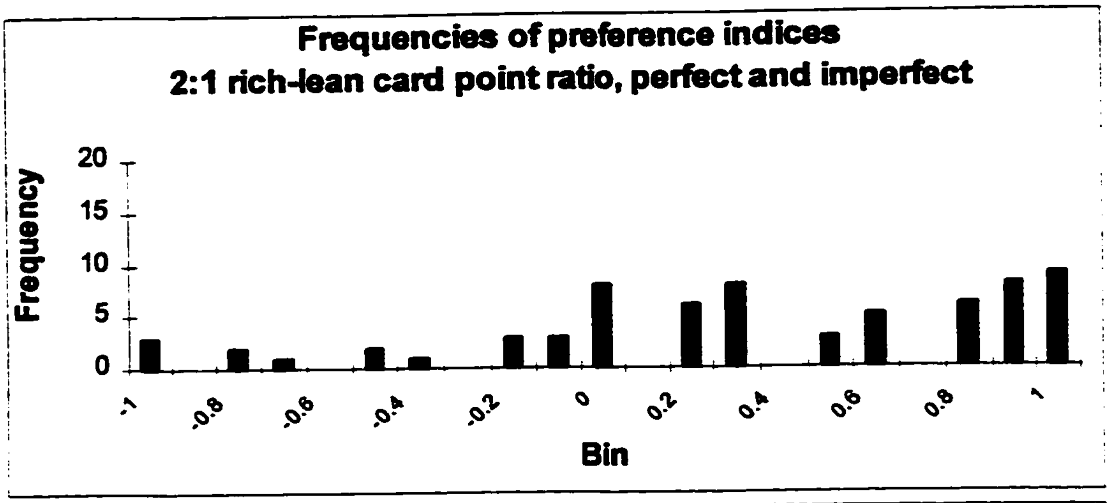


Experiment 7a: Distributions of preference indices.





Experiment 7b: Distributions of preference indices.



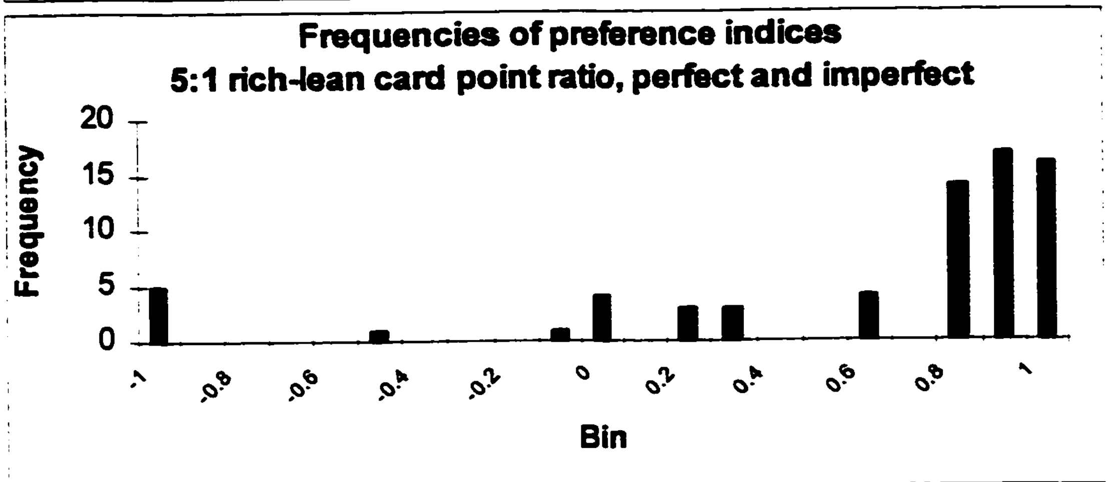
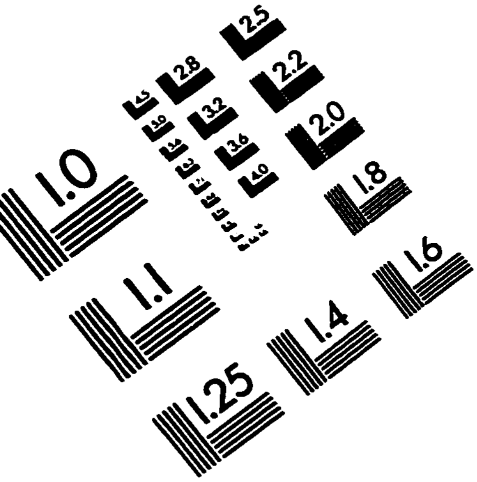
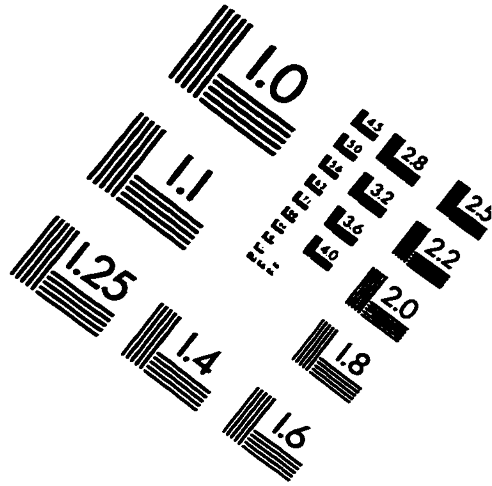
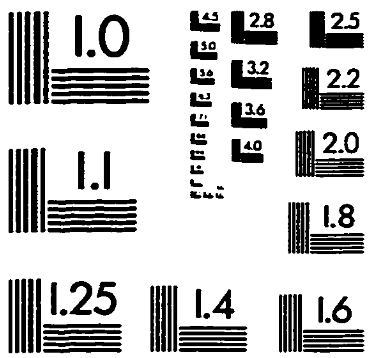


IMAGE EVALUATION TEST TARGET (QA-3)

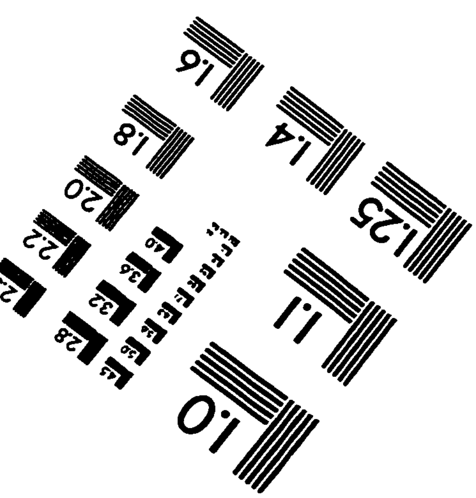


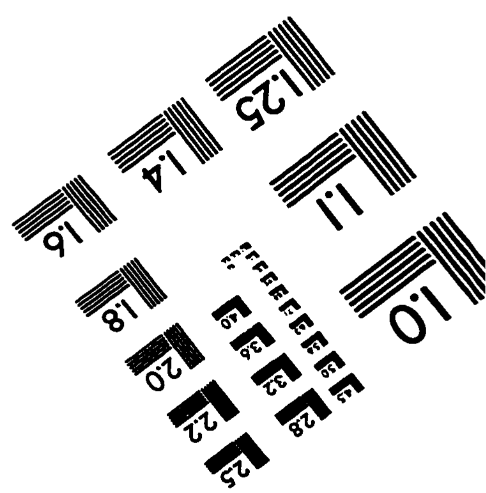




150mm

6"





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