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ANA CAROLINA TROUSDELL FRANCESCHINI

Seleção de pacotes de respostas envolvendo ganhos e perdas de *tokens* com ratos: um estudo experimental dentro da análise do comportamento econômico

Selection of response packages involving token gains and losses with rats: an experimental study under the economic behavior analysis

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(Versão corrigida)

Tese apresentada ao Instituto de Psicologia da Universidade de São Paulo como parte dos requisitos para obtenção de título de Doutora em Psicologia

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Prof. Dr. ____

Instituição: ___________________________Assinatura:_______________________

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Aos meus avós

Meus amados e incansáveis defensores,
Meus guias nas tempestades
Modelos de amor incondicional
Levo vocês para sempre comigo.

"Onde quer que eu vá,
sinto o cheiro de festa..."

Agradecimentos

Ao longo de doze anos, **Tatu** (vulgo Maria Helena Hunziker) me ensinou o sentido de duas palavras: “orientar” e “serendipidade”. Serendipidade é um anglicismo (*serendipity)* que se refere a descobertas inesperadas e afortunadas. Ambos os conceitos exigem o difícil treino de escutar os dados, deixar que eles guiem nosso olhar para além dos objetivos imediatos. Tatu me ensinou que devemos seguir os dados mesmo que eles nos conduzam a trajetos impensados. Serendipidades ocorreram em todas as minhas pesquisas em Psicologia, da iniciação científica ao doutorado. Coincidência? Creio que não. Os eventos só se transformam em serendipidade a partir do incentivo, do suporte, do olhar crítico e encorajador de alguém que faz por merecer cada letra da palavra O-R-I-E-N-T-A-D-O-R-A. À Tatu, dedico trecho do poema “Guia-se só a razão” de Fernando Pessoa:

> Como o olhar, a razão
> Deus me deu para ver
> para além da visão
> o olhar de conhecer.

Um tema interdisciplinar como é a Economia Comportamental depende de um diálogo constante. Tive a felicidade de poder dialogar com **Jorge Oliveira Castro Neto,** um ícone da Economia Comportamental no Brasil que combina um olhar fundamentado, científico, à uma curiosidade e amplitude ímpar. Sua participação na pesquisa foi crescente: começou quando ele interrompeu suas férias para oferecer preciosas sugestões na qualificação do projeto, aprofundou-se quando ele aceitou se tornar co-orientador, cresceu nos construtivos comentários durante a coleta e redação e culminou na defesa da pesquisa. Jorge, torço para que nosso diálogo se prolongue ainda por muitos anos. Essa pesquisa contém muito de você!

The path of this research has crossed the Brazilian frontiers and lead me to the city of Portland, OR, where **Tim Hackenberg**, **Allen Neuringer** and **Greg Wilkinson** have opened the doors of their inspired laboratories at Reed College so I could collect and discuss my data. I received many valuable and generalized tokens there with Reed´s amazing students, during the weekly lab meetings, in various occasional talks in the corridors, in many serious discussions with Greg about MED equipment and TV series, on my attempts to bathe my subjects with warm water and baby shampoo (not very popular!), and in providing an unlimited supply of (saltless) popcorn to my rats. I am indebted to Tim and friends for the unexpected last-minute invitations to great music concerts in the Portland nightlife, and to Allen and Martha for the blessed retreats to the Ridge (hard work on chores included!). I also thank **Lauren, Jasmine, Marisol, Lisa, Shirin** and **Emma** for sharing your thoughts, college premises and long night hours with me. The generosity of Reed College and Portland´s weirdness will always call me back to this amazing place!

Tive também a felicidade de conviver com o animado grupo de pesquisadores em meu "lar acadêmico", o LABC. Lá pude desfrutar dos conselhos da **Tauane**, compartilhar a sala de coleta com o **Amilcar**, acompanhar as descobertas do **Eduardo**, conviver com a presença amiga da **Angélica**, dividir boas risadas com a **Márcia**, discutir Jogos dos Bens Públicos com a **Luana**, e ser monitora de AEC II com a **Lígia**. Também pude observar o crescimento e o brilho no olhar de duas dedicadas estagiárias, **Larissa Pedrosa** e **Lais Nicolodi**. Pesquisadoras como vocês construirão o futuro da Economia Comportamental brasileira... e ele está em boas mãos.

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RESUMO

O objetivo desse estudo foi testar as hipóteses de simetria e assimetria entre reforçamento e punição utilizando análise oriunda da Economia Comportamental. Foram utilizados cinco ratos *Sprague Dawley,* treinados em uma cadeia comportamental mantida por economia de *tokens*, em uma caixa tendo como *operanda* duas rodas e uma barra: respostas de girar a roda produziam *tokens* (LEDs) e as de pressionar a barra trocavam os *tokens* por sacarose. O elo de produção de *tokens* consistia em um esquema concorrente, sendo um oferecendo reforçamento positivo (adição de *tokens*) e o outro um esquema misto de reforçamento positivo e punição negativa (adição ou remoção de *tokens*, respectivamente). A variável independente foi a exigência de determinado número de respostas de girar a roda para liberação de 1ml de sacarose (preço unitário), sendo a variável dependente a alocação de respostas entre os dois esquemas concorrentes. Todos os sujeitos estabeleceram distribuições estáveis de respostas (analisados como “pacotes de respostas”) entre os dois esquemas, os quais variaram em função do preço unitário. Os resultados confirmaram que os LEDs tiveram função de estímulo discriminativo, mas não foram claros sobre a sua função punitiva quando removidos contingente à resposta. Consequentemente, os dados obtidos não permitiram que se concluísse sobre as hipóteses testadas. Os resultados foram então analisados por três modelos explicativos do comportamento de escolha: melioração, maximização e *satisficing*. O modelo de *satisficing* foi o que produziu a melhor explicação das escolhas molares de todos os sujeitos, sob todos os preços unitários. O modelo de melioração ofereceu explicações adequadas para três sujeitos, especialmente quando o preço unitário era baixo, enquanto o de maximização foi adequado na condição de preços unitários altos, mas apenas para dois sujeitos.

Palavras-chave: Economia Comportamental, tokens, (as)simetria ganho-perdas, maximização, melioração, satisficing.

ABSTRACT

The objective of this study was to test the hypotheses of symmetry and asymmetry between reinforcement and punishment using an analysis that stems from behavioral economics. Five Sprague Dawley rats were used, submitted to a behavioral chain maintained by a token economy. The operant chamber had two response wheels and a lever: wheel-spinning responses produced tokens (LEDs) and lever-presses exchanged tokens for sucrose. The token-production link was a concurrent condition: a positive reinforcement (token production) schedule, and a mixed schedule with a positive reinforcement and a negative punishment component (token production and removal, respectively). The independent variable was unit price, that is, the number of wheel-spins required to produce 1 cc of sucrose; the dependent variable was response allocation between the two concurrent schedules. All subjects established stable response distributions (considered as "response packages") between the two schedules, which varied according to unit prices. The results confirmed that the LEDs acted as discriminative stimulus, but were not clear as to their punitive function when removed, response-contingently. Therefore, the results did not support any conclusion about the tested hypotheses. They were then analyzed based on three choice models: melioration, maximization, and satisficing. The satisficing model produced the most comprehensive explanation of molar choices among all subjects and unit prices. The melioration model produced adequate explanations for three subjects, mostly when unit prices were low, while maximization was adequate in the condition when unit prices were high, but only for two subjects.

Keywords: Behavioral economics, tokens, gain-loss (a)symmetries, maximization, melioration, satisficing

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The present work is inserted within an interdisciplinary research area called "economic behavioral analysis" (EBA)[1], which is a branch of modern behavioral economics. This interdisciplinary field overlaps behavioral analysis and economics to produce an ampler understanding of individual and social human behavior. EBA researches tend to adopt concepts and methods that, although compatible with the principles of both sciences, are not the ones typically found in the most traditional works in their mother-sciences. This characteristic imposes some challenges for those who are entering the field, as they must familiarize themselves with new concepts and techniques that are not part of their original repertoire. Some of these practices and their conceptual fundaments will be exposed here.

Although there is a variety of themes that today fall under the realm of EBA, it is possible to identify a few that attract a larger concentration of researches. One is choices that involve gains and losses. There is an on-going debate on whether organisms react to a gain and a loss of the same magnitude with equal or different intensities. The so-called gain-loss asymmetry hypothesis states that people tend to respond more intensely to avoid a loss than they do to produce a gain of the same magnitude (Kahneman & Tversky, 1979; 1992; Thaler, 1981; Ainslie, 2016). The alternative hypothesis of symmetry states that organisms react with equal intensity, only in opposite directions (Farley & Fantino, 1978). The aim of the present study is to test the symmetry or asymmetry hypothesis using an experiment with rats that made concurrent choices that involved gains and losses of conditioned reinforcers (tokens).

Behavioral Economics: Recent History in the Psychological Field

Psychologists and economists share a common interest in using scientific methods to find

[1] The economic behavior analysis is also called operant behavioral economics (Foxall, 2015).

and explain regularities in human behavior. So the natural intuition would be that the two areas should joint forces in their common pursuits. But this kind of intellectual alliance is not easy to obtain and has been an intermittent process for decades.

Contemporary behavioral economics is a broad interdisciplinary research agenda that intertwines psychology and economics. This interdisciplinary dialog gained strength in the late 1960's and early 1970's, parallel to the emergence of the field of experimental economics (Kagel & Roth, 1995; Svorencik & Maas, 2016). There are two lines of psychological thought that claim this alliance with economics. The term "behavioral economics" was introduced in the psychology vocabulary by Kagel (economist) and Winkler (psychologist) in the paper "*Behavioral Economics: areas of cooperative research between economics and applied behavioral analysis*", published in 1972 (Ainslie, 2016).

In the same year, Rachlin and Green (1972) published a study on delay-discounted choices, in which they reported an experimental procedure with pigeons that reproduced a preference reversal tendency that was also being observed in experimental economic studies with humans at the time (Grether & Plott, 1979). When pigeons were offered a concurrent choice between a small immediate reinforcement (2-sec exposure to grain) and a larger reinforcement (4-sec exposure to grain) delayed by 4 secs, the subjects invariably preferred the small, immediate one. However, when offered a choice between a delay of "t" + 2 secs ("t" is a fixed period of time), followed by a 2-sec exposure to grain and a delay of "t" + 4 secs, followed by a 4 secs exposure to grain, they reversed their preferences and chose the larger delay. The relevance of this finding to economics is that it violates a basic understanding (axiom) about human behavior that is fundamental to economic (neoclassical) theory: that people have stable, well-defined preferences, and make choices consistent with these preferences (Tversky &

Thaler, 1990). Rachlin and Green's (1972) demonstration that pigeons showed similar tendencies for preference-reversals, suggested that this phenomenon involved more basic behavioral processes, with interspecies generalization.

These events fit into broader changes occurring at the time, with the emergence of experimental economics, which advocated for the validity of laboratory testing as a source of economic data. Without the influence of this methodological "revolution" (Guala, 2005), the acceptance of laboratory data in economic theories would probably be marginal (Nagatsu, 2010; Svorencik & Maas, 2016). More traditional branches of economics (neoclassical) do not tend to delve deeply into the behavioral processes that determine human preferences; they only assume that preferences exist, can be empirically observed, quantified, and used to predict future choices. This economic disregard for the psychological fundaments of preference formation can be traced back to a methodological statements from economist Samuelson (1938), who suggested that economists should "get rid of psychological presuppositions" and adopt an "operationalist methodology", in which preferences must be derived from *actually observed choices*. The general idea is that, once preferences have been systematically identified, they can be used to predict future choices as long as a set of axioms about human nature ("rationality") holds true (Muramatsu, 2009). The already mentioned assumption on choice stability is one of these axioms. This pragmatic approach has been a target of constant criticism from behavioral economists (from all backgrounds), who advocate that (1) the axioms of human rationality are unrealistic and do not stand experimental testing; and (2) the explanatory and predictive powers of economic models can strongly improve with a better understanding of the behavioral processes that determine human choices (Muramatsu, 2009).

In the same period, Herrnstein published a series of experiments that culminated with the proposition of the matching law (Herrnstein, 1970), a descriptive model of choices that derives from the process of melioration, discussed below. A decade later, in the early 1980's the interaction between economic theory and experimental psychology was propelled further by the publication of two pivotal papers from Hursh (1980; 1984) and two books "Behavioral Economics", by Allison (1983), and "Microeconomics and Human Behavior: towards a synthesis of Economics and Psychology" by Alhadeff (1982). A common aspect in all of these works is that they propose parallels between principles of reinforcement and economically-relevant variables like consumer demand, wage rate, labor supply etc. and procedural translations of these concepts into laboratory practices with animals. All of the works mentioned up to this point are based on the behavioral analysis approach, which is the scientific branch of the philosophy of radical behaviorism.

Simultaneously, but somehow independently, a second branch of behavioral economics was formed following the publication of the paper "*Prospect theory: an Analysis of Choices under Risk*" (1979) by psychologists Kahneman and Tversky. In this article, they criticize the excessive economic reliance on axioms about the human nature (as the stability of preferences mentioned before), and reported a series of systematic errors found when these axioms are tested experimentally. This kind of criticism of the economic understanding of human behavior, based on laboratory testing, is a common feature of many behavioral economic works until today. The difference between Kahneman and Tversky's papers (among others) and the studies from Rachlin, Green, Herrnstein, Kagel, Winkler etc. is that the former are based on a line of psychological thought called cognitivism, and the latter are based on the principles of behavioral analysis/ behaviorism.

One founding proposition of behaviorism was to remove introspective methods and other non-refutable assumptions from psychology. Coherent with this guideline, behavioral analysts place a strong emphasis on identifying observable relations between living organisms and environmental contingencies. A key behavioral analyst, Skinner (1904-1990), defended that references to mental processes were superfluous to any explanation of behavior (Skinner, 1974; Baum, 2005). Mental processes are understood in this context as internal events, i.e. events that occur "inside the organism's skin", which are seen as behaviors themselves, and thus cannot be taken as the causes of behavior. So profound was Skinner's statement that it divided the field of psychology between those who agreed with his ideas, and those who formed the so-called "cognitive reaction". This group rejected Skinner's propositions and (re) introduced mental processes like believing, thinking, imagining, feelings as possible causes of behavior (Ainslie, 2016). The two branches established separate dialogs with economics, and these two versions of behavioral economics (EBA and the cognitivist branch) co-existed within psychology almost without any contact since their birth (Ainslie, 2016).

Economic Behavior Analysis

The goal of economic behavior analysis (EBA) is to study economically-relevant behavior, using a system of logic and language that is acceptable to both scientific fields. These classes of behaviors refer to a broad range of human behaviors that have been identified by economic theories as responsible for the way our society is organized. Examples are the behaviors of consuming, working, investing, trading goods, borrowing, or lending money, each one encompassing a large class of functional relations and topographies.

The interaction between behavioral analysis and economics has been advised by Skinner, when he stated that "an adequate science of behavior should supply a satisfactory account of the individual behavior that is responsible for the data in economics in general" (1953, p. 400). Prominent economists reciprocate the defense of the benefits of a joint research effort. Robbins (1945) advocates that economists should resort to other sciences in their attempt to grasp the relationship between individual behavior and systemic facts. The main attention of economists, he says, should be focused chiefly on the search for general laws that organize the network of economic systems: how wages, prices, profits, production of goods, etc., are established and maintained. However, the economic phenomena itself can only be explained by *going beyond* such relations and invoking the "laws of choices", which are best seen when contemplating the behavior of individuals. In consonance with Skinner's assertion, Robbins states that the observation of individual behavior can provide insights into the larger economic phenomena, because it is "conditioned by the same environmental restrictions and is capable of being subdued under the same fundamental facts of scarcity as any larger society" (Robbins, 1945, pp. 19-20).

A distinguishing advantage of EBA to economics is the inductive approach adopted in its investigations. One of the main objections from the so-called "orthodox" economists (neoclassics) against the advance of the cognitivist approach to behavioral economics is that this area is mostly concerned with discrediting economic concepts on the basis that they are inconsistent with this or that psychological concept (Foxall, 2015). The inductive approach from EBA means that this area is more concerned with testing the empirical validity and usefulness of behavioral relations, and less with the consistency between facts and theories. The result is that, somewhat by contrast with the rest of the field, many accomplishments from EBA came from demonstrating the relevance of economic concepts to the study of choices (Foxall, 2015). This suggests that EBA is a particularly fitting partner to test the empirical realism of economic concepts and to propose improvements.

From the standpoint of behavioral analysis, one of the benefits of this intellectual alliance is that the laboratory testing of economic concepts can direct the attention of experimentalists to new phenomena previously ignored, and to new functional relations previously unnamed (Hursh & Roma, 2015). Additionally, economics can greatly extend the audience for analytic-behavioral studies, and generate novel applications. Maybe a simple way to summarize the benefits from EBA is to say that it combines the strengths of two sciences in favor of an ampler understanding of behavior. Behavioral analysis provides quantitatively precise tools to dissect economically-relevant behavior up to its most basic processes, and economics provides the way to escalate these findings to much broader levels, up to an entire society.

Despite of these benefits, entering the field of EBA presents a twofold challenge to any scientist, as they must overcome reservations on the acceptability of knowledge produced under different methods and rationales. In his paper "*Behavioral Economics*", Hursh (1984) voices this suspicion from his colleagues in the very first sentence: "why economics? is a question frequently asked of those interested in the relevance of economic theory for behavior analysis" (p. 235). From a psychologist's point of view, economic theory is not yet derivable from current behavior principles (Hursh, 1980; Alhadeff, 1982). Modern economic theories rose from separate spheres of practical and philosophical inquiries (Robbins, 1945), part from intuitions and part from observations of aggregate tendencies of social groups, accumulated over centuries (Hursh, 1980). It should be no surprise if they are not always directly applicable to the analysis of the behavior of individual subjects (Hursh, 1980). Similar concerns arise from economists who search the analytic-behavioral literature for answers to economic problems. Despite a few isolated cases, the experimental work of behavioral analysts are based on concepts that are foreign to economists, and are not designed to generate data in the form that would be most useful for economic investigations (Alhadeff, 1982).

This state of things puts EBA in an uneasy mediating suspension between the goals and methods from behavioral analysis and economics. Methodological and conceptual pluralisms are at the same time its greatest strengths and biggest challenges. Scientists tend to come to this field carrying a specific kit of sharp methodological tools and concepts from their motherland – and are largely in ignorance of the ones used in the other discipline (Simon, 1997). Two challenges for every economic behavior analyst are to (1) learn how to communicate your scientific achievements in a manner that is understandable to the other side, and (2) situate the advances of the other side into your own logic system. Therefore, one important step in the development of EBA is to establish a conceptual system and methodological practices that are deemed acceptable by both audiences. There have been important improvements on this front. Some will be exposed now.

Seeing choice as behavior and vice versa

From an economic standpoint, human behavior presents four fundamental characteristics. First, humans have multiple needs. Second, the external world does not offer full opportunities for their complete fulfillment. Third, time and resources are limited, and liable to alternative uses. Forth, human needs have different degrees of importance. The conjunction of these four means that all behaviors assume the form of *choices* (Robbins, 1945): every behavior requires time and energy that cannot be recovered, and requires giving up the opportunity of doing other things. Thus, more important needs must be attended before less important ones.

The notion that behavior is choice and vice versa has also been present in the analytic-behavior literature for over 40 years (Grace, 2005; Baum, 2004; 2010). It is explicit in the description of an operant setting made by Herrnstein (1970):

> "Even in a simple environment like a single-response operant conditioning chamber, the

> occurrence of the response is interwoven with other, albeit unknown, responses (…). No matter how impoverished the environment, the subject will always have distractions available, other things to engage its activity and attention, even if these are no more than its own body, with its itches, irritations, and other calls for service. (…) there is no way to avoid some such a context for any response... whether or not the experimenter happens to know what the other alternatives and their reinforcers are (pp. 254-5).

Every choice is a trade-off

The economic thinking is that every behavior involves a cost-benefit account of "wanted" and "unwanted" aspects, embedded in any environmental contingency. They are inseparable dual sides. Responding in one alternative requires sacrificing the opportunity to respond in other options, that is, it has "opportunity costs". Opportunity costs are a salient aspect in operant experiments with concurrent schedules, where every response involves giving up reinforcement from the other alternative schedule (Baum, 2010; Rachlin, Battalio, Kagel, & Green, 1981).

Responding also requires that organisms make physical effort and spend time that could be used in other activities that might be more "pleasant" to the organism ("leisure", in economic language). Reaching a state of satiation requires a previous and maybe uncomfortable state of deprivation; punishments can also produce a "pleasurable relief" when it ends. Different consequences may appear immediately or only after a long time has passed. In sum, various aspects of behavior are inextricably intertwined and cannot be separated. So, to behave is to incur in "unwanted", costs in order to produce "wanted" events. This understanding is described in economic language as a cost-benefit *trade-off*, and is seen as an embedded aspect of every choice/behavior.

Response Packages and Commodities Bundles

If the complex nature of behavior/choices is accepted, then it becomes equally necessary to recognize that it cannot be studied experimentally in its entirety (Findley, 1962). Instead, it must be broken into some type of basic unit. The determination of this basic unit of analysis depends on experimenter's individual understanding of what are the fundamental properties of this object of study.

A molecular approach sees behavior as consisting of discrete units – responses - occurring at moments in time and strung together in chains to make up complex performances; a molar view sees behavior as composed of behavioral patterns, or activities, that are integrated wholes, i.e. indivisible into smaller units, and extended in time (Baum, 2004). Some authors consider the molar and molecular views as two irreconcilable behavioral paradigms (Baum, 2004). Others criticize this dichotomy and call for a more conciliatory approach in which behavior is seen as multiple processes that function simultaneously on various time scales (Hineline, 2001).

The choice for implementing a molecular or molar level of analysis guides the selection of the basic fundamental units. Molecular analyses typically focus on the description of how specific responses are emitted one after another, under the control of numerous classes of variables. One response is followed by another in a continuous and flowing manner; the consequences of each segment giving rise to the specific conditions controlling the next (Findley, 1962). This view has accumulated a rich literature, with careful and sophisticated analyses of specific operants and respondents, and of how responses and environmental stimulus become functionally linked.

Despite being the preferred unit of analysis by behavioral analysts, responses are not the only option. Behavioral analysis possesses the technology and conceptual framework to support larger behavioral samples, composed of many operants (Findley, 1962). One EBA practice is to adopt the *distribution* of responses among the alternatives available in the experimental session, also called "packages of responses" (Rachlin, Battalio, Kagel, & Green, 1981; Premack, 1971). An economically-inspired practice that entered the EBA field is to view experimental contingencies as a large number of response packages, from which the subject chooses. For instance, a rat in an operant situation will spend some time and energy pressing a lever, another amount of time and energy eating pellets, and another amount sniffing the chamber. All of these actions are seen as forming a chosen package that combines a quantity of lever-pressing, a period of leisure time, and eating so much food (Rachlin, Battalio, Kagel, & Green, 1981).

This unit of analysis – package of responses – demands equally diverse correlates in terms of the consequences that they produce. A package of responses can comprise various response topographies and functions, and produce different types of reinforcers, like food, water, leisure, etc. The package of *reinforcers* that derive from a package of responses is called in economic language as "commodity bundles". An example that can clarify this distinction is to think of a consumer going to the supermarket. The response package in that situation would include all choices that are made within the time that s/he spends in the supermarket: browsing, picking up products from the shelves, paying up etc. The groceries, clothing, cleaning products, etc. that this consumer left the supermarket with, would be the commodity bundle. Economists tend to adopt commodity bundles as their basic unit in the analysis of consuming behavior, while behavior analysts prefer to focus on the response packages emitted by consumers. Both types of units are acceptable, and can be found within the EBA literature.

The adoption of response packages is a strategy to incorporate the inseparable reinforcing and punishing functions (trade-offs) that happen over time in any contingency, and to produce more realistic approximations to the complex functional relations (values), that determine economically-relevant behaviors, inside or outside of the laboratory. It is not, however, a consensual practice among those who study economically-relevant behavior. Killen (1981) criticizes the use of response packages by calling it a “hypermetropic” view of the events that occur within experimental sessions. He argues that packages obscure the observation of processes that are operating in a molecular level of analysis, between single responses. Obviously, any dependent variable makes some aspects of behavior more salient, while obscuring others. There is no unit of analysis with zero downfalls. Both molar or molecular views, and basic units like single responses or packages, can be found in EBA researches and are consistent with this area’s fundamental principles.

Unit Prices and Choice Trade-offs

Another strategy to incorporate the understanding of choices/behavior as cost-benefit trade-offs is through the concept of unit price, originally proposed by Hursh (1980; 1984; Hursh, Raslear, Shurtleff, Bauman and Simmons, 1988). Unit price is a single metric that subsumes “cost” factors, typically defined in terms of response requirements, and “benefit” factors defined in terms of reinforcement magnitude (Foster & Hackenberg, 2004).

One example of unit price in a simple contingency, with a fixed ratio (FR), would be to divide this FR ratio by the magnitude of the reinforcer, like grams of food, number of pellets, volume of liquids etc (Hursh, 1980). For example, a FR 10 schedule producing 1 cc of water has a unit price of 10, the same as a FR 20 producing 2 cc or a FR 5 producing 0.5 cc.

The (As) Symmetry Debate

Every living organism has a long-standing history of gaining and loosing reinforcers. Despite being such common occurrences, the study of the behavioral processes involved in gains and losses presents recurrent challenges to behavioral scientists. Can gains and losses be separated and directly compared? Any quantitative choice model that expresses the effects of gains and losses, or reinforcement and punishment, with positive or negative mathematical signs has the implicit assumption that gains and losses can be measured using a single metric scale.

There are alternative models of choices that assume a different statement, that gains and losses are qualitatively different events and *cannot* be converted into mathematical signs or added up (Simon, 1955; 1956; 1990). The argument is that different consequences (either gains or losses) address different and incommensurable dimensions of value.

If the assumption of single-scaling of gains and losses is accepted, the next problem becomes: how much each of these events should add or subtract to the future probability of choices? There are competing answers to this question, expressed in the hypotheses of symmetry and asymmetry. The hypothesis of symmetry states that a single punisher subtracts an absolute value equivalent to the value that a single reinforcer adds; the alternative hypothesis of asymmetry states that the two types of events produce different impacts on behavior.

The (As)symmetry Debate in Behavioral Economics

On the side of economics, this debate is centered on contrasting the hypothesis of symmetry with a specific version of asymmetry, called loss aversion. It states that not only the two events – gains and losses – have different impacts on behavior, but more specifically that losses have *larger* impacts than gains of equal magnitude (Kahneman and Tversky, 1979; 1992; Thaler, 1981).

Kahneman and Tversky (1979; 1991; 1992) propose that loss aversion occurs because subjects can be more protective of their current state than they would be sensitive to the possibility of improving this state. This would happen because human choices are strictly dependent on the subject's *status quo*, that is, in her/his situation before any choice is made (Tversky & Kahneman, 1991). The *status quo* could refer to the subject's financial situation, health conditions, state of deprivation etc. As a result of this *status-quo* dependence, people would be reluctant to make choices that may result in losses, or would respond more intensely to the actual occurrence of losses, than they would respond to choices that may produce gains. Loss aversion is one of the tenets of a reference-dependent choice model called Prospect Theory (Kahneman & Tversky, 1979; 1992). There is a vast literature providing empirical support for the existence of loss aversion in humans, gathered in laboratory studies (Tversky and Kahneman, 1992; Thaler, Tversky, Kahneman, and Schwartz, 1997; Rabin, 2000), in the stock exchange market (Benartzi & Thaler, 1995; Haigh & List, 2005), corporate businesses (Fiegenbaum, 1990), among many other studies.

The (as) symmetry debate in Behavioral Analysis

Within behavioral analysis, the (as) symmetry debate assumed a different shape, revolving around other questions and arguments. Despite some points of contacts, this debate cannot be directly overlapped with the loss aversion discussion from other branches of behavioral economics. Historically, the analytic-behavioral debate involves the investigation of symmetric or asymmetric processes between reinforcement and punishment, which are broader processes than gains and losses. There last two would be described in this language as *positive* *reinforcement* and *negative punishment*, respectively, and encompass only two among the four basic behavioral processes of reinforcement and punishment. The other two, not directly covered by the loss aversion hypothesis, are negative reinforcement and positive punishment.

It is commonly assumed that behavior is jointly determined by reinforcement, which increases behavior frequency, and punishment, which decreases behavioral frequency, but exactly how the two combine to influence the future probability of responses is an open matter (Critchfield, Paletz, MacAleese, & Newland, 2003). Skinner's (1953) writings endorse the notion of asymmetry (Carvalho Neto & Mayer, 2011), when he questions the effectiveness of punishment and defends that reinforcement is the only behavioral process capable of generating, strengthening, and maintaining behavior. In other words, Skinner seems to lean towards an idea opposite to loss aversion, that reinforcement would produce more powerful effects than punishment. His arguments are criticized by Farley and Fantino (1978), and deVilliers (1978; 1980), among others, who favor the idea of symmetry. Farley and Fantino (1978) posit that "whatever the process that accounts for an increased probability of a response due to reinforcement is the same process, working in reverse, that results in a decreased probability of a response due to punishment" (pg. 37). In support of this statement, they report an experiment with a concurrent-chain procedure. In the initial link, pigeons chose between two response alternatives, each offering an identical but independent VI 1-min schedule. The reinforcement of each alternative was the initiation of the terminal link of the chain. Three events occurred in the terminal link: (1) there was a change in color of the pecked disk, (2) the other, non-pecked disk, became dark, and (3) a sequence of electric shocks and food presentations initiated, and was independent of additional pecks. This quantity of food and shocks was determined by the alternative chosen in the initial link. The quantities produced by each VI were systematically varied across several experimental phases, in search for “points of equivalence”, that is, of two bundles (combinations of food and shocks) that would result in a distribution of responses in the initial link of about 50-50% in each alternative. The rationale is that electric shocks, a supposedly aversive event, would reduce the positive/appetitive value of food, and thus can be measured in terms of “negative food units”. The mathematical manipulation of the results suggest that “the effects on choice behavior of positive and aversive stimuli appear to be equal, though opposite in sign” (Farley & Fantino, 1978, pg. 37).

De Villiers (1974; 1980) also concludes in favor of the hypothesis of symmetry after performing a series of experiments with pigeons and rats. In the experiment with rats, electric shocks were delivered response-independently, and could be cancelled by lever-presses under VI schedules. The author concludes that when shock-frequency reduction is taken as a measure of negative reinforcement, the relation between response rate and (negative) reinforcement frequency on VI avoidance schedules is comparable to those observed with comparable VIs reinforced by food deliveries. This study differs functionally from Farley and Fantino’s (1978) in that it compares the effects of negative punishment and positive reinforcement, while the latter uses an experimental arrangement that compares the effect of two (supposedly) aversive and appetitive events, commonly used in schedules of reinforcement and punishment.

In another experiment, deVilliers (1980) exposed pigeons to a concurrent VI schedule, reinforced with food, and an overlapped but independent concurrent punishment schedule that produced electric shocks. He observes that, with unequal frequencies of food but equal rates of punishment associated with the two keys and several intensities of shocks, the response and time allocation of all six pigeons were indicative of symmetric effects.

Critchfield, Paletz, MacAleese, and Newland (2003), investigated the interspecies generality of deVilliers' (1980) findings, by submitting human subjects to an adapted procedure with similar concurrent schedules. They exposed college students to a game in which they could earn money by clicking in one of two sides of a computer screen. The clicking response was first established by positive reinforcement under a concurrent VI (no-punishment baseline), and then a punishment was superimposed upon both response alternatives. In this punishment condition, the subjects could lose part of their previously-earned money under an independent VI schedule. Critchfield *et al.* (2003) are cautious in concluding whether reinforcers and punishers did have equal ou unequal impacts upon behavior. For two out of seven subjects, one punisher did appear to be more efficacious than one reinforcer. On the other hand, when the aggregate results are computed together, punishers seems to have *lower* functional value than reinforcers with nominally equal magnitudes.

Rasmussen and Newland (2008) used an adapted version of this procedure to directly test the hypothesis of symmetry, or as they state: "that one cent lost is equivalent to one cent gained". Different from the previous studies, which took a more general asymmetry as the alternative hypothesis, they tested the loss aversion hypothesis specifically. Also different from Critchfield *et al.*, who superimposed the punishment schedule on *both* response alternatives (the two sides of the computer screen), the VI punishment was superimposed on only one side of the screen, while the other side remained exclusively a positive VI schedule. The two sides were arranged so that the value of net reinforcers (reinforcers *minus* punishers) in the punished alternative was equal to the reinforcers from the non-punished alternative. The rationale is that if a punisher weights more than a reinforcer, then choice allocation should shift towards the unpunished option. Their results show that all participants demonstrated bias towards the unpunished alternative, leading to the conclusion that reinforcers and punishers were *not* symmetrical in that experimental situation. They conclude that "losing a penny is *three times* more punishing than earning that same penny is reinforcing" (p. 165, italics added). Interestingly, this quantitative result is in consonance with Tversky and Kahneman's (1992) estimation that losing money would produce an impact 2.25 times more intense than earning the same amount.

A significant contribution from the studies of Critchfield *et al.* (2003) and Rasmussen and Newland (2008) on the analytic-behavioral debate on (as)symmetries is to establish experimental procedures with humans that is supposedly comparable to previous works with nonhuman subjects. However, when interspecies generality is examined, the conclusions are contrastingly different. The studies with pigeons and rats from Farley and Fantino (1978) and deVilliers (1974; 1980) are favorable to the hypothesis of symmetry, while in the studies with humans - built in such way as to approximate the experimental conditions with nonhumans - the results are either inconclusive or favorable to the hypothesis of asymmetry/ loss aversion.

At face value, these discrepant findings suggest that reinforcement and punishment might be symmetric for rats and pigeons, but asymmetric for humans, who exhibit a tendency towards loss aversion. But these conclusions are premature, since the two types of experiments – with nonhumans and humans - are not directly comparable in at least two relevant aspects. First, both the Farley and Fantino (1978), and deVillier (1974; 1980) studies with nonhumans established *positive* punishments (the introduction of electric shocks as punisher), while the more recent experiments with humans established *negative* punishments, with the loss of previously earned money. So, albeit the two groups of studies are conceptualized to be directly comparable, they might not have established the same functional relations. Second, the experiments with nonhumans employed two different kinds of stimuli, food and electric shocks, while the experiments with humans employed a single stimulus – money.

A potentially fruitful way to reconcile these differences is to build an experiment with nonhuman subjects who gain and lose a single type of stimulus. Token economies, or token systems, is an experimental procedure with that critical advantage (Hackenberg, 2009). Tokens are an originally neutral stimulus like LEDs, plastic chips, or points, that acquire conditioned functions within an experimental chain. Token systems are an interconnected set of contingencies that specify the relations between token production, accumulation, and exchange (Hackenberg, 2009). They consist of a chained procedure with three links: initial, intermediary, and terminal. They can be earned in the early links of the chain, and exchanged for other reinforcers in the last – terminal – link. The initial link is the token-production schedule, when responses are reinforced with tokens. The intermediary link, also called the exchange-production schedule, establishes the conditions that must be met before exchange opportunities are made available, like the accumulation of a pre-determined number of tokens. The terminal link is the token exchange schedule, the schedule by which tokens are exchanged for other reinforcers (Hackenberg, 2009). There is a conceptual difficulty as to how to properly name the reinforcers that are exchanged for tokens. In studies with nonhumans, tokens can be exchanged for reinforcers called primary, which are usually essential to the subject's survival and immediately consumable, like food or water. Studies with humans that trade tokens for money or goods have a less clear characterization, with reinforcers being either primary or secondary. To avoid this conceptual confusion, reinforcers traded for tokens are simply named as terminal reinforcers (Hackenberg, in press).

Loss Aversion in Token Economies.

Tokens obviate the need for *post hoc* transformations of qualitatively different stimuli because their value is defined according to a common metric: units of the terminal reinforcer. This makes token economies a particularly fitting procedure to explore choice (a)symmetries between gains and losses, as they permit reinforcement and punishment with nonhuman subjects to be measured on the same scale (Hackenberg, 2009).

The validity of token studies is, however, directly dependent on our current knowledge about the functional characteristics of tokens. Tokens are conceptualized as conditioned reinforcers based on their correlation with other reinforcing stimuli for which they are exchanged (Bullock & Hackenberg, 2015; Kelleher, 1966). If tokens function as conditioned reinforcers, then in theory the loss of tokens should function as conditioned punishers (Hackenberg, 2009). But there are procedural issues to be addressed before the effects of token gains and losses with nonhumans can be properly compared to gains and losses of money or other conditioned reinforcers with humans. One problem is that humans carry a vast and previous history responsible for establishing money or points as effective conditioned reinforcers, and their loss as effective punishers. With nonhumans, however, the effectiveness of token losses as conditioned punishers depends on maintaining the effectiveness of tokens as conditioned reinforcers. The system in which tokens acquire and maintain their reinforcing effectiveness must be established and maintained within the experimental context (Pietras & Hackenberg, 2005).

Pietras and Hackenberg (2005) investigated whether token losses can acquire punishing functions in two experiments with pigeons. They first established a basic token economy, with three links. In the Initial link, the pigeons had to peck a key in order to produce tokens (illuminated LEDs). In the exchange-production link, superimposed on the initial link, they had to accumulate a number of tokens in order to initiate the terminal link with the opportunity to exchange the tokens. In the terminal link, they had to peck a different key in order to exchange the tokens for food. Each peck in the token-exchange schedule would produce a quantity of food and remove one of the previously accumulated tokens. This was the "standard phase" of the procedure.

Once performances stabilized, they imposed a multiple schedule in the initial link. This schedule continuously alternated between two components, a punishment and a no-punishment component, within the same session. The standard phase became the "no-punishment" component, and the punishment component differed in the two experiments. In Experiment 1, the punishment component was FR 10, meaning that every 10^{th} response extinguished one of the previously accumulated LEDs. The schedule of token removal was then decreased to FR 2, such that every second response resulted in token removal. So, in the no-punishment component, subjects could only earn tokens, and in the punishment component tokens could be earned and lost. Their rationale was to continually preserve the conditioned-reinforcing value of tokens in the no-punishment component, while observing if there was any response-suppressing effects of their removal during the punishment component (Pietras & Hackenberg, 2005).

A sequence of manipulations followed, with parts of this chain being systematically extinguished and reinstated over a large number of sessions. The results show that responding is suppressed in the punishment component, between 30-40%. But the authors suggest that this decrease in responding can also be attributed to the rate of food reinforcement being much lower in the punishment than in the no-punishment component (Pietras & Hackenberg, 2005). Experiment 2 aims to separate the token-removal suppressive effects from those of decreased rate of food delivery. This was done by yoking the density of food reinforcement in the punishment component to the one from the no-punishment component. The only difference was whether token losses were contingent on a response or not. If response-contingent token removal is responsible for response suppression, then response rates should be lower in the response-contingent component than in the other, non-contingent one. Their results suggest that the suppressive effect from token removal is partially independent from the accompanying decrease in the density of primary reinforcement. So token removal might share functional characteristics with punishment contingencies, similar to what was already demonstrated with other kinds of aversive stimuli (Pietras & Hackenberg, 2005). The observed differences, however, are too modest to warrant strong conclusions.

Raiff, Bullock and Hackenberg (2008) replicate the same experimental conditions and include a new phase in which reinforcement density is yoked across conditions, rather than across component within the same session. Like in the previous work, the baseline condition involves no loss, and the token-loss condition involves a conjoint schedule of punishment in one of the two components. In a third and novel condition – the yoked condition – one of the components involves either yoked food density (Part 1) or yoked token losses (Part 2).

In Part 1, there is a baseline (no-loss) condition for a number of sessions, then the token-loss condition imposes a conjoint FR 2 schedule of token loss in one of the components (like before), and then the yoked food condition begins. Now, tokens are produced and accumulated normally, but are exchanged for exactly the same number of food reinforcements that had been earned under the previous token-loss condition. In Part 2, the yoked-loss component removes tokens following the same rates as the prior token-loss condition, and these losses are not contingent on any response. The results show that, in the yoked-food condition (Part 1) response rates are reduced, but less than under the contingent token-loss. Because food reinforcement rates are equal, this difference can be attributed to the rate-suppressing effects of the token-loss contingency, apart from the reductions in the rate of food reinforcement. Response rates under the yoked token-loss conditions (Part 2) are affected little, if at all, by the non-contingent token loss. This allows a separation between the effect of contingent token losses and the effect of loss per se (non-contingent).

Together, the Pietras and Hackenberg (2005) and Raiff, Bullock, and Hackenberg (2008) studies support the conclusion that the observed response suppression in pigeons is due in large part to token losses, rather than to collateral changes in token or food reinforcement. These findings open a door to test whether the (asymmetric) results that Rasmussen and Newland (2008) found with humans working on a computer screen can be observed in a token system using nonhuman subjects.

Research Objectives

The general objective of the present study is to test the two hypotheses of symmetry and asymmetry, specifically in relation to positive reinforcement and negative punishment (gains and losses), by using rats and a token economy. The procedure has similarities with the Pietras and Hackenberg (2005), and Raiff, Bullock, and Hackenberg (2008) studies, in that it establishes a token economy in which the subjects can earn tokens and accumulate tokens (LEDs) in the initial and intermediary links, and exchange them in the terminal schedule. Also similar is the fact that there are conditions under which previously earned and accumulated tokens will be lost. Different from these studies are the facts that rats are used instead of pigeons, and that the initial (token-production) link of the chain does not present a multiple schedule with two components, but a concurrent schedule. In this respect, the present work resembles the Rasmussen and

Newland (2008) experiment: the initial link is a concurrent schedule between a purely positive reinforcement schedule, and a mixed schedule that alternate a positive reinforcement component and a negative punishment component.

To accomplish the general objective of contrasting the two (as)symmetry hypotheses, three intermediate objectives are established. The first is to verify **if rats can respond discriminatively as a function of earning and loosing tokens in the form of illuminated and extinguished small LEDs**, similar to what was observed with pigeons in the Pietras and Hackenberg (2005) and Raiff, Bullock, and Hackenberg (2008) studies. The relevance of this point is because there is a general suspicion of experimental psychologists that rats may not be sensitive to changes in small visual stimulus (Bachrach, 1965), and thus might be inadequate subjects for a procedure that uses LED illumination and removal as discriminative and conditioned stimulus (tokens).

If this first point can be verified, it will lead to the second objective, which is to verify **how do they allocate their responses in the initial link if the token-production (initial) link is a concurrent schedule, with one alternative being a positively-reinforcing FR, and the other being a mixed schedule of positive reinforcement and negative punishment.** The goal is to expand the findings from Rasmussen and Newland (2008), that humans show bias towards the unpunished alternative (suggestive of asymmetry), despite the fact that the two alternatives offer similar reinforcement rates. The present experiment will create an analogous condition with rats, in which the subjects can allocate responses between two simultaneously present schedules, one with a punishing component and another without this component.

The third experimental objective is to investigate **if the allocation of responses between these two alternatives vary as a function of unit price increases.** This introduces a difference between the present procedure and the one used by Rasmussen and Newland (2008). The original study establishes equal rates reinforcement in both schedules. More in line with a behavioral-economic notion of choices as trade-offs, the present experiment imposes the same *unit price* between the two response alternatives, meaning that both require the exact same number of *responses* to initiate the terminal link.

Similar to the Rasmussen and Newland's (2008) rationale, a consistent preference towards the purely positive-reinforcing FR schedule will be seen as indicative of loss aversion. In contrast, a consistent indifference between the schedules would be seen as indicative of a *lack* of loss aversion, and suggestive of symmetry. It should be clarified that, in the present context, preference is operationally defined in terms of the distribution of responses per trial, more specifically, as a greater number of responses in one schedule in relation to the other. This follows the definitions stated by Todorov & Hanna (2005) that "to choose" in a concurrent schedule is to respond in one alternative rather than the other, and "to prefer" is to either to respond more often or to spend more time in one alternative.

Another clarification is that the present study calls "a complete trial" or simply "a trial" every occasion in which the subject completes all three links of the behavioral chain. That means, fulfilling all response requirements to produce a token (initial link), accumulate six tokens in the panel (intermediary link), and exchange all accumulate tokens for the terminal reinforcer (terminal link).

Method

Subjects

Five male Spraguey Dawley rats, aged five months, served as subjects. They were housed in Reed College's animal colony with constant air renovation, controlled room temperature, and light-dark cycle of 12 hr. (7 a.m. – 7 p.m.). The animals were housed in pairs in transparent polycarbonate home cages measuring 10.5" L x 19" W x 8" H. After sessions, all subjects were put together in an exercise arena for 4 hrs. where they could exercise and socialize. This was a fenced area of 22 ft^2, enriched with several paper tubes, small pieces of soft wood for chewing and food pellets. After this period, they returned to their home cages (in pairs) and spent the rest of the day in the animal colony, where they received no food or liquids. So, food was freely available during eight hours per day, either in the experimental chamber (4 hrs.) or in the exercise arena (+4 hrs.). Access to fluids varied according to the experimental phase.

Equipment

Five extra tall Med Associates Modular Test Chamber[2] measuring 12" L x 9.5" W x 11.5" H served as the experimental spaces. Figure 1 shows an overview and details of the chambers. On the left wall, with equal distance from the center, there were two response wheels made of stainless steel[3] with an optical encoder that registers a response for every 90 degrees rotation. A clicker device[4] installed behind the wheels and out of reach to the subjects made a "click" feedback sound every time a spinning response was registered. In the center of the wall and between the wheels there was a panel with six colored LEDs (light-emitting diodes) arranged in

[2] For detailed specifications: http://www.med-associates.com/product/value-pak-extra-tall-modular-test-chamber/

[3] http://www.med-associates.com/product/response-wheel-for-rat/

[4] http://www.med-associates.com/product/response-feedback-clicker-module-for-rat/

two rows with three LEDs each. The LEDs in each row were sequenced green, yellow, and red. The LEDs were always presented from left to right and from the top row to the low row (upper-right picture of Figure 1). In the center of the opposite wall there was an equal panel of LEDs, placed on top of a stainless steel retractable lever, with adjustable tension set to 25 grams[5]. On the left side of that wall there was a 1.5 L x 1.5” H square hole, allowing access to a transparent 50 cc liquid receptacle located outside of the chamber (lower-left picture of Figure 1). Liquids reached this receptacle through a plastic tube connected to a 60 cc syringe installed in a pump device[6] that allows the manipulation of volume per reinforcement and makes a light sound with each release (lower lower-right picture of Figure 1). The chamber was housed within a ventilated shell (upper-left picture of Figure 1). The central light of the room was turned on and the doors of the external shells were kept partially open to allow for a mild diffused illumination in the chambers and preserve the animal’s circadian circle. Four food pellets were scattered on the floor of the chambers. Experimental contingencies were controlled by a MED-PC customized software on a PC-compatible computer located in an adjacent room.

[5] http://www.med-associates.com/product/retractable-lever/

[6] http://www.med-associates.com/product/single-speed-syringe-pump-standard-speed-3-33-rpm-other-options-from-0-008-to-20-rpm/

Figure 1: Overall view of the experimental chamber (upper left picture), front/left, back/right wheels, and wheel panel (upper right picture), retractable lever, lever panel, and liquid receptacle (lower left picture) and syringe pump (lower right).

Procedure

There were 102 experimental sessions that lasted 6 months. They were conducted daily - Monday to Monday - from 12 p.m. to 4 p.m.

Pre-experimental preparations

Prior to the experimental phases, each subject had his free fluid intake measured for 22 days. For this, they were housed individually in the home cages, with *ad lib.* food and a bottle with water. For 5 days their 24-hr intake was measured. Then, the water bottle was replaced by a bottle with a 10% sucrose solution, which remained as the only fluid available for 2 days, to assure that all animals experienced this other fluid (forced intake). Then, for 15 days, two bottles were placed in the cage, one containing water and the other the sucrose solution, and their average intake was measured. Subjects were then housed in pairs for a week with *ad lib.* food and water (no sucrose solution).

Experimental Phases

For the lever-press (LP) training the wheels were not installed in the chamber. The subjects were deprived of water for 24hr and placed in the experimental chamber with all six LEDs illuminated on the lever panel. Small releases of the sucrose solution were used to reinforce successive approximations to the fluid receptacle, then to the lever, and the response of pressing the lever. After LP responses were shaped, they were maintained under FR 1 and reinforced by 0.2 cc of sucrose until the end of the 2-hr session. Afterwards, the subjects were put back in their home cages, where they had free access to food and water, but no sucrose solution. Eight additional sessions ensured the maintenance of this new response.

LED Discriminative training

The discriminative training was composed of 3 parts: panel training, 3-LED, and 2-LED discrimination. For the panel training, the computer program automatically turned the lever panel on and off for one minute. The distribution of “on” and “off” minutes was random, with no more than three consecutive minutes under the same condition. When the panel was on (SD) lever-pressing was reinforced under FR 1. There was no maximum limit to the number of reinforcements that the subject could get during this period. When the panel was off (SΔ) lever-pressing had no programmed consequences (extinction). This condition was kept until at least 80% of lever presses occurred with the SD period, for three consecutive sessions.

For the 3-LED discrimination, the panel would still turn on and off randomly for one minute, but now lever-pressing during the SD period had two consequences: the release of 0.2 cc of sucrose and the removal (extinguishment) of three LEDs. Another lever-press would produce the same consequences, which would turn the lever panel completely off and initiate the SΔ period until the minute was over. So, for each SD minute, subjects could get a maximum of two reinforcements. Once again, this condition lasted until they were issuing at least 80% of lever-presses during the SD period.

The 2-LED discrimination was similar to the 3-LED, except that LP in the SD period would now turn off two LEDs in the panel. So, for every SD minute, subjects could get a maximum of three reinforcements.

Wheel Spin (WS) training

To shape the wheel-spinning response, one wheel was installed in the chamber in the same position where the retractable lever was. Turning this wheel in 90 degrees was reinforced under FR 1 with 0.2 cc of sucrose. On the next day, the wheel was installed in the wall opposite to the liquid receptacle. Now, the subjects had to turn the wheel and then cross the chamber to consume the reinforcer.

Chain Shaping

From this point on, the chamber was configured as described in the equipment section. That is, the retractable lever was installed back in the chamber, next to the liquid receptacle and the lever panel; the two response wheels and the clicker device were installed in the opposite wall of the chamber, with equal distance to the wheel panel.

Shaping of the initial link. The first session of this phase started with both the lever and wheel panels turned off. One wheel-spinning response (90 degree turn) in any of the wheels made a “click” feedback sound and made the wheel panel blink twice and turn off. Then, the lever panel in the opposite wall turned on, signaling that additional wheel-spinning had no programmed consequences (extinction). One lever-press would release the reinforcer and turn off the lever panel, signaling that now lever-presses had no programmed consequences (extinction) and spinning any wheel would be reinforced again.

Insertion of the Intermediary link. The intermediary link imposes additional conditions to produce the *opportunity to exchange* tokens for sucrose in the terminal link. This new requirement was that six tokens must be accumulated on the wheel panel.

So, on the first session under this new condition, one wheel-spin illuminated only three, instead of six LEDs in the wheel panel. Now, the subject had to emit another wheel-spin and accumulate three more LEDs before the wheel panel would blink and the LEDs could be exchanged for the sucrose solution. On the second session, one wheel-spin illuminated only two LEDs. The other experimental conditions remained unchanged.

Terminal link adjustment. On the third session, another adjustment was made, this time on the token-exchange requirement. Until now, one lever-press released the reinforcer and turned off six LEDs. Now, one lever-press turned off only two LEDs, so the subject could obtain three reinforcements until the lever panel was completely turned off, and he had to return to the wheels to illuminate more LEDs.

Table 1 describes the complete chained response that the subjects were trained to perform at this point.

Table 1: Basic chain description

Schedule	Chain Link	Response	Consequences
Token Production	Initial	1 WS	click feedback + 2 LED_w
Token Accumulation	Intermediary	+2 WS	+ 2 click feedback + 4 LED_w W panel blinks 2x & turns off +6 LED_L
		(Rat crosses the chamber)	
Token Exchange	Terminal	1 LP	1 reinforcement; (-2) LED_L;
		+2LP	+2 reinforcements; (-4) LED_L

Legend:
WS = wheel-spin; LP = lever-press; LED_w = LEDs from the wheel panel; LED_L = LEDs from the lever panel

Unit Price Increase

The primary independent variable of this study is unit price, that is, the number of responses required on the initial link in order to produce 1 cc of sucrose in the terminal link. Since the (intermediary) token accumulation and (terminal) token exchange schedules were unchanged, unit price manipulation always happened in the (initial) token-production link, with a variation on the number of responses required to initiate the terminal link. Across several sessions, the token-production schedule was gradually increased, and so was the unit price. For the five initial sessions, the subjects were kept in the same condition as the last experimental phase: Conc (FR 1 FR 1). This means that one wheel-spin in any wheel delivered two tokens, three wheel-spins would accumulate six tokens in the wheel panel and complete the intermediary link requirement, and these six accumulated tokens could be exchanged for a total of 0.6 cc of sucrose in the terminal link. So, at this point, the unit price of 1 cc of sucrose was 5 (3 WS / 0.6

cc). Then, the number wheel-spins required in both wheels was raised every five days, first to Conc (FR 3 FR 3) resulting in a unit price of 15 (9 WS/ 0.6 cc), then to Conc (FR8 FR8) with unit price of 40, to Conc (FR10 FR10) with unit price of 50, and to Conc (FR 14 FR 14) with unit price of 70.

Unit Price Increase under Concurrent Schedules

From this point on, one of the wheel always offered FR: +2 and the other always offered Mix: +3; -2. The first notation, FR: +2, means that a certain number of responses on the FR schedule illuminated two LEDs in a panel (thus the notation "+2"). The second notation, Mix: +3; -2, describes a mixed schedule with two alternating components. The first component was a positively reinforced FR: +3, meaning that certain number of responses in this schedule illuminated three LEDs, and initiated the next component of negative punishment, FR: -2. Now the same number of responses extinguished two of the previously illuminated LEDs (so one LED remained on) and re-initiated the positive FR: +3 component. Once again, responses would illuminate three LEDs (so there would be four LEDs in the panel), and re-initiate the FR: -2 component, and so on.

Conc (FR 14 Mix 6). For 10 sessions, the left wheel offered FR 14: +2 (fourteen wheel-spins were required to illuminate two LEDs) and the right wheel offered Mix 6: +3; -2 (six wheel-spins were required to illuminate three LEDs, then the next six wheel-spins would turn off two LEDs, then the next six wheel spins would turn on three more LEDs, and so on).

Similar to the final condition of the previous phase, exclusive responding in any schedule resulted in a unit price of 70. There was no programmed punishment for switching between the FR: +2 and Mix: +3; -2 schedules, so, alternatively, subjects could switch between wheels within the same trial and generate non-exclusive response packages. Some non-exclusive packages would result in less wheel-spins (lower unit prices) per trial, and some would result in more (higher unit prices). Under these unit prices ranged from 53 to 102.

Conc (Mix 6 FR 14). For the next 10 sessions, schedules were reversed: the left wheel offered Mix 6: +3; -2 and the right wheel offered FR 14: +2. The unit price range was the same.

Conc (FR 21 Mix 9). For the next 10 sessions the token production schedule was raised to Conc (FR 21 Mix 9), meaning that the left wheel offered FR 21: +2 and the right wheel offered Mix 9: +3; -2. In this condition, unit price ranged from 80 to 155, with unit price for exclusive responding of 105.

Conc (Mix 9 FR 21). Ten more sessions happened with reversed schedules.

Conc (FR 28 Mix 12). For eight sessions, token production was raised again. Now the left wheel offered FR 28: +2 and the right wheel offered Mix 12: +3; -2. Unit price ranged from 107 to 197, with unit price for exclusive responding of 140.

Conc (Mix 12 FR 28). For the last eight sessions, the schedules were reversed.

Table 2 summarizes the ranges of unit prices that were established in each condition.

Table 2: Unit price ranges (independent variable) per experimental phase

Condition	Unit Price Range (# wheel-spins per 1 cc of sucrose)
Conc (FR 14 Mix 6) & Conc (Mix 6 FR 14)	53 - 102 exclusive responding: 70
Conc (FR 21 Mix 9) & Conc (Mix 9 FR 21)	80 - 155 exclusive responding: 105
Conc (FR 28 Mix 12) & Conc (Mix 12 FR 28)	113 - 197 exclusive responding: 140

Results

Side preferences or biases are a common feature in concurrent choice experiments, especially with rats (Kagel, Battalio, & Green, 1995). They can influence package selection in two ways. First, it increases the probability of exclusive packages happening on the preferred side, regardless of which schedule is in place. Second, it might increase the formation of "inefficient" packages, that is, packages that required more wheel-spins than exclusive responding to complete a trial. This happens if the subject emits what will be called "lost" wheel-spins, that is, when the subject wheel-spins in one wheel but switches to the other side before completing the requirement for reinforcement. Side biases might increase the probability of "lost" wheel-spins on the preferred side.

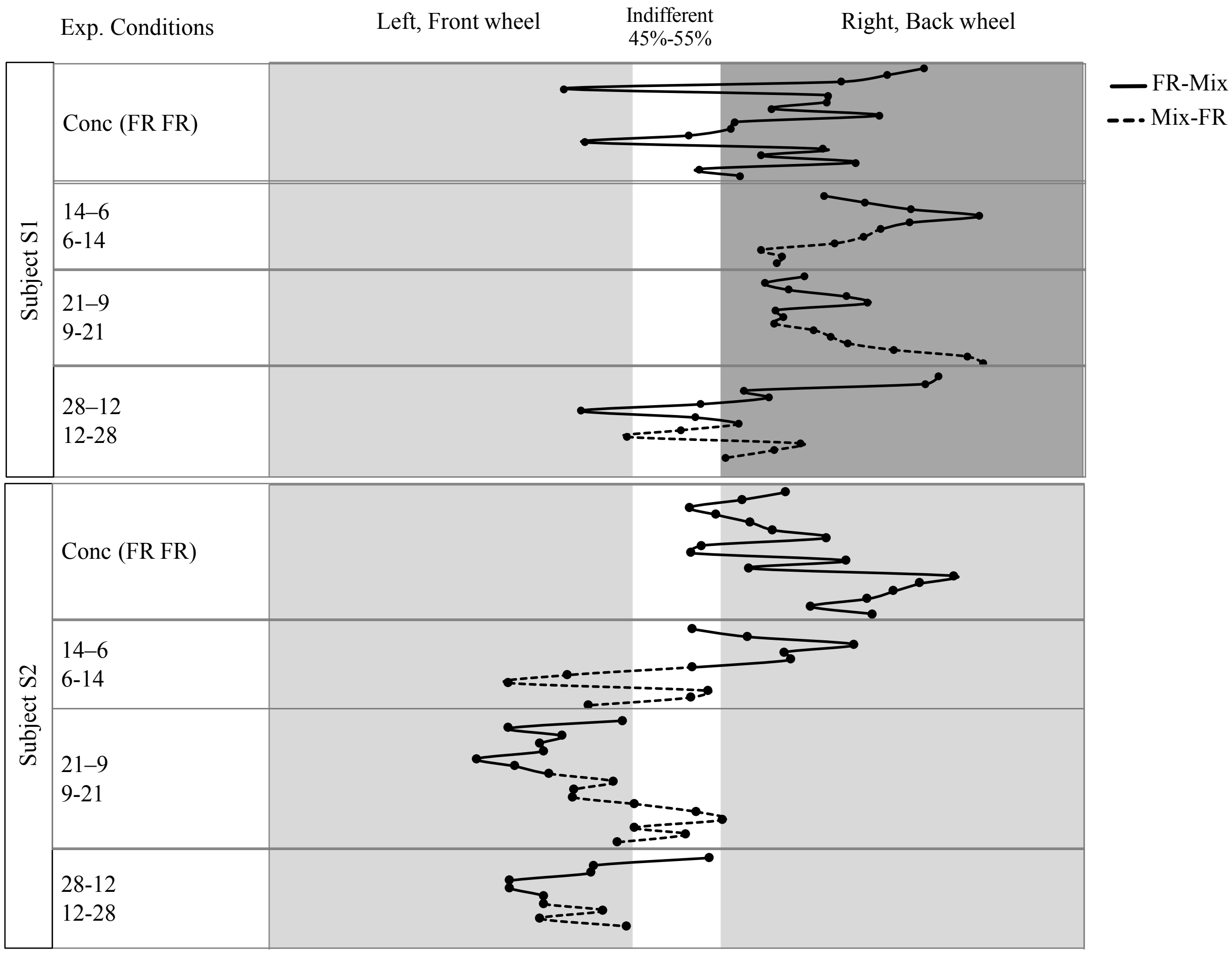
Side biases can be discerned by comparing response distributions on the Conc (FR-Mix) and on the reversed Conc (Mix-FR) conditions. Both conditions offer the same unit price range, but the schedules appear in different wheels. If a subject has no side bias, the reversal of sides should produce a reversal in the proportion of responses allocated to each wheel. Figure 2 shows that all five subjects displayed side biases, in weaker or stronger intensities. Subject names and experimental phases are listed on the left side of the figure. For short, the general notations Conc (FR Mix) and Conc (Mix FR) are marked as FR-Mix and Mix-FR, respectively, and their specific conditions are represented only by their ratios. For instance, the condition Conc (FR 14 Mix 6) is represented simply as 14-6, the condition Conc (Mix 6 FR 14) is represented as 6-14.

Each session is identified in Figure 2 by a black circle. Sessions connected by straight lines are FR-Mix, and those connected by dotted lines are Mix-FR. The notation Conc (FR FR) refers to the Unit Price Increase Phase that happened before Phase 14-6. That was the phase when both wheels offered the same FR, and the ratio was raised every 5 sessions. It was included in the analysis to examine the possibility that side biases were established there (see Discussion).

One way to look at these figures is as if they were a sketch of an experimental chamber seen from above. The grey columns are the left and right wheels. Black circles on these left or right gray areas mean that the subject allocated between 55% and 100% of responses on that side. The closer the black circles are to the outer border, the stronger the preference for that side. A black circle located in the outer border to the left or right would mean that the subject spent that whole session working exclusively on the wheel located on that side. A black circle in the white, centered, indifference area means that the subject allocated between 45% and 55% of his responses in one wheel, suggesting that he was indifferent between sides/ schedules during that session. The darker shade of gray marks the preferred side from subjects with strong side biases.

For subject S1, the majority of sessions in the Con (FR FR) phase appear in the right side, although there were a few sessions with indifference or slight preferences for the left. All session in Phases 14-6, 6-14, and 21-9 are on the right side, as well as the majority of sessions in Phases 28-12 and 12-18. Subject S3's preference for the right side is evident in all phases, with only two sessions located in the indifference area, during the Conc (FR FR) phase. S4 alternated between indifference and preference to the left side during phases Conc (FR FR), and the initial sessions of Phase 14-6. Then, he shows a consistent preference for the left until the end of the experiment.

Subjects S2 and S5 are considered as showing weak biases, because they both chose different sides under different experimental phases. S2 showed preference to the right side in phases Conc (FR FR) and 14-6, with a few indifferent sessions, and preference to the left side on Phases 21-9, 9-12, 28-12, and 12-28. S5 varied between the right and left sides in the Conc (FR FR) and 14-6 phases, and then preferred the left side during Phases 21-9, 9-21, 28-12, and 12-28.


Exp. Conditions
Left, Front wheel
Indifferent
45%-55%
Right, Back wheel
FR-Mix
Mix-FR
Subject S1
Conc (FR FR)
14–6
6-14
21–9
9-21
28–12
12-28
Subject S2
Conc (FR FR)
14–6
6-14
21–9
9-21
28-12
12-28

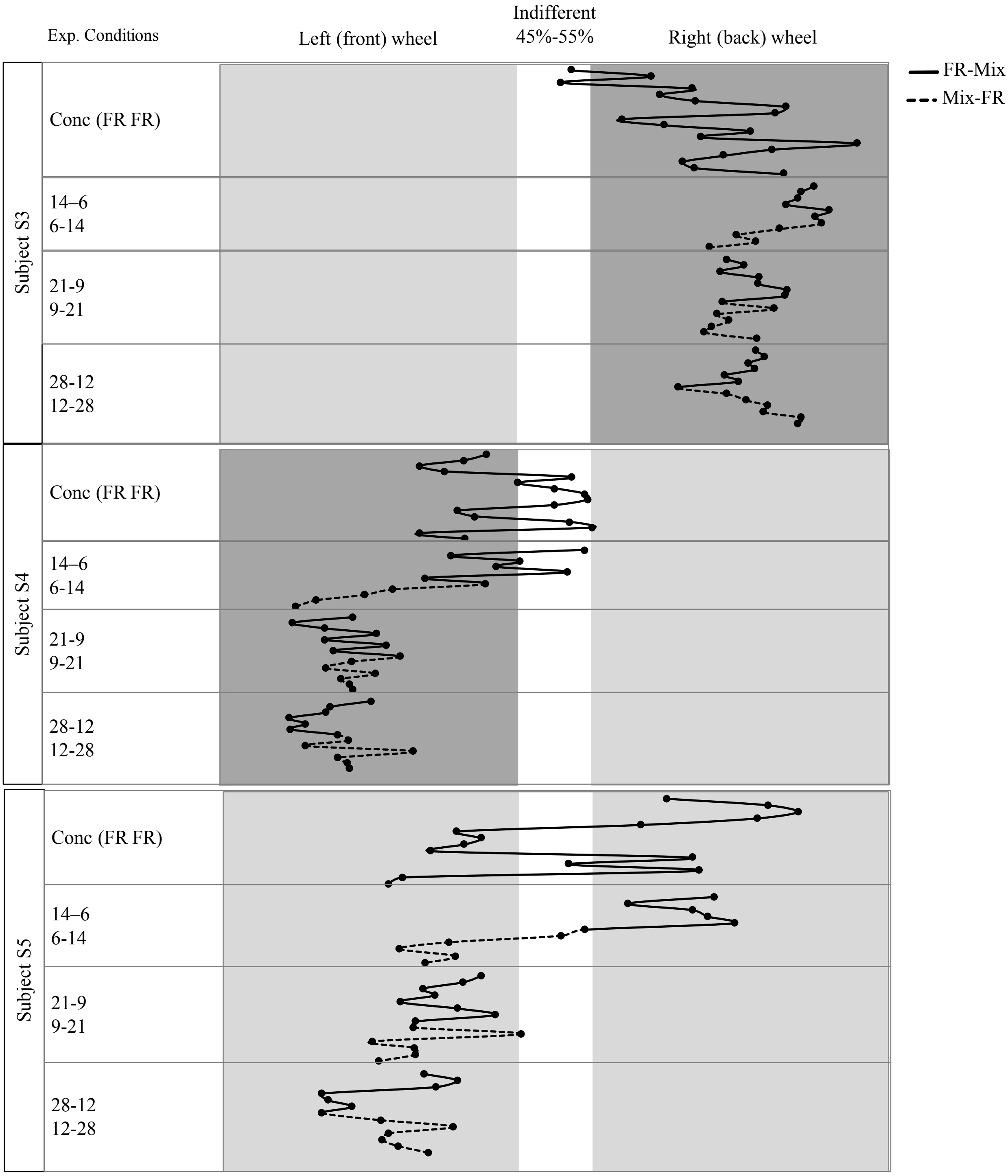


Figure 2: Overall percentage of responses in the left and right wheels. Subject names and experimental phases are in the left-side columns. Black circles are individual sessions. Straight lines interconnect FR-Mix sessions, dotted lines interconnect Mix-FR sessions. Circles located in the white middle area are sessions with response allocation between 45% and 55% on one side (indifference). Circles in the gray areas are sessions when more than 55% of responses happened on that side. Darker gray shades mark the preferred sides of subjects with strong bias.

Figure 3 shows the discriminative indexes (responses emitted in the reinforcing periods, divided by total responses) for wheel-spinning (black circles & line) and lever-pressing (gray horizontal bars & line), and the total number of completed trials per session (gray vertical columns on the secondary vertical axis). The dotted line on the x-axis marks 80% of responses during the period in which these responses were reinforced. All subjects showed discriminative responding for the wheel-spinning response, with most of their responses located above the 80% line. Lever-pressing indexes vary per subject. Subjects S1 and S4 show lever-pressing percentages consistently above 80%. Subjects S2 and S5 show percentages below this line, but stable around 75%. Subject S3 had a decaying discriminative index for the lever-pressing response, as unit price ranges increased along the experiment. An informal observation during the experiment might help understand these trends. During trials, and especially on the highest unit price ranges, the subjects recurrently paused mid-trial (i.e. after initiating a trial and before reaching the terminal link), and did activities like: looking and sniffing the illuminated LEDs on the wheel panel, crossing the chamber, pressing the lever and immediately "checking" (more precisely, nose-poking and sniffing) the liquid receptacle, even though no "free" liquid was ever released. These topographies were filmed in various occasions. One effect of these mid-trial "extra" activities was a decrease in the lever-pressing discriminative indexes, due to non-reinforced lever-presses being issued during the initial and intermediary links. This happened with three out of five subjects across all phases, and became more recurrent for subject S3 in the last phase, despite the fact that they never produced any extra sucrose.

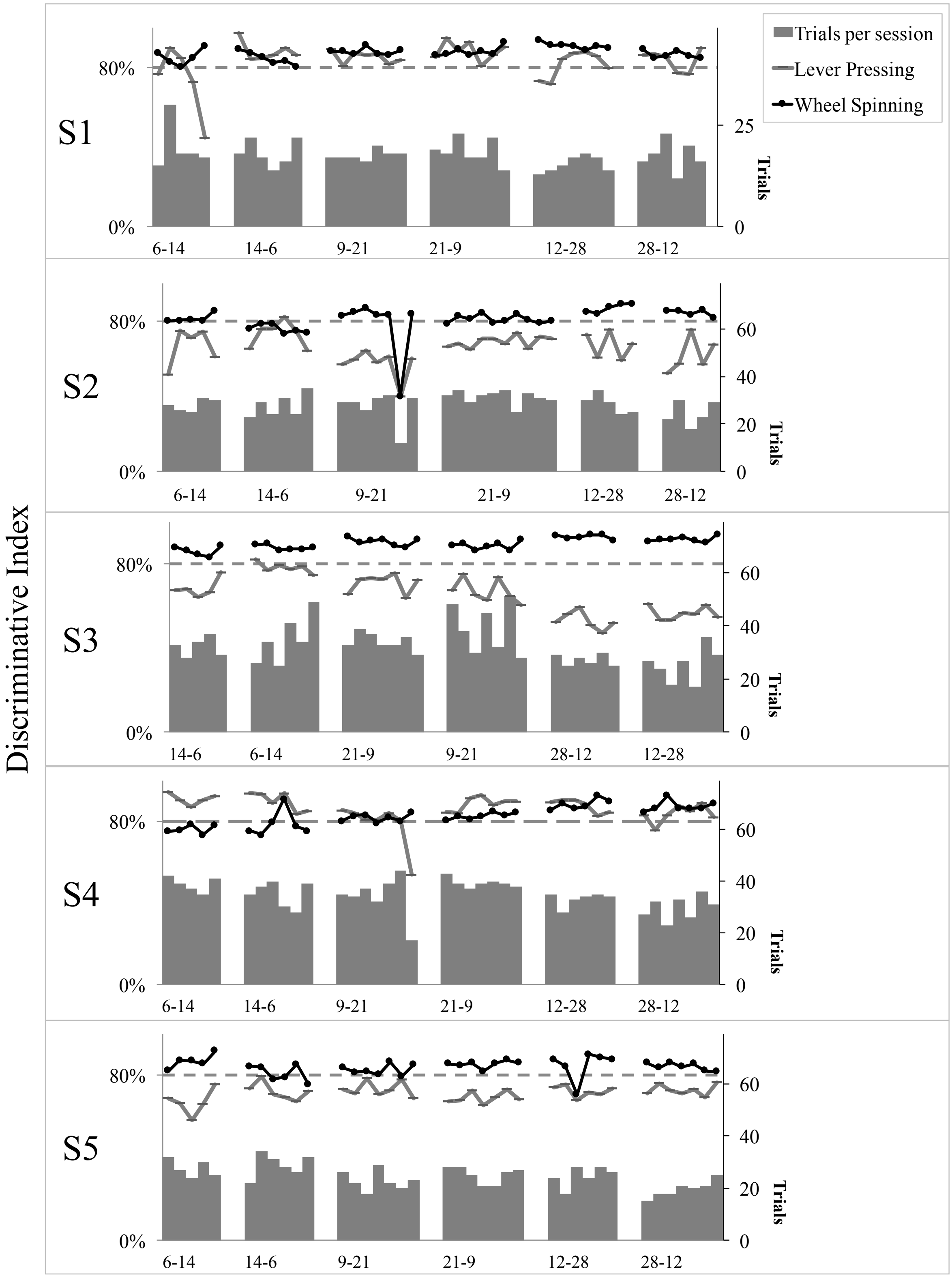


Figure 3: Discriminative indexes for wheel-spins (black circles) and lever-presses (gray bars) per experimental condition, plus the number of completed trials per session (gray columns, in the secondary right-side axis).

In the present procedure, the intermediary and terminal links were held constant across all experimental conditions, so all completed trials produced the same volume of 0.6 cc of the sucrose solution. The only flexibility provided in this chain was in the initial link, on the token-production schedule. Whenever the subject worked exclusively on one wheel, a fixed number of wheel-spins would complete the LED panel and initiate the terminal link. This would form a package with *exclusive* responses, without any mid-trial switching. Exclusive packages would result in unit prices of 70, 105, and 140 wheel-spins per 1 cc of the sucrose solution in each experimental phase, respectively. If the subject responded exclusively on the mixed schedule, the alternation of reinforcing and punishing components would impose seven components of positive reinforcement (token gains) and six components of negative punishment (token removals) before the trial was completed. This means that all tokens that were removed during these alternations would be recovered before the terminal link initiated, and that the final package - the one that completed the trial - would have no permanent token loss.

Alternatively, subjects could switch between wheels at any time and form *non-exclusive* packages, with assorted proportions of responses in the mixed and FR schedules. If this switching occurred *after* the punishing component of the mixed schedule ended, then the response package would end with a permanent token loss, and the resulting unit price for that trial would be higher than if he had responded exclusively on one schedule. If the subject switched from the mixed to the FR schedule *before* the punishing component ended, then he would have earned greater number of tokens in the mixed schedule (+3 LEDs instead of +2 produced on the FR schedule) with fewer responses. In this case, the final package would have a unit price lower than exclusive responding. Figure 4 compares the number of exclusive and non-exclusive packages that were selected by each subject along the experiment. In the first phase (conditions 14-6 and 6-14), the subjects were forming about the same number of exclusive and non-exclusive packages, but starting in phase 21-9 there is a tendency for all subjects to increase the selection of non-exclusive packages and decrease exclusive packages. This tendency was more pronounced with subjects S1, S2, and S5. Subject S3 consistently formed more non-exclusive packages in most sessions, but chose about the same number of both categories in the last three sessions of condition 12-28. Subject S4 formed more exclusive packages during conditions 21-9 and 9-21, but reversed this tendency in the last two conditions of the experiment.

Table 3 shows the percentage of packages chosen by each subject that resulted in unit prices equal or below exclusive packages, per experimental phase. Except for subject S2 in phases 14-6 & 6-14, and 21-9 & 9-21, and subject S5 in phases 14-6 & 6-14, and 28-12 & 12-28, all others consistently "paid" unit prices equal or below exclusive packages in about 50% of trials. The experimental phase that resulted in the lowest unit prices being "paid" is the one that offered the intermediary unit price range, that is 21-9 and 9-21, with an average percentage of packages with lower unit prices of 60%.

Table 3: Percentage of response packages with unit prices equal or below exclusive responding selected per experimental phase by each subject.

Subject / Phase	14-6 and 6-14	21-9 and 9-21	28-12 and 12-28
S1	58 %	60 %	53 %
S2	34	49	54
S3	65	63	58
S4	54	66	62
S5	44	61	40
Phase averages	*51 %*	*60 %*	*53 %*

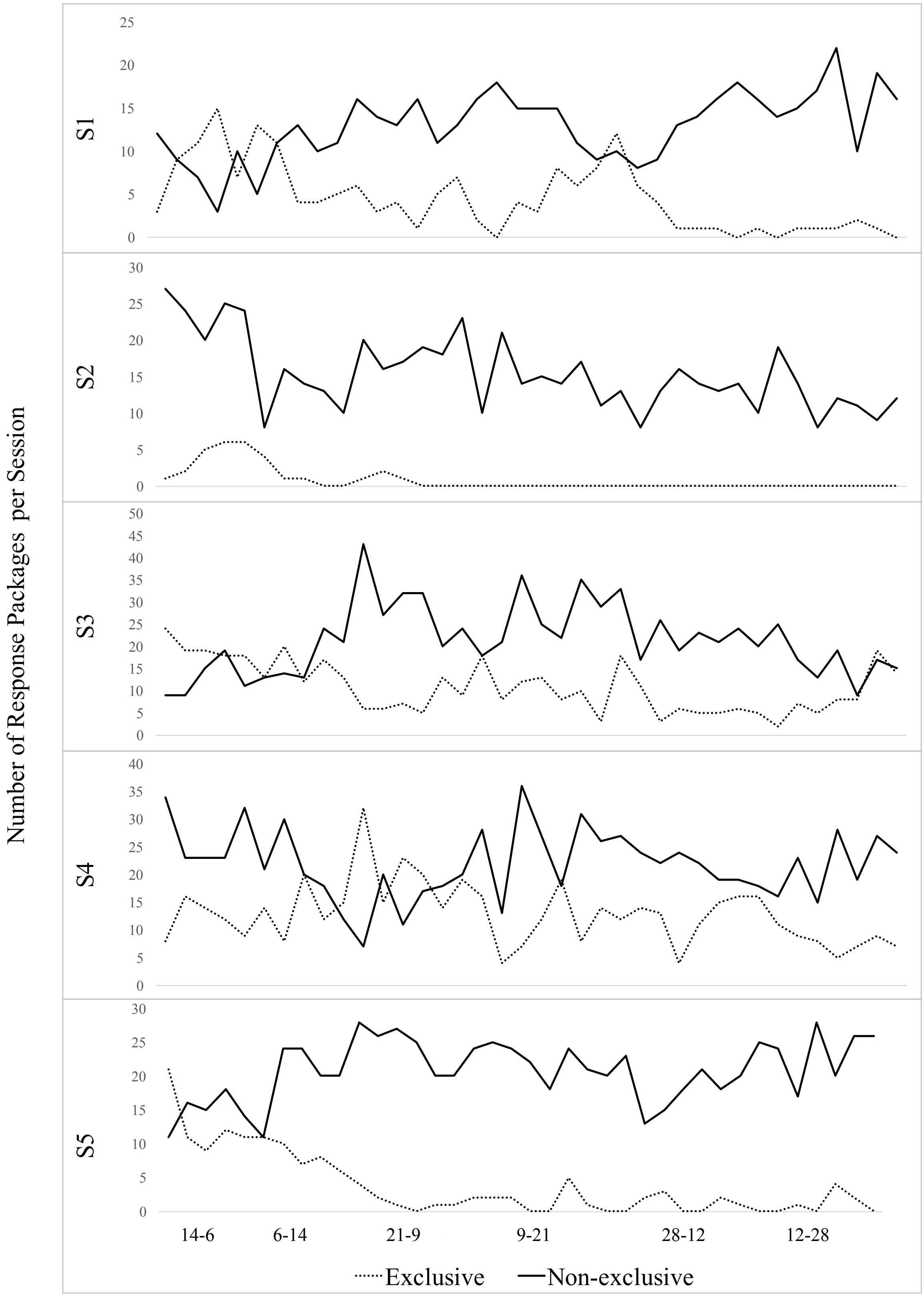
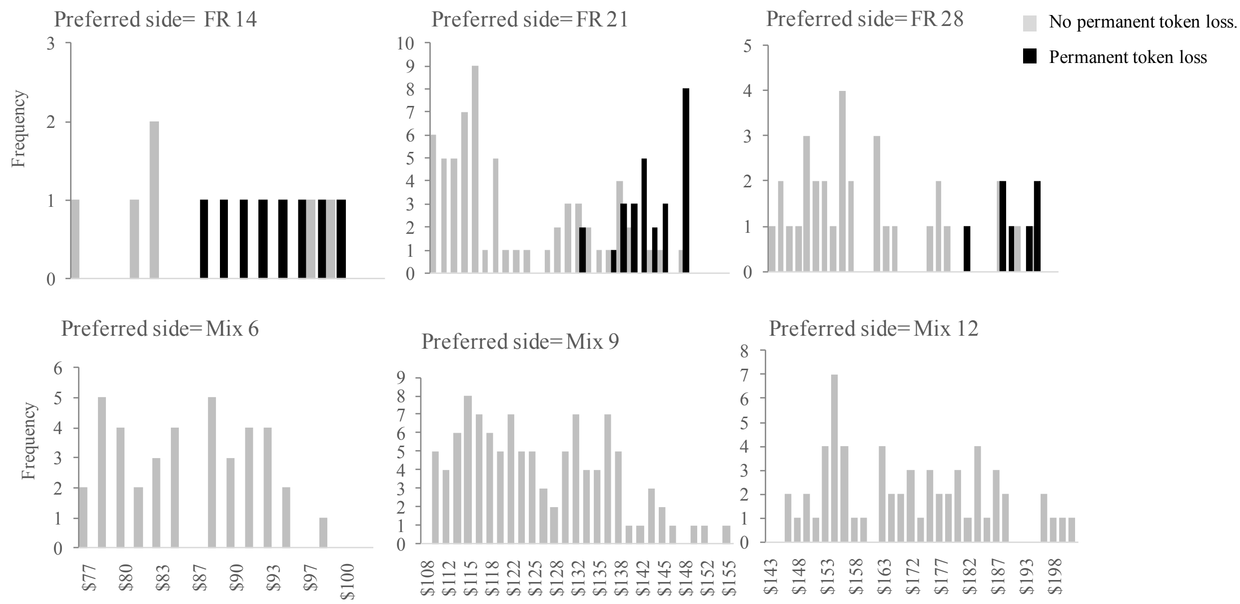


Figure 4: number of exclusive and non-exclusive packages selected across the experimental conditions.

Figures 5 and 6 show the number of packages that were formed with unit prices higher than exclusive responding, and the schedule that was operating on the subject´s preferred side. Figure 5 shows non-exclusive packages formed by the three subjects with strong side bias, S1, S3, and S4. The gray columns represent packages that ended *without* permanent token losses, and the black columns represent packages that ended *with* permanent token losses. The final unit price "paid" appears in the abscissas. Packages that ended with permanent token losses appear frequently whenever the preferred side offered the FR schedule, and are practically non-existent when the preferred wheel offered the mixed schedule. Subject S1 "paid" various high unit prices while completing trials with token losses when the preferred (right) side offered either FR 14, FR 21 or FR 28, but chose only one package that ended with token losses when the preferred side offered Mix 6, and zero thereafter. In contrast, this subject formed packages that ended without token losses abundantly when the preferred wheel offered the mixed schedule. These tendencies were even more extreme with subjects S3 and S4. When the preferred side offered FR 14, FR 21, or FR 28, these two subjects not only showed frequent selections of packages with token losses, but also these packages are situated in the higher unit price ranges. When the preferred side offered Mix 6, Mix 9 or Mix 12, there are no packages that ended with token losses, and the packages are concentrated in unit price ranges closer to exclusive packages.

S2 – Weak preference for Left (almost no preference)



S5 – Weak preference for Left (almost no preference)

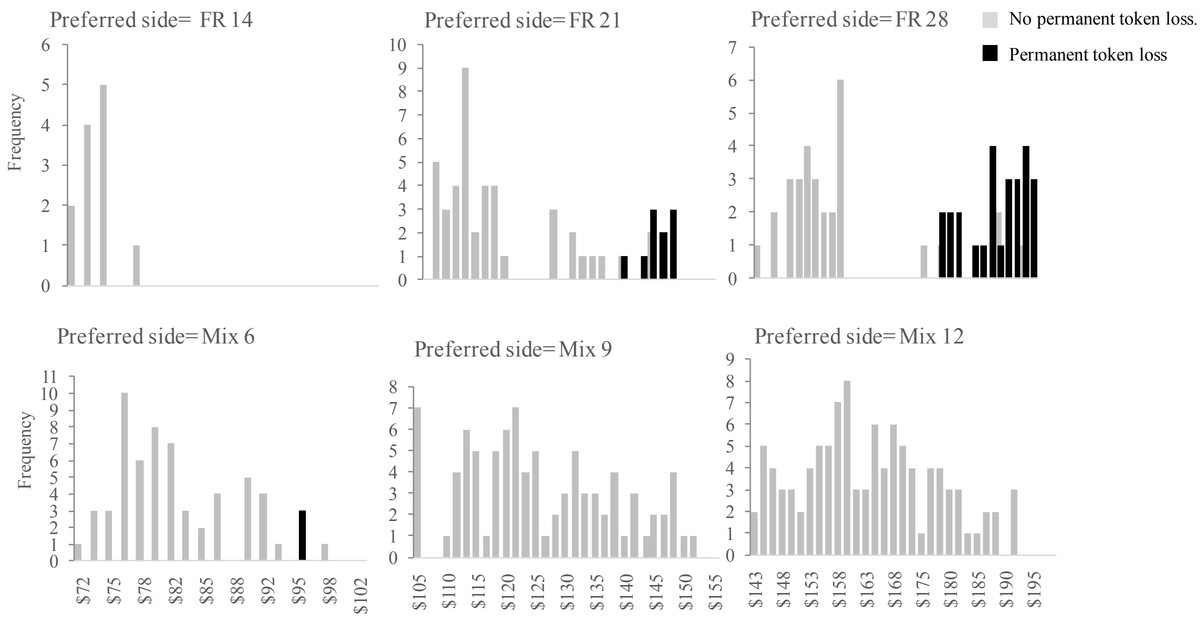
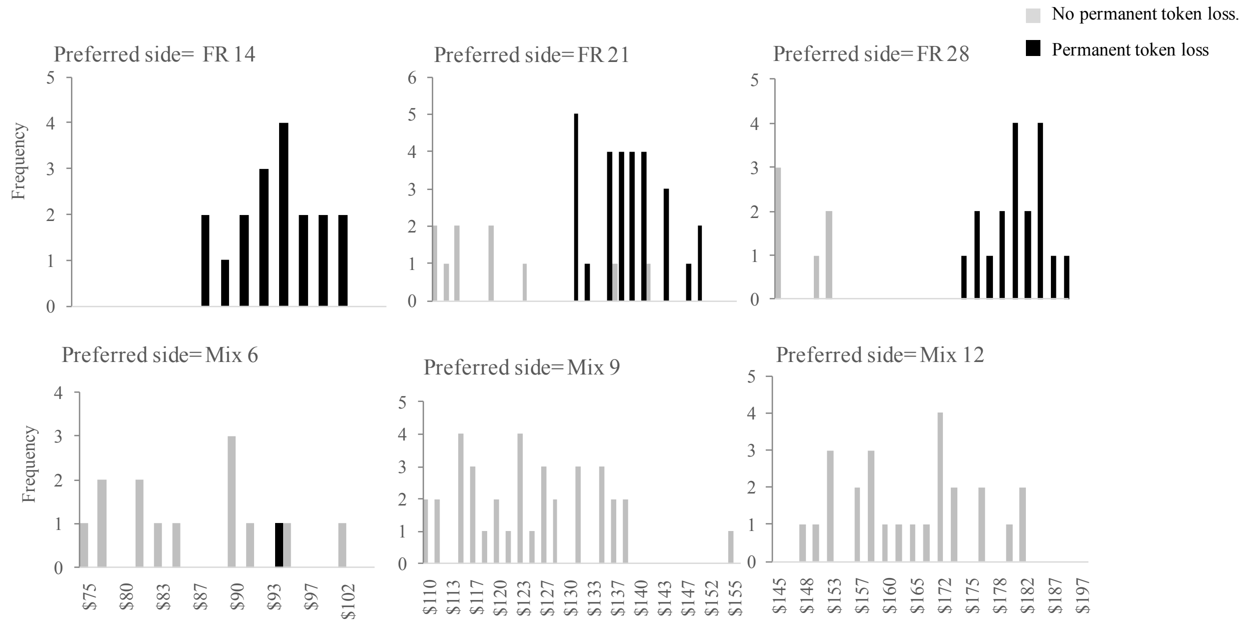
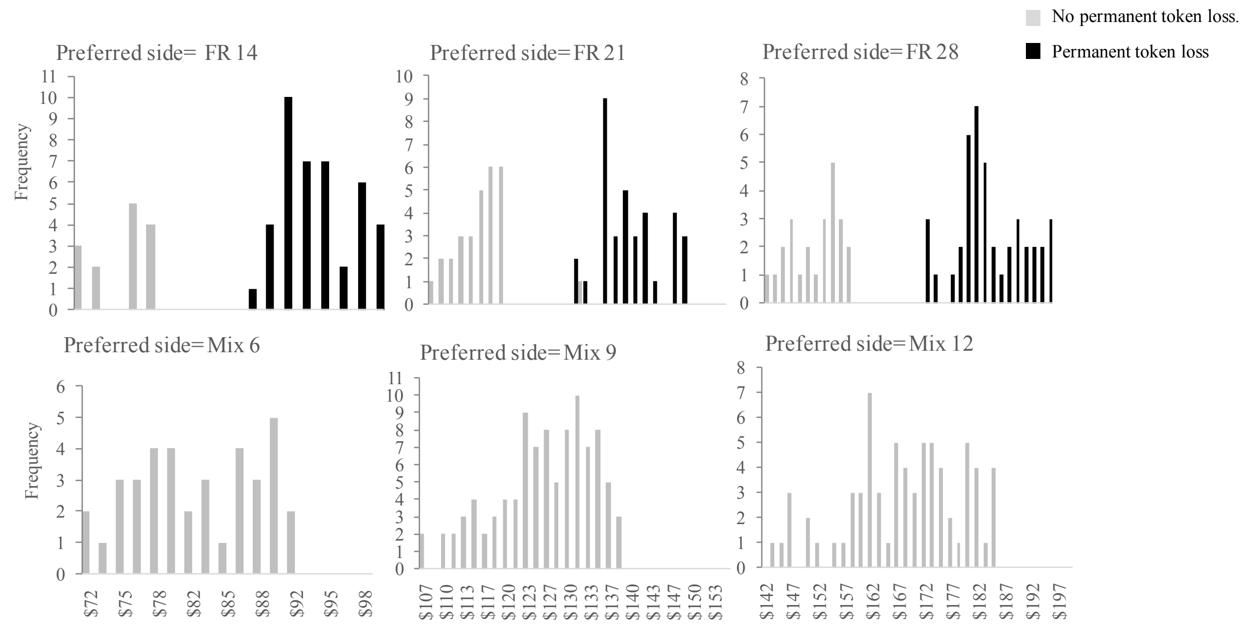


Figure 6 shows the same information for the two subjects with weak side bias, S2 and S5. It shows the same tendencies: almost no packages that ended with token losses when the (weakly) preferred side offered the mixed schedule. In simple words, whenever the wheel in the preferred side offered the mixed schedule, they worked more efficiently and did not switch from the mixed to FR schedule until the tokens that were previously removed were recovered. When the preferred side offered FR, they worked more and worst, forming many packages that ended with token permanent losses.

S1 – Strong preference for Right



S3 – Strong preference for Right



S4 – Strong preference for Left

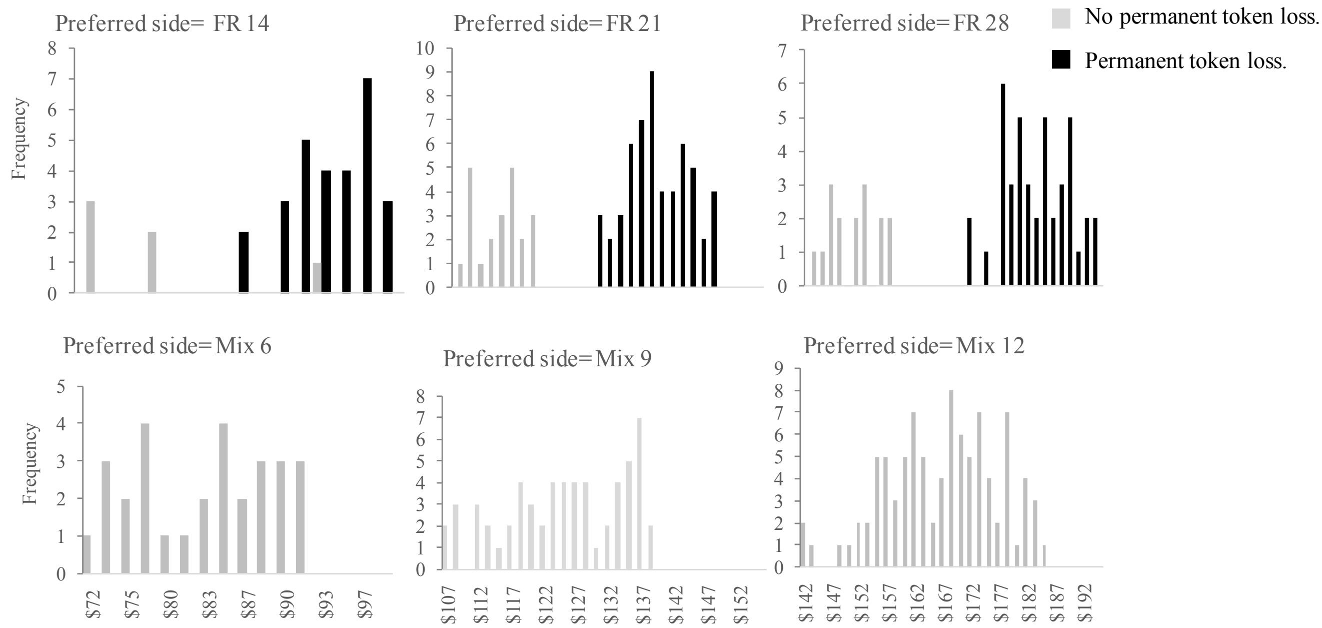
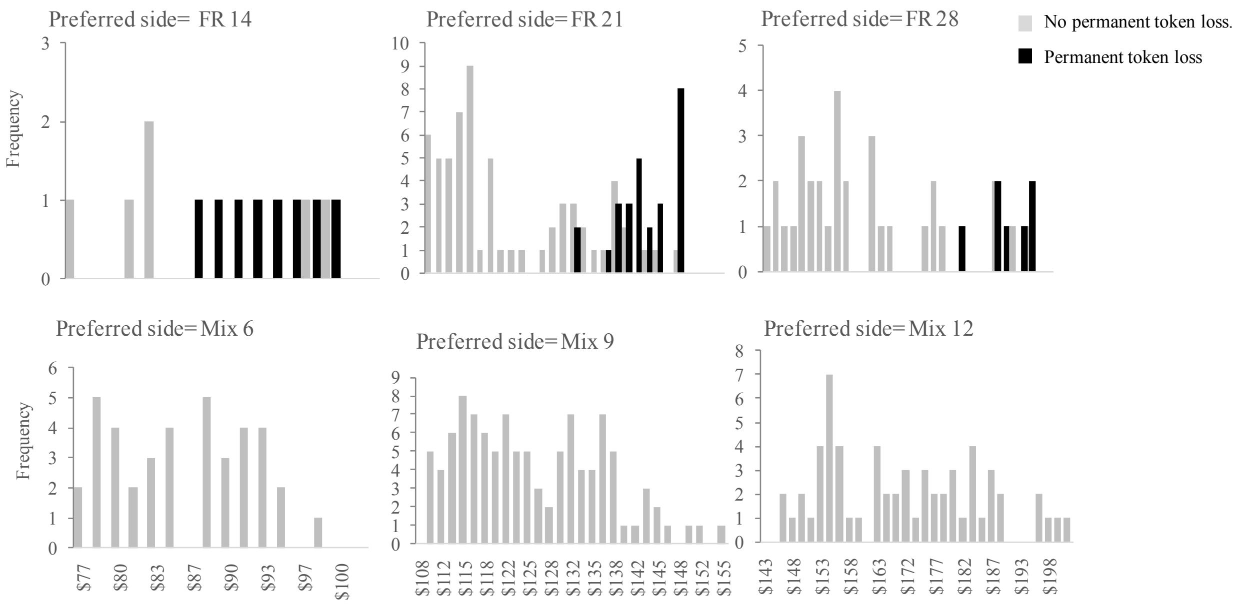


Figure 5: Frequency of packages with unit prices above exclusive responding as a function of side preference. The "x" axis shows unit prices per package. Light-gray columns are packages that ended without token losses and black columns are packages with token losses. The graphs on the top row are package selections when the preferred side offered FR and the graphs on the lower row are selections when the preferred side offered the Mixed schedule.

S2 – Weak preference for Left (almost no preference)



S5 – Weak preference for Left (almost no preference)

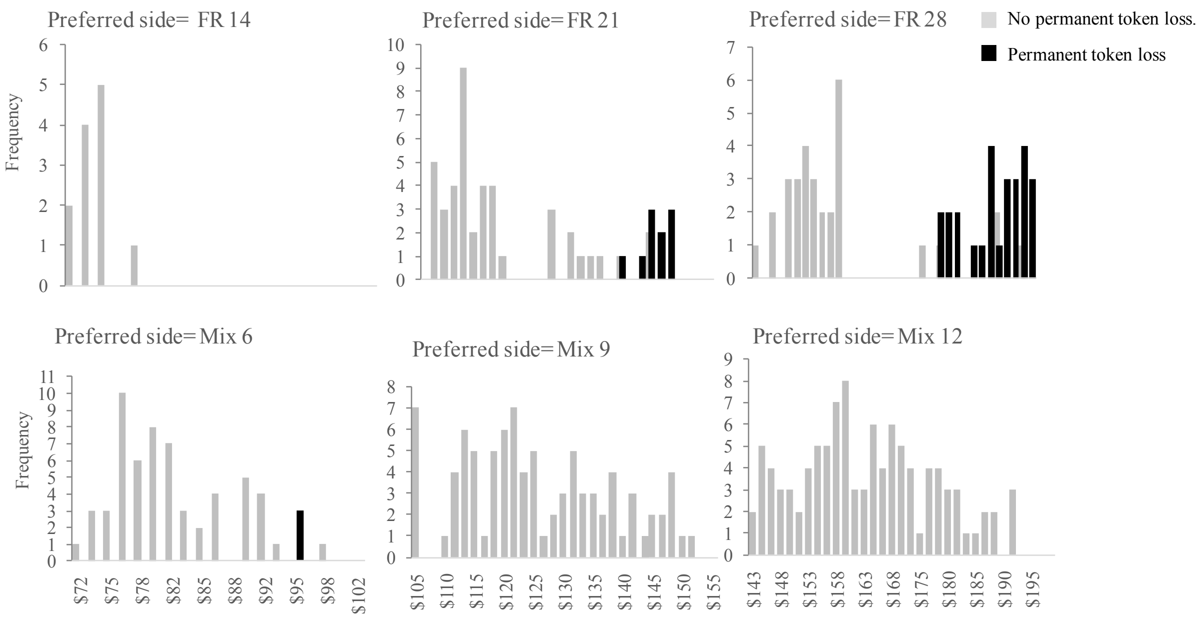


Figure 6: Frequency of packages with unit prices above exclusive responding as a function of side preference. The "x" axis shows unit prices per package. Light-gray columns are packages that ended without token losses and black columns are packages with token losses. The graphs on the top row are package selections when the preferred side offered FR and the graphs on the lower row are selections when the preferred side offered the Mixed schedule.

Discussion

Our results show that all subjects responded discriminatively as a function of token illumination (gains) and removal (losses) at some point during the experiment. The fact that token gains can acquire discriminative and conditioned reinforcing functions in behavioral chains has already been established in previous studies with pigeons and LEDs (Bullock & Hackenberg, 2015), and rats, using glass marbles as tokens (Malagodi, Webbe, & Waddel, 1975). One particular contribution of the present study was to show that this specific stimuli - LED illumination - can be used as tokens with rats, in contrast with a general suspicion that rats may not be sensitive to this kind of subtle visual stimulus (Bachrach, 1965). Evidence that token *removal*, in the form of LED extinguishment, can also acquire discriminative functions is more scarce. Pietras and Hackenberg (2005) and Raiff, Bullock, and Hackenberg (2008) did find supporting evidence with pigeons, but to the extent of our knowledge, the present experiment is the first to show this possibility with rats.

Figures 5 and 6 suggest that the *response of switching* between schedules at specific moments within a trial – a requirement for the formation of non-exclusive packages without token losses – became a function of token illumination and removal, whenever the mixed schedule was on the subject's preferred side. This suggests an answer to the first experimental question of this study, whether rats can respond discriminatively to changes in such a subtle visual stimulus as LEDs. The tentative response is "yes", they can respond discriminatively as a function of LED illumination *and* removal, but our results also show that there was another controlling variable at play: the schedule that was running on the subject´s preferred side.

It was previously mentioned that side bias is a common feature in concurrent procedures, especially with rats. There are some experimental strategies intended to diminish the impact of this variable, like exposing the subjects to a number of forced choices before they are allowed to "freely" choose in a session. This ensures that the subjects are equally reinforced in both schedules before establishing preferences. The practice expresses an assumption that side bias might be the result of operant training procedures. Forced choices were not used in the present study because of technical difficulties presented by the wheel apparatus. There is no way to prevent wheel-spinning responses to happen, unless the wheels are mechanically locked. To impose a number of forced choices followed by "free" choices would require that the sessions were interrupted to manually lock and unlock the wheels, so this procedural strategy was not implemented here.

It is possible that forced choices might have prevented side biases, especially on the Conc (FR FR) phase. In this phase, both wheels offered the same schedule, so the subjects had no reason not to respond exclusively in their preferred side, and thus establish a stronger reinforcement history on that side. Curiously enough, despite this characteristic, none of the subjects worked exclusively on only one wheel, in none of the sessions of the experiment. They always tried the other side. This can be observed in the fact that there is not a single circle in Figure 2 located on the outer border of either side. Additionally, not all subjects maintained the same side preferences showed in the Conc (FR FR) training phase in the other experimental phases. Subjects S2 and S5 changed preferences in different phases, and subject S4 showed several sessions with side indifference during the Conc (FR FR) phase before establishing a clear side preference. So, despite potentially having established a stronger history of reinforcement on one side - which could have determined side biases and could have been prevented by forced choices – some subjects showed adaptive schedule preferences as a function of the experimental phase.

Another reason not to attribute side biases to an (unplanned) stronger history of reinforcement in the training phase is because this tendency may not be purely due to ontogenetic reasons, but also to phylogenetic or epigenetic origins. Physiological studies support the existence of behavioral lateralization in rat populations. Like humans, it seems that rats can be “lefties” or “righties”. These characteristics are mostly attributed to inter-hemispheric asymmetries involving genetic and environmental factors, during the prenatal and postnatal development of the brain (Vancassel, et al., 2005). Anatomical brain asymmetries in rats have been previously correlated with preferred direction of rotation, nocturnal and drug induced circling behavior, side preferences in Y-mazes, reaching behavior, or spontaneous side preferences (Castellano, Diaz-Palarea, Rodriguez, & Barroso, 1987).

It is our interpretation that inter-hemispheric asymmetries might result in subjects feeling more comfortable in using one pawn or working in one side of the chamber, especially during our long sessions (4 hrs.), which required a lot of physical effort (up to 200 wheel-spins per trial). This would have affected the effort/cost side of the trade-off relation. In one condition (say, FR-Mix) the cost of responding might have been higher than in the other condition (Mix-FR), even though unit price ranges were the same. A hypothetical parallel would be to compare the performance of humans filling out written forms with their dominant and non-dominant hands. EBA researchers with an analytic-behavioral background might feel motivated to explore the determinants of side bias more deeply. If side biases were, at least in part, due to training procedures, then this influence might be dissipated with the use of other apparatus that allow for the imposition of forced choices, like levers. Another possible exploration on this topic would be to quantify the impact of this variable by searching for points of indifference between sides, by employing a titration procedure. In this procedure, the ratios on each side are gradually and systematically manipulated until the subjects vary their response concentration ("preferences").

In terms of the interaction with economic theories, preventing the occurrence of side biases might be seen as a less pressing issue. First, because humans also present side biases so this should not prevent interspecies comparisons. Second, the molar analyses presented in the next section of the present work suggest that side biases did not prevent a clear identification of behavioral patterns and their determinants. Third, and maybe more importantly, Figures 5 and 6 suggest that token removal (LED extinguishment) only became a discriminative stimulus for switching responses *when the mixed schedule was on the subject's preferred side*. This raises potentially interesting inquiries as to why this (clear) association occurred. As it will be discussed below, one of the key operant responses in the present experiment was the response of switching between the wheels. Switching at precise moments within a trial was a key requirement to forming response packages with lower unit prices or packages that ended without token losses. Figures 5 and 6 show that one of the controlling variables of discriminative switching was whether the mixed schedule was running on the preferred side. Studying this regularity might feel like a more motivating to an experimenter with an economic background. From this standpoint, the investigative focus should not be on the finding procedures that reduce side biases in concurrent choice studies, but on finding ways to incorporate side biases into the analysis of choice determinants without losing sight of other determinants.

The second - and principal - experimental question focuses on whether the subjects showed (as)symmetric tendencies towards positive reinforcement or negative punishment. On this respect, our results were uninformative. Had the subjects exhibited token loss aversion, they would have favored the purely positive-reinforcing FR schedule. This would appear in Figure 2 as a concentration of black circles (sessions) on the left border of the figure during the Conc (FR

Mix) condition, represented by the straight lines. Likewise, when the schedule sides were reversed, in the Conc (Mix FR) condition represented by the dotted lines, there would be a concentration of black circles on the right border of the figure. A symmetric process would appear as a concentration of circles closer to the white, indifference, area, meaning that the subjects were indifferent between the FR and mixed schedules. None of these tendencies appear in Figure 2. Instead, the subjects showed a consistent proportion of responses in the FR and mixed schedules, regardless of which side each schedule was running. Although the proportion of responses on the FR and mixed schedules per package changed between subjects, they all showed a tendency to quickly stabilize their response distribution within a few sessions after every unit price manipulation. So, there is a clear regularity in the package selection of these subjects, but these selections are not suggestive of any preference towards one schedule or the other, and thus are uninformative on the matter of (as)symmetries.

These results may be due to the fact that there was no changeover delays (COD) or any other punishment for switching between wheels at any time during a trial. Herrnstein (1961; 1970) dedicated a large portion of his work with pigeons to evaluating the relevance of using CODs to induce exclusive preferences on concurrent schedules. He tested the effects of a 1.5 sec COD to punish pigeons from alternating between two keys in a concurrent schedule, and concluded that "the COD seems to play a role in the … tendency of the relative frequency of responding to match the relative frequency of reinforcement" (1961, p. 272), a relation called Matching. Herrnstein found that this correspondence between relative responses and reinforcements could not be obtained when the COD was omitted. His subjects showed "excellent matching, on the one hand, and atypical absolute rates functions, on the other, probably because of the COD" (1970, p. 271). He also observed that "it was found, without the

COD, that the distribution of responses tended to stay around 50-50, without regard to the distribution of reinforcements" (1970, p. 248). Finally, he argued that "switching" is a third operant in a concurrent schedule (in addition to the responses on the two apparatus), and should be extinguished by the COD if the intention of an experimenter is to study the matching law. Herrnstein (1970) elaborates on the possible functions of the switching response,:

> "If the response alternatives are situated near each other, the subject´s left-right or right-left sequences may be adventitiously reinforced. If so, the usual tally of left and right responses cuts across the response classes actually being maintained by the reinforcement, and matching in the ordinary sense is no longer an appropriate expectation. By imposing a delay between a response to one alternative and reinforcement for the other, the COD discourages these adventitious response clusters" (p. 251).

In other words, the imposition of a COD is a strategy to prevent the selection of response sequences (packages), by "breaking" these sequences into their individual responses, and clearly associating each reinforcement to only one schedule. In line with Herrnstein's predictions, our subjects ended up selecting sequences of responses (packages) instead of concentrating responses on one or the other side. One of the downsides is that our results cannot be analyzed using the matching equation. Whenever a trial was completed through a *combination* of responses on the mixed and FR schedule (non-exclusive packages), there is no accurate way to assign each reinforcement to a single schedule. Of course, whenever a trial was completed with an exclusive package, that association was easily found. The impossibility of using the matching equation for our results became greater during the last experimental phases, when the number of exclusive packages decreased, and even reached zero for some subjects (Figure 4). This, however, should not be a problem as long as this was not the objective. On the other hand, if the lack of COD has prevented the investigation proposed on the second experimental question –

about (as)symmetries – it warrants further consideration.

There were two reasons for not imposing a COD. The first was based on Herrnstein's observation that response sequences would only be selected "if the response alternatives are situated near each other". One characteristic of the response wheels is that they require the subject to be situated *in front of it* to respond. The wheels have a metal plate on both sides, and small bars on the front (see Figure 1). Spinning can only occur if the subjects grab the front bars of the device and turn. Switching between wheels required a complete body move from one side of the wall to the other. Before this experiment began, it was cogitated that this extra effort might operate similarly to a COD, because (1) it should take about the same time (1-2 sec.) to make that move, and (2) in addition to the passage of time, it would require extra physical effort. However, our results on this regard were unexpected. The subjects not only switched often (so this response was not suppressed), but switching seemed to have acquired important functions throughout the experiment, as it will be discussed further in the next section of this work.

It was previously mentioned that many sessions were filmed and showed some unpredicted topographies, especially the fact that the subjects made various "mid-trial pauses" during the initial and intermediary links, and used this time in activities like sniffing the illuminated LEDs in the wheel panel, crossing the chamber, pressing the lever, or sniffing the interior of the liquid receptacle. Economically-speaking, these activities would be considered as the "leisure" part of the response package. As they were not systematically registered, they cannot be analyzed in much detail, except for the "extra" lever-pressing that caused the lever-pressing discriminative indexes to remain below 80% in Figure 3. The fact that lever-pressing responses recurrently occurred despite never reinforced with sucrose suggests that there were other functions responsible for their maintenance. One possibility can be vented based on the findings from Bullock and Hackenberg (2015), with pigeons. In one experiment with a token chain, they compared the duration of the trials that occurred during a "standard" condition (regular token chain) with the duration of a tandem condition, that is, a similar sequence of schedules, but with no visual stimuli (tokens) signaling the passages of links. They observed that during the tandem condition, durations were *shorter* and response rates were *higher* than on the equivalent chained conditions. The longer durations in the chained conditions were due to weaker behavior in the early links of the chain. These results are consistent with previous findings from Kelleher (1957; 1966) with chimpanzees and pigeons, and from Malagodi, Webbe, and Waddel (1975) with rats. A commonly found effect in all of these studies is that token economies that employ FR schedules tend to produce prolonged pauses in the links that are most temporally distant from the terminal link (similar to the "leisure periods" from the present experiment). Hackenberg (2009) argued that one of the functions of tokens is to organize coordinated sequences of behavior over extended time periods. Tokens bridge temporal gaps between behavior and delay reinforcement, a characteristic common to conditioned reinforcers (Hackenberg, 2009; Kelleher & Gollub, 1962). So, the prolonged pausing from our subjects can be seen as an expected behavioral characteristic commonly seen in token economies.

The unsolved issue in this matter is why the subjects dedicated a consistent portion of these pauses to an apparently unreinforced lever-pressing. Once again, these reasons can only be hypothesized here. Two are cogitated: (a) potential discriminative functions of lever-pressing: as this response was directly related to terminal reinforcements, they might have acted as an additional signal as to which point of the trial the subject was; or (b) the pairing between the terminal reinforcer and lever-pressing might have established conditioned reinforcing functions, helping to sustain the behavioral chain especially at the higher unit price ranges when trials tended to last longer.

Another relevant aspect of the mid-trial pausings is that they might have contributed or even became part of the switching topography. Instead of simply moving from one wheel to the other, in many trials the switching topography consisted of *fully crossing the chamber and then coming back to the wheel on the other side*. This might seem counterintuitive at first glance, as it is a topography that requires a more strenuous effort to compose a response package than simply moving aside. Some interpretations can be offered, in connection to the previous discussion on the absence of CODs. It is possible that the extra effort required to switch between wheels (either by moving the body aside or by crossing the chamber back and forth) was not functionally equivalent to the time passage of 1.5 sec. used by Herrnstein's COD, despite the fact that it took longer to make the switching. It is also possible that this extra effort *was* functionally equivalent to a COD, but the the reinforcement obtained with the response of switching (from selecting specific response packages) was enough to worth the extra effort. This last possibility will be further explored in the next section, when the controlling variables of package selection are analyzed using three choice models.

The second reason for not imposing a COD was our understanding that it introduced an arbitrary control in the experimental situation, one that is probably absent in choices outside of the laboratory setting. It was our interpretation that not using a COD - but instead, imposing the "natural" effort of moving the whole body for switching - would establish a choice contingency more similar to the situations in which choices occur outside of the laboratory. The use of COD induces the subjects to establish a clear preference towards one schedule, which facilitates the analysis in terms of one or other theory of choice, but it might also eliminate some possibly relevant controlling variables in concurrent choices. This interpretation seems to find empirical support here. Absent the COD, our experimental contingency controlled the emergence of individual patterns of choosing specific combinations of responses and switches (packages), regardless of the side each schedule was operating. This is a relevant result if one accepts that the objective of all behavioral sciences is to find regularities in behavior. Regularities were clearly found in the fact that, despite showing a preference for one side or the other, all subjects (1) selected exclusive and non-exclusive packages as a function of unit prices (Figure 4); (2) The selections of non-exclusive packages resulted in a reduction in unit prices in 50% to 60% of trials (Table 3); (3) the switching response became a function of LED illumination and extinguishment for all subjects, whenever the mixed schedule was on their preferred side (Figures 5 and 6). The next section will provide further analyses of the switching, as a key aspect of the molar choice patterns. To summarize this point, the absence of COD might have allowed the emergence of clear regularities on the choice patterns produced in this experimental situations and highlighted new controlling variables that could not be observed otherwise. On the other hand, this absence might have prevented the second and principal experimental question on (as)symmetries from being answered. Our subjects neither concentrated their choices on one schedule (suggestive of asymmetries) or were indifferent between the schedules (suggestive of symmetries). This is a point that warrants further studies, for example, by replicating the present situation with and without a COD to verify if clearer results in terms of (as)symmetries can be gathered.

The third question addressed the effects of unit price increases. One of these effects (absent any COD), was an increased selection of non-exclusive packages, that is, in the number of packages in which the subjects switched mid-trial. This can be observed in Figure 4. This increase in packages that included mid-trial switching is an unexpected regularity if one considers that the last unit price ranges imposed very stringent response requirements. The 28-12 and 12-28 phases demanded a lot of physical effort in the form of about 200 responses per trial. This could have induced the subjects to avoid the additional effort of constantly switching between wheels, and to conserve energy by simply responding in one of the wheels. But this did not happen. Instead, all subjects increased the number of mid-trial switches and produced a larger number of non-exclusive packages as the unit price ranges increased. A possible reason is the fact that, by switching between the wheels at precise moments, the subjects could form non-exclusive packages that resulted in *lower* unit prices per trial. Table 3 shows that this actually occurred in more than half of all trials, and that during conditions 21-9 and 9-21, the percentage of lower unit price packages reached about 60% of trials for all but one subject.

Forming non-exclusive packages with lower unit prices required that the switching between wheels occurred at very precise moments within a trial. There were only two ways to produce packages with unit prices below exclusive responding.

(a) The subject emits enough spins in the first positive component of the mixed schedule, and illuminates three LEDs. These three tokens would have been earned with a lower number of responses than on the FR schedule. Then, *before he is punished with the extinguishment of two LEDs* on the negative component of this schedule, he switches to the FR schedule and completes the trial there.

(b) The subject illuminates three LEDs on the positive component of the mixed schedule, then extinguished two LEDs on the negative component, and then illuminates three more LEDs in the second positive component. The result would be four illuminated LEDs, with less wheel-spins than would be required in the FR schedule. Then, he switches to the FR side *before losing additional tokens on the negative component*, and completes the trial on the FR schedule.

Note that alternatives (a) and (b) do not require that these exact order of events occur. The subjects could first earn some tokens on the FR schedule and then move to the mixed schedule, for instance. The key point is that the switching response must occur *at very precise moments* within a trial, *as a function of LED illumination and removal.* This depends on a well-established discriminative responding of the switching response as a function of the visual (LED) stimuli. The concentration of exclusive packages in the first experimental phase, with the lower unit price range, suggests that this kind of discrimination was not established when unit price ranges were low. Under these conditions, responding exclusively in one schedule was a recurrent pattern, appearing in about 50% of the trials from four out of five subjects (S1, S3, S4, and S5). These results seem in line with Herrnstein's (1970) observation with pigeons that "without the COD, that the distribution of responses tended to stay around 50-50, without regard to the distribution of reinforcements" (p. 248). So, in the lower unit price ranges, our rats seem to have behaved similar to Herrnstein's pigeons. However, as unit price ranges increased, there was a drop in the number of exclusive packages, and a clear selection of non-exclusive ones. Furthermore, more than half of these non-exclusive packages were the product of a switching response that occurred at very precise moments mid-trial, resulting in the lowest unit prices allowed by that (stringent) contingency. So, it seems empirically and conceptually reasonable to hypothesize that the increased difficulty in completing a trial in Phases 21-9, 9-21, 28-12, and 12-28 induced the subjects to search for better trade-offs between the (high) efforts required per trial, and the (fixed) terminal reinforcement. In short, in response to the third experimental question, the effect of the increases in unit price ranges was a higher selection of non-exclusive response packages with lower unit prices, which in turn required that the response of switching became a function of LED illumination and extinguishment (gains and removals).

These findings might provide additional information in regards to the possibility of using LED extinguishment (token removal) as discriminative stimulus with rats. To produce a token system with nonhumans that is functionally similar to experiments with humans earning and losing money, it must be clearly demonstrated that rats can respond discriminatively with LED extinguishment. This point was clearly demonstrated in the present experiment and, to the extent of our knowledge, is a novel finding.

On the other hand, using tokens economies and rats to test (as)symmetries also requires that these LED extinguishments act as punishers. This kind of evidence was offered by both the Pietras and Hackenberg (2005) and Raiff, Bullock and Hackenberg (2008) experiments with pigeons, when they observed that LED extinguishment partially suppressed their subject's responses. Our results do not provide a clear evidence that LED removals acted as punishers. A working hypothesis before our data collection began was that if token removal were to become an aversive stimulus, the subjects would choose the mixed schedule less often, or avoid this schedule altogether. What happened, instead, was the selection of packages in which *switching became a function of token removal*. This does not mean that LED extinguishment became a punisher: our subjects did not avoid the mixed schedule and did not show overall response suppression. So, it seems that under the present contingency LED removal have merely functioned as a discriminative stimulus to the switching response, and not as a punisher.

It is conceptually possible to analyze the packages of response with low unit prices – previously labelled as (a) and (b) - in terms of the functional roles of tokens. Responses on the mixed schedule in both (a) and (b) were first controlled by token gains. After earning three tokens on the mixed schedule, the subjects either switched immediately (a) or continued working on the mixed wheel a bit more (b). Sequence (a) would suggest that switching might have been an avoidance response, as it prevented the loss of the three previously earned tokens. If they continued working on the mixed schedule - sequence (b) - the subjects experienced the loss of two tokens, but continued responding until these tokens were recovered. This suggests that token removal may also have acquired negative discriminative functions, as if saying “don’t switch now!”. Switching occurred only after the tokens were recovered. These are, however, conceptual exercises that, although in consonance with our data, are not unequivocally supported by them.

To sum up, our results support the proposition that rats can respond discriminatively to token removals in the form of LED extinguishment – which to our knowledge is a novel finding of this experiment – but do not provide sufficient empirical basis to the notion that LED extinguishment acquired punishing functions. This sole fact might be the reason that our inquiries as to (as)symmetric processes were left unanswered. If token removal did *not* function as a punisher, then there is no reliable way to observe (as)symmetries between positive reinforcement and negative punishment under this procedure. On the other hand, the consistent regularities in package selection found in the present experiment warrant additional attention, in search for the controlling variables that determined such patterns. EBA provides a number of choice models that can be used to this end. In the next section, the results of this experiment will be analyzed using three EBA predictive and explanatory models: melioration, maximization and satisficing.

EBA Models of Choice

Maximization

It was previously said that what behavioral analysts call "environment" is viewed by economists as sets of packages. The general idea can be exemplified in a typical operant chamber. If a rat in an operant chamber is observed over a long period of time, a pattern of choices might emerge. That is, the interaction between the subject and the environment may start selecting some response packages more frequently than others. The economic understanding is that such pattern is established because the frequently selected package provides the best balance between all pleasant and unpleasant dimensions of that constrained situation. Conceptually, the rat is seen as choosing the packages that provide the best trade-off (Rachlin, Battalio, Kagel, & Green, 1981; Premack, 1971). The assumption of value maximization is that response packages are selected as to maximize a set of properties in the environment (Rachlin, Battalio, Kagel, & Green, 1981).

Under a given set of experimental conditions (environmental constraints), a rat might behave so as to obtain an ideal combination of food pellets and water, or a plant may orient its leaves and roots so as to obtain an ideal combination of sun and water. Maximization proposes that these combinations will generate the maximum utility under these environmental constraints (Rachlin, Battalio, Kagel, & Green, 1981). In operant experiments, environmental constraints are imposed by limiting session times, limiting the number of responses before a session ends, restricting the types of responses that are reinforced etc. Models of choice that are based on economic theories like value maximization and satisficing (exposed below) typically adopt overall environmental constraints as critical variables. Models of choices that stem from other approaches, like melioration (also below), tend to emphasize more local and relative controls, and hold overall restrictions constant (Grace, 2005).

Value maximization guides the experimenter to a particular angle of observation, leading to questions like: "what kind of consequences is this behavior producing, and what are their relevance (value) to the subject"? Maximization assumes that constant exposure to choice trade-offs would eventually result in the emergence of a behavioral pattern that optimizes one aspect of the environment in the long run (Mazur, 1981). For instance, a deprived pigeon in an operant concurrent situation can choose to peck one of two keys, in order to receive food. According to maximization, this subject can initially distribute responses between the keys in various forms, but eventually will settle on the distribution that provides the maximum rate of food delivery. By doing so, the subject's choices should stabilize around this response distribution (Mazur, 1981). Once this steady-state condition is established, departures from this maximum would occur only when conditions were changed, that is, when the behavior of the pigeon is constrained in another way. The objective of maximization theory is to predict behavior under these new set of constrains (Rachlin, Battalio, Kagel, & Green, 1981).

Melioration

The melioration theory proposes that choices are controlled by shorter-term consequences (Herrnstein & Vaughan, 1980). Rather than maximizing overall rate of reinforcement, subjects can be more sensitive to the *local* rates of reinforcement, i.e. the number of reinforcements produced by responding on one alternative, divided by time spent on that alternative (Vaughan, 1985). In a concurrent schedule, if the local reinforcement rate on one *operanda* is higher than the other, melioration specifies that more time/energy will be spent on the "better" immediate alternative, even if this choice distribution does not yield the higher overall reinforcement in the long run (Boelens, 1984; Vaughan, 1985).The basic intuition is that the lure of an immediate positive consequence sometimes can be difficult to overcome, even if it is deleterious to larger future consequences (Tunney & Shanks, 2002). Melioration states that repeated choices can predictably and reliably converge to a stable pattern of choices that produce sub-optimal overall value, but with higher immediate value (Herrnstein & Prelec, 1991). Herrnstein and Prelec (1991) suggest that this could be the underlying behavioral process responsible for substance abuse and other problems of self-control.

Melioration has gathered empirical support from several studies with concurrent choices and non-human organisms, who "meliorate" under a wide range of settings, at the expense of maximizing. The results of experiments with human experiments, however, have been more ambiguous. Humans sometimes fail to maximize when that violates the principle of melioration, but they seem to maximize in other settings, given appropriate conditions or explicit verbal instructions (Herrnstein & Prelec, 1991). Herrnstein, Vaughan, Lowenstein, and Prelec (1993) proposed that melioration in humans could be the result of a process of "value accounting". The idea is that the consequences of past choices fade as new experiences occur. In a repeated choice situation, the consequences of the past "N" choices would have a more deterministic effect on current choices than earlier consequences. Herrnstein *et al*. (1993) suggest that these "N" events establish a so-called "averaging window", that encompasses the past trials that are determinant of the next choice. To support this point, they performed a series of experiments in which undergraduate students chose between earning money in three alternatives. One alternative offered a fixed amount, paid in coins immediately deposited in a bin, and the other two offered delayed payments. The contingency established that choosing the immediate alternative did not maximize total earnings. Payment delays on the other alternatives were determined by the moving average (averaging window) of the last N choices in that alternative. This window was systematically varied to N=3, N=5, N=10, and N=20. With small averaging windows (low N), payment delay was rapidly affected by the subject's last choices; in large averaging windows, changes occurred more slowly. Herrnstein *et al*. compared the "large averaging window" with the choice of a workaholic between spending time with work or family: the effect of a single evening spent at the office in reducing the quality of family life is small. Over many evenings, however, the effects may be dire and more difficult to reverse. Their experimental results showed that small windows favored maximization, and large windows favored melioration. They also observed that larger averaging windows consistently increased the variance among subjects.

Melioration and maximization are assumed to be competing theories of choices. Melioration states that choices are selected at a local, molecular, level and maximization assumes a global, molar, organizing pattern (Baum, 2004). Empirical studies that compare these models to observed choices are not hard to find. One example is the Herrnstein, Lowenstein, Prelec, and Vaughan (1993) study mentioned before. Some comparative studies in behavioral analysis sometimes mistakenly assume that melioration is equivalent to another behavioral economic theory, called satisficing. One example is Kubanek, Snyder and Abrams (2015). The supposition of equivalence is disturbing, as each is based on distinctive assumptions and they generate different predictions. It is our understanding that satisficing stands on its own independent feet as an alternative choice model.

Satisficing

Both value maximization and melioration are the basis for quantitative descriptions of behavior in which the effects of gains and losses are expressed by positive and negative mathematical signs, and choice explanations are based on their net value (net reinforcement). Two examples are the matching equation (Herrnstein, 1970; Herrnstein & Vaughan, 1980) and the subtractive model, proposed by deVilliers (1974; 1980). Both are conceptually based on the process of melioration. The basic assumption of every model that either explains choices or formulates choice predictions based on net reinforcement calculation is that gains and losses can be converted into a single quantitative scale, and directly added-up.

Satisficing theory (Simon, 1955; 1956) disputes the notion that categorically different events can be directly compared, and proposes that they are multidimensional and incommensurable. Incommensurability means that different aspects of any experimental contingency cannot be directly compared. Supposedly appetitive events, like leisure or earning food, have different properties and address different needs of the organism. The same goes for supposedly aversive or "unwanted" costs, like physical effort or time expenditure. Incommensurability is especially salient in out-of-the-laboratory social choices, when the choices of one person can affect (the values of) more than one person (Simon, 1990).

Satisficing theory tackles the study of choices from a different angle. Instead of assuming that organisms establish preferences for a single alternative that maximizes one dimension of value (be it local or global), it assumes that organisms with repeated choices will end up selecting a stable *pool of choices*. When a person has to constantly choose between two events, maximization predicts that, after repeated choices, a single alternative that maximizes one aspect of the situation will prevail (like, for example, rate of reinforcement over time). Moreover, it assumes that this maximized aspect will be the one that provides the best trade-off in the long-run. Melioration predicts that repeated choices will be controlled by the highest immediate outcome (example: immediate reinforcement, instead of a delayed reinforcement of higher magnitude). Satisficing predicts that the subjects will establish a stable pattern of *variation* among a restricted group of alternatives, because each one addresses a different dimension of value. This means that, according to satisficing, no specific aspect of the contingency is fully maximized. For example, an experimental subject making a concurrent choice between an immediate reinforcement of smaller magnitude and a delayed reinforcement of larger magnitude may alternate between the two, and produce a combination of immediate *and* delayed reinforcements over time. Satisficing suggests that this selected cluster of choices will produce "good enough" consequences, as they address the two dimensions of the subject´s needs that are present in that situation – time and magnitude of reinforcement. The term satisficing was coined by psychologist and economist Herbert Simon (1956), as a combination of "satisfy" and "suffice". Simon (1979) argues that by giving up a single-scale value maximization, a richer set of properties from the contingency can be retained.

There are many relevant points of contact between analytic-behavioral concepts and the conceptual bases of the satisficing theory. Satisficing offers a body of hypotheses on how organisms with multiple needs/ motivations make choices in novel environments, where there are no immediate recognition of the contingency and the consequences of any choice are unknown or uncertain (Simon, 1978). When a novel situation arises, and a great amount of energy must be spent exploring a broad range of possibilities, not all options are searched with equal probability. Instead, only a small number of searching patterns emerges (Simon, 1978). Satisficing states that explorative patterns (also called heuristic searches) are determined by the organism's existing repertoire. The subject's behavior would follow patterns that have been reinforced in other domains in the past (Simon, 1956; 1978; 1990). Past experiences would also determine the degree to which the consequences of each action will affect the probability of this and other actions being repeated in the future. The life history of every organism includes a range of reinforced and punished experiences that form a "guiding baseline", and determines how new behaviors are shaped. This baseline is named "aspirational level" (Simon, 1956).

Aspirational level is a dynamically adapting behavioral selection threshold. Consequences above that threshold – i.e. that attended to one or more of the organisms present needs – are "good enough" in the sense that they are more likely to be repeated; consequences below this threshold – i.e. that resulted in an insufficiently fulfillment of needs – are more likely to be dismissed. Like any baseline, aspirational levels tend to rise and fall in consonance with changing experiences. In a benign environment that provides ample reinforcing alternatives, aspirations rise; in a harsher environment they fall (Simon, 1979). Explained in these ways, these concepts should sound familiar to behavioral analysts. In essence, they follow a similar understanding that behavior is determined by the organism's history of reinforcement and the immediately present environmental contingencies. These similarities allow relevant points of contact between satisficing and behavioral analysis.

Satisficing theory is also not opposite to maximizing. The two have points of contact, but satisficing proposes a larger range of controlling variables, and makes broader predictions than maximization. Satisficing states that, whenever a number of "good enough" alternatives is found, exploratory behaviors diminish, and are substituted by a stable pattern of alternation among this cluster of choices. They are "good enough" in the fact that, by alternating actions within this cluster, the organisms can obtain a larger variety of consequences that address multiple dimensions of value. It is compatible with the possibility that, over time, the selected cluster of responses can converge to a single alternative, which might be the one that maximizes one single dimension of value. If so, a process of satisficing may eventually become equivalent to maximizing, taking the costs of search into account (Simon, 1979; Binazadeh & Shafiei, 2013). In short, satisficing is not necessarily opposed to maximization, but it assumes that maximization is too simplistic, "too crude to be … descriptively relevant" (Diecidue & van de Ven, 2008, p.

687), and searches for broader and more realistic behavioral explanations. It does that by expanding the number of variables that are seen as deterministic of choices.

Satisficing entered the psychological realm through peculiar doors. It is the framework of modern computer simulations of complex cognitive behaviors and artificial intelligence. These areas are focused on producing computer algorithms that simulate how organisms make new choices, by integrating an immense mass of complex variables from past and present experiences (Simon, 1990; Diecidue & van de Ven, 2008; Binazadeh & Shafiei, 2013). Satisficing provides a simple selective process for initiating and restricting environmental exploration after a range of "good enough" options have been found (Simon, 1979). It is also very popular in neuroeconomic and cognitive psychology researches on learning.

Satisficing is yet to make a direct contact with behavioral analysis. In contrast to the large number of EBA papers referencing value maximization and melioration – either to defend or to refute them – this literature is largely silent on satisficing. In the rare studies in which satisficing is mentioned, it is sometimes confusedly mistaken for melioration. One reason for this situation might be the lack of usable translations of concepts that, if taken at face value, might sound too internalist for analytic-behavioral standards. Indeed, Simon at some point in his life became a self-declared cognitive psychologist, constantly invoking cognitive concepts like "human computational limits" or "cognitive architecture" to hypothesize about behavior. On the other hand, he fiercely defended that behavior was determined by external environmental conditions and reinforcement. For example, see his analysis on the path choices of a rat in a maze (Simon, 1956). So, despite using internalistic language, in many cases cognitive constructs are not an essential part of Simon's arguments. An important exercise for economic behavioral analysts is to develop a repertoire to detect whenever internalistic hypotheses are critical to the behavioral explanation, and when they are simply superfluous additions.

Recently, Rachlin (2015) performed this type of exercise in a review of the behavioral-economic book “Why nudge: the politics of libertarian paternalism”, by Cass Sunstein. Sunstein argues that governments should use “nudges” in policy-making, i.e. environmental manipulations that maintain many alternative actions available to people, but increases the probability of people choosing the ones that produce better long-term and socially ample consequences. Rachlin makes a constructive argument in favor of behavioral analysts joining the interdisciplinary discussion on this matter, by stating:

> “Sunstein couches his recommendations in a dichotomy between two internal processes (System 1 and System 2) corresponding to areas of the brain governing fast, intuitive thinking and slow, analytic thinking… Fortunately, none of the nudges proposed by Sunstein depend on the “psychology” represented by System 1 and System 2. The book remains focused on choice architecture. The behavioristic reader can easily translate from neurocognitive to behavioral terms and so see nudges as means of bringing behavior under the control of wide and abstract reinforcer contingencies” (p. 198).

The basis of Rachlin’s argument seems to be that economic behavior analysts should not abandon the debate with scientists from other approaches because of their use of internalistic language, if these concepts are not fundamental to the analysis. He claims that by doing this exercise in tolerance and scientific clarity, EBA-researchers can create novel opportunities to apply what has already been found about long and short term contingency controls, and produce efficient economic and social policies with high social impacts. In line with Rachlin’s claim, the incorporation of satisficing theories into the EBA literature might require a repertoire of identifying the functional analysis behind the verbal topography of their explanations.

There are at least two potential benefits for taking satisficing more seriously within EBA. One is the attention it calls to different and broader set of variables, which can be incorporated into quantitative models in a tractable manner. Second, it can open new lines of communication between behavioral analysis and economics, and produce fruitful opportunities to (1) empirically test satisficing theories with experimental procedures used by behavioral analysts, and (2) establish a productive role for analytic-behavioral studies in the public-policy debate, where satisficing theory is already being applied.

EBA Analysis of the Experimental Results.

Each model – maximization, melioration, and satisficing – addresses a different aspect of behavior and predicts the formation of a particular behavioral pattern. It is possible that they all emphasize a specific set of functional relations, while obscuring others. By using all three to analyze the same behavioral data, the present work will search for potential complementarities among these frameworks. Melioration predicts that choice selection will be organized locally, i.e. as a function of the consequences of the last choices. Maximizing predicts that repeated choices will converge into a recurrent selection of a single alternative that provides the best (globally maximizing) trade-off. Satisficing predicts that repeated choices will converge into a stable alternation of choices among a cluster of alternatives.

Melioration Analysis of the Results

The melioration analysis was based on the averaging window proposed by Herrnstein, Lowenstein, Drazen, and Vaughan (1993), which assumes that choices are controlled by the consequences of the past N trials. In the Herrnstein *et al.* study, the averaging window was the independent variable. The present analysis searched for an averaging window that was predictive of choices. To do so, the observed unit price of each trial was compared to the moving average of the last N trials, or periods. A 5% acceptance criteria was used to define the observed unit price for each trial. For instance, if a trial ended up with a unit price of 100 wheel-spins, then any moving average that produced a value between 95 and 105 was considered as an acceptable predictor for that trial. Following that criteria, moving averages with various “N” were tested, ranging from N=2 (i.e. moving average of the last 2 trials or periods) to N=10 (moving average of the last 10 trials or periods), across all experimental phases. The moving averages of the last N=9 and N=10 trials were discarded, as they did not generate significant predictions for the observed unit prices. Figure 7 shows which values of N were the best predictors of observed unit prices. The “y-axis” displays how many times each value of N (x-axis), was a good predictor. For all subjects, the averaging windows of N=2 was the best predictor, followed by N=3, and N=4. Altogether, the most accurate unit price predictions were found when N was small, between 2 and 4 periods.

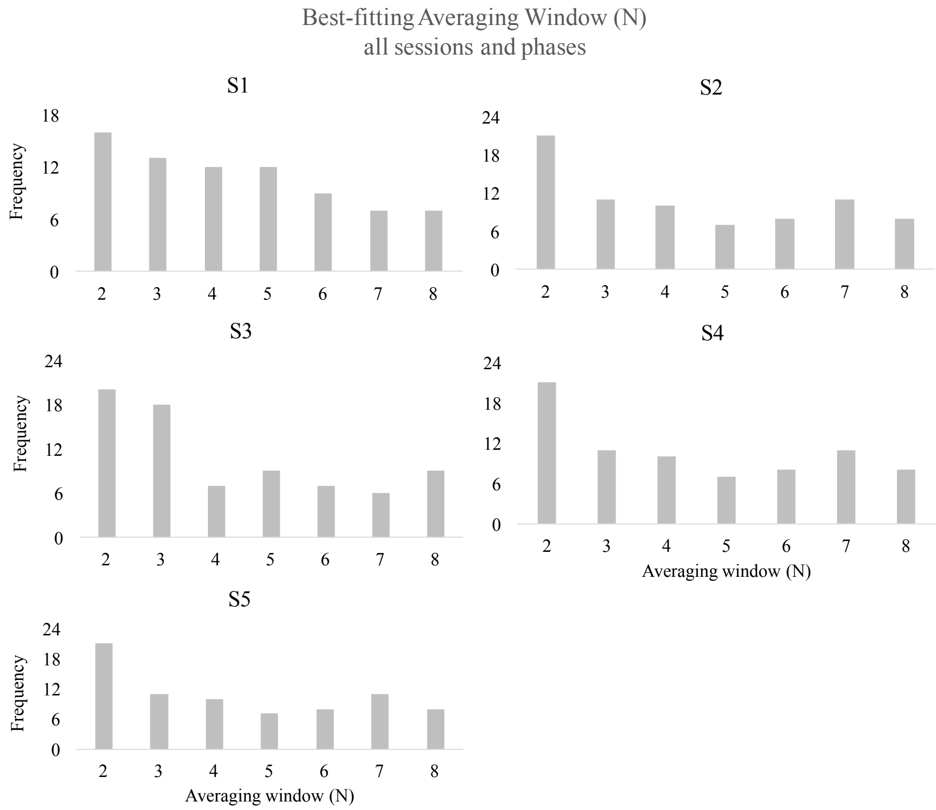


Figure 7: Frequency of the values for N (number of periods used in the moving average) that best predicted the unit prices of each trial, in all phases of the experiment.

Figures 8 to 10 compare the observed unit prices (full black lines) from all five individual subjects, and the prices that were predicted by a melioration model with an averaging window between N=2 and 4 (gray full lines). The model initially produced three predictions for unit prices per trial, one for each value of N. It then selected the prediction with the smaller difference with the actually observed unit prices. The dotted lines show the difference between the predicted unit price, and the unit price actually "paid" on that trial. The closer the dotted line is to zero the better was this model's predictions.

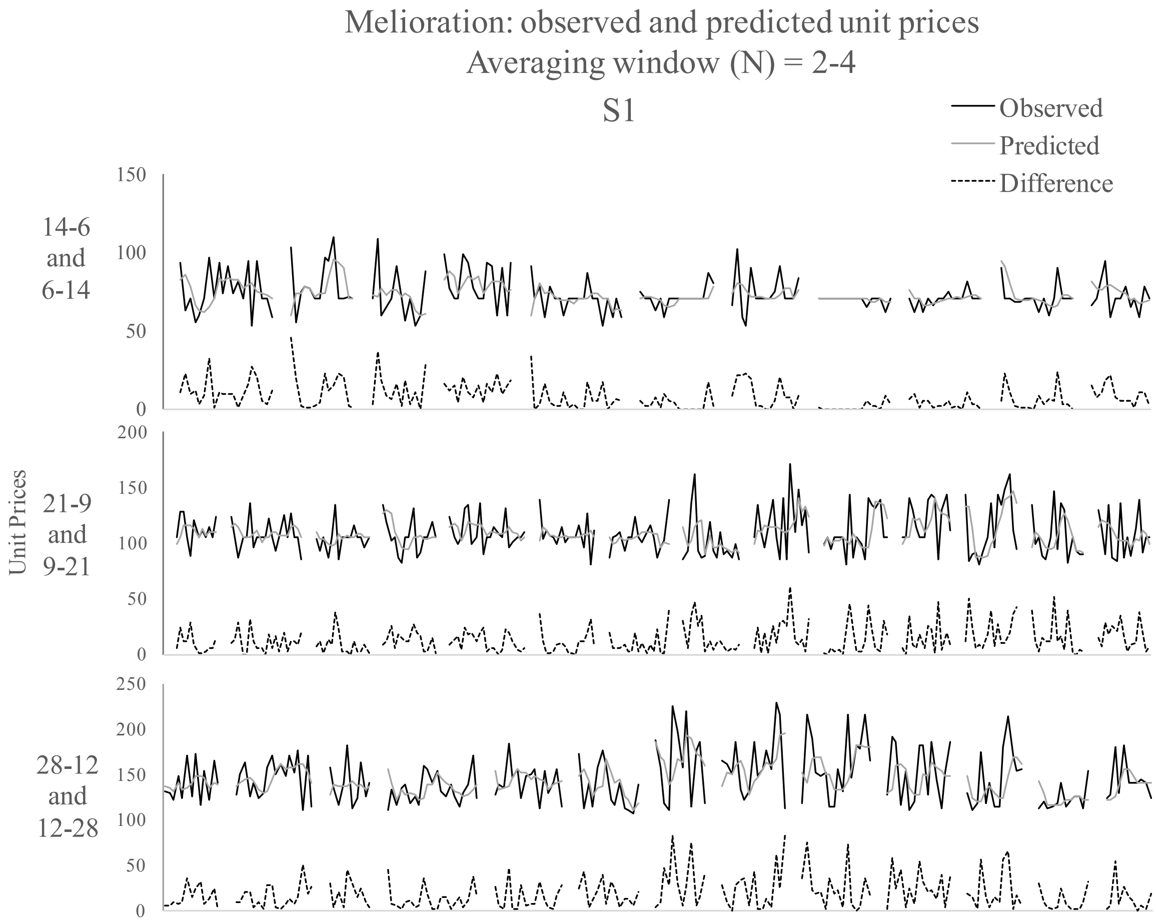


Figure 8: Predicted unit prices (gray lines) and observed unit prices (black lines) for all trials, sessions and phases for subject S1, considering a moving average between N=2 and N=4. The dotted lines are the difference between these two values.

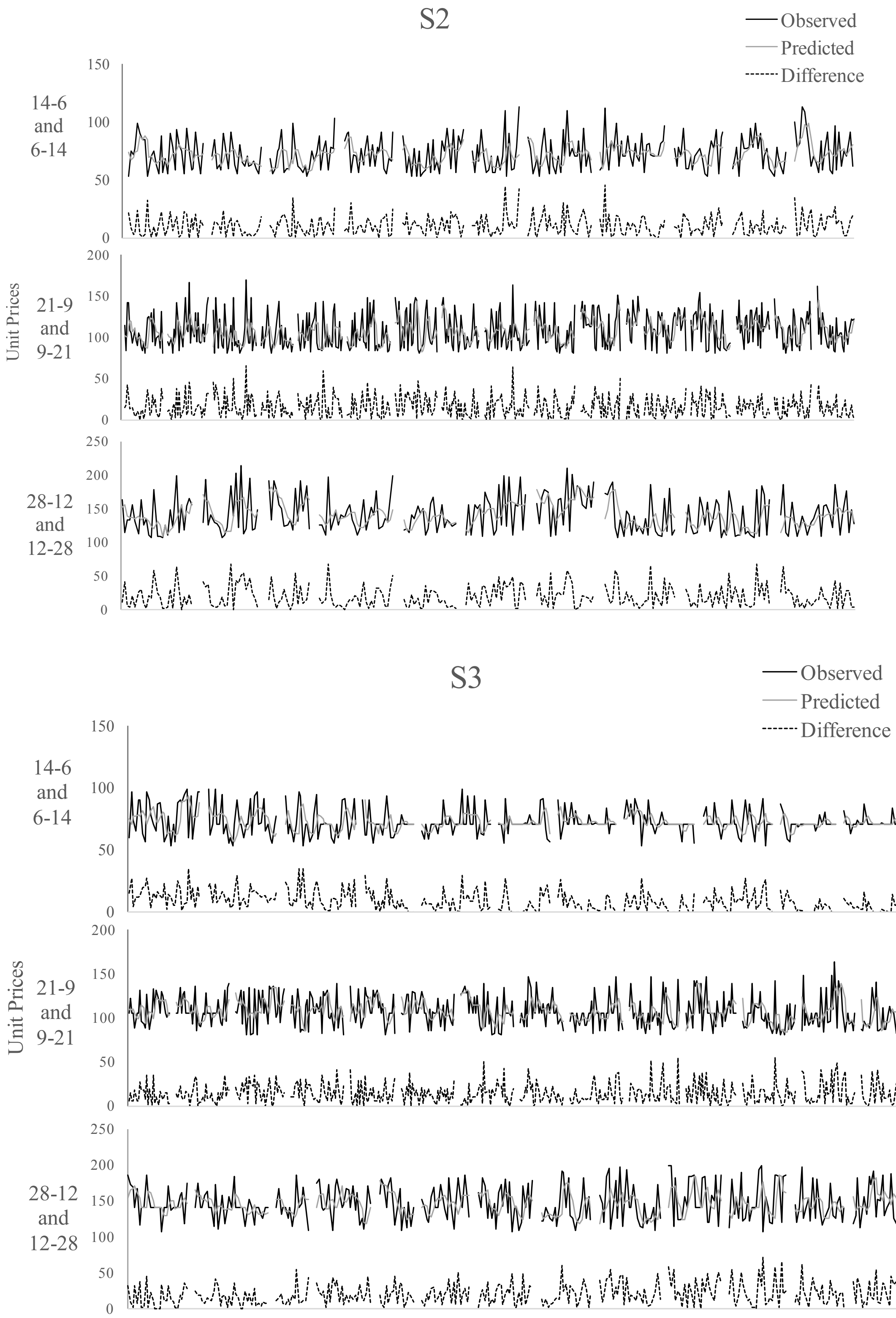
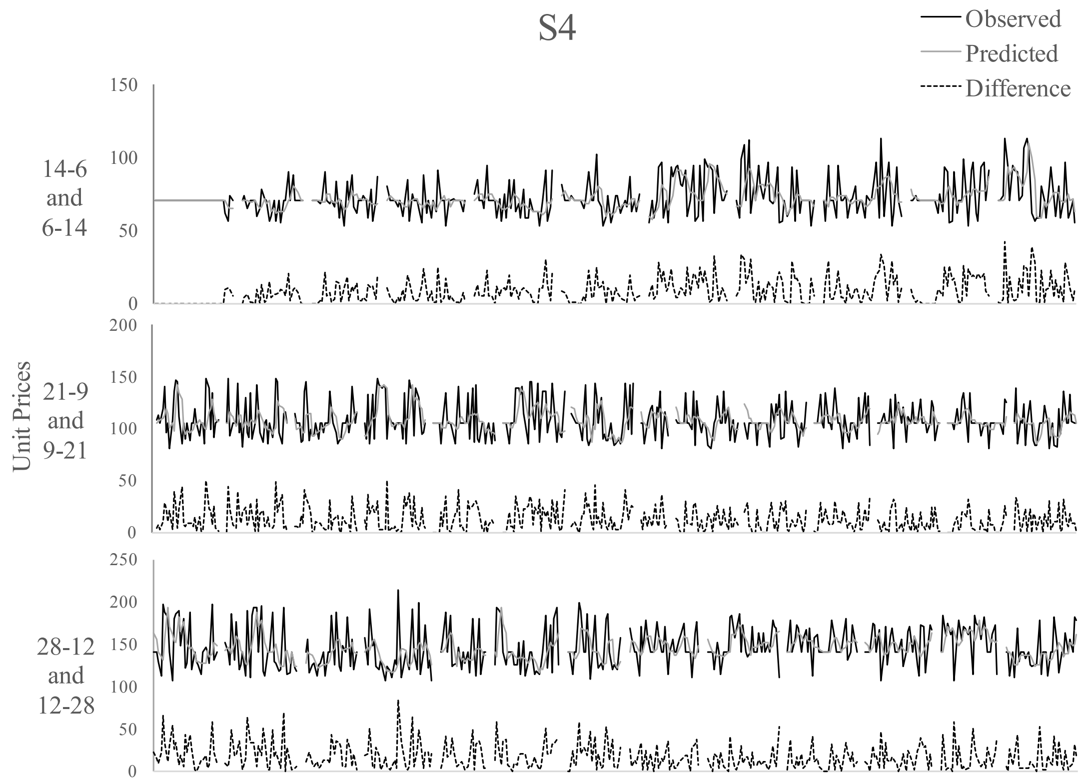


Figure 9: Predicted unit prices (gray lines) and observed unit prices (black lines) for all trials, sessions and phases for subject S2 and S3, considering a moving average between N=2 and N=4. The dotted lines are the difference between these two values.



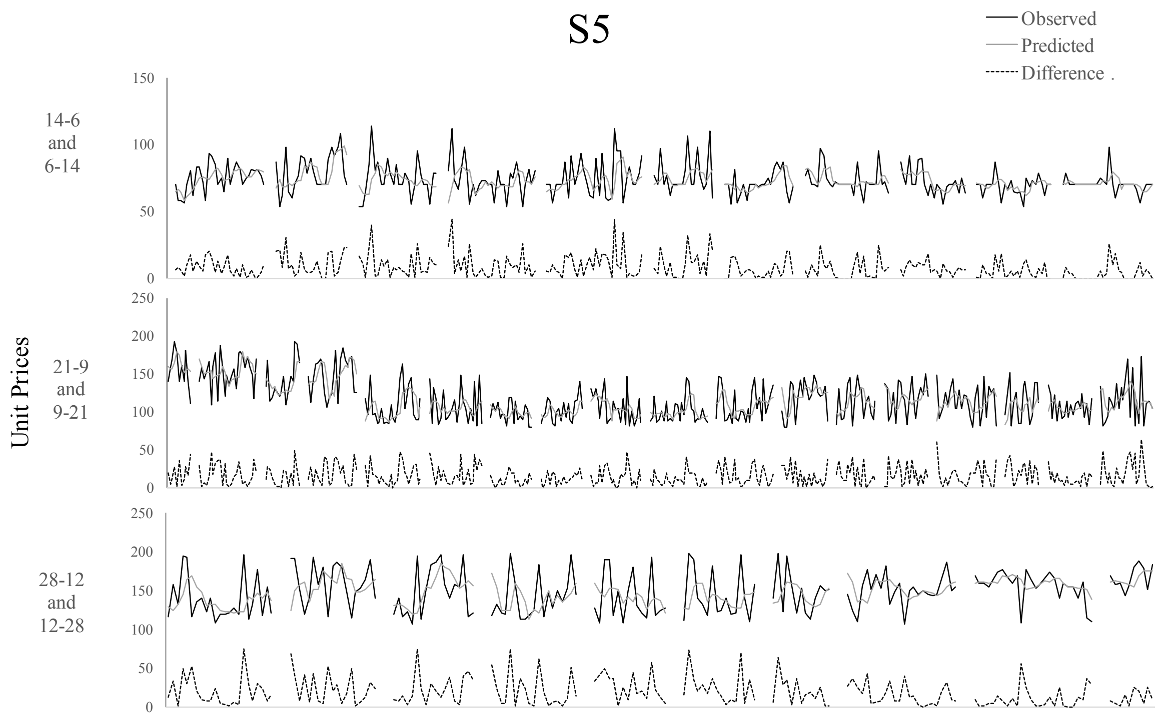


Figure 10: Predicted unit prices (gray lines) and observed unit prices (black lines) for all trials, sessions and phases for subject S4 and S5, considering a moving average between N=2 and N=4. The dotted lines are the difference between these two values.

Table 4 summarizes the predictive accuracy of this melioration model. It shows the percentages of observed unit prices that matched their predicted values, accepting an upper and lower margin of error of 5%. The shaded cells in the table are the cases in which more than 50% of that phase's trials were accurately predicted.

Table 4: Accuracy of melioration predictions, with an averaging window N= 2-4 periods.

Subject / Phase	S1	S2	S3	S4	S5
28-12	54%	49%	49%	43%	46%
12-28	44%	41%	40%	60%	67%
21-9	56%	42%	47%	54%	40%
9-21	46%	44%	50%	62%	42%
14-6	48%	38%	40%	43%	68%
6-14	68%	41%	57%	63%	51%

Although the melioration model used here was inspired in the study from Herrnstein *et all.*(1993), our results are not directly comparable to that work. The earlier experiment directly manipulated the averaging window as the independent variable, while the present study deducted this window based on the observed data. Nonetheless, it should be noticed that both models support similar conclusions in terms the adequacy of the melioration theory to explain choices when N has a low value. In general, our melioration model was able to accurately predict between 40% and 68% of the choices of four out of five subjects, using the moving average of the last 2-4 trials as predictors, on a local level of analysis. The best fits occurred with subject S4, about whom the model produced a good predictive power (above 50% of choices) in most of the experimental conditions, except for 28-12 and 14-6. The worst fits were the choices from subject S2, with only in 38%-49% accuracy, and from subject S3, whose choices were adequately predicted only in the lowest unit price range (6-14).

Package Categorization and Random Analysis

The maximization and satisficing models are based on the EBA notion that all experimental contingencies are a broad but identifiable set of response packages. The models focus on identifying if the subjects established any pattern of recurrently choosing one or more of these packages. If so, they supply a technical and conceptual framework to organize and explain these patterns. Thus, the first step in these analyses is to describe the environmental constraints that were present in our token system, and the possible response packages that could be formed by the subjects. For another example of this kind of EBA analysis in a simpler FR condition, see Rachlin et al (1981).

In the present procedure, both the intermediary and terminal links were always held constant, and all trials produced the same volume of 0.6 cc of sucrose solution. This was an environmental constraint. The only flexibility within this chain was located in the initial link, on the token-production schedule. Here, the subjects could form a broad range of response packages that would complete the trials. This range was defined in each experimental phase by the unit price, our primary independent variable. Unit prices were manipulated by simultaneously increasing the ratios on the FR and mixed schedules, while preserving the fact that exclusive responding in any of the schedules would complete the trial with the same number of wheel-spins. A critical aspect was that the subjects could “freely” switch between schedules at any point, before initiating the terminal link, and that some combinations of responses would initiate this link with a number of wheel spins lower than exclusive responses (thus, “pay” lower unit prices), and other combinations would initiate it with a number higher (“pay” higher unit prices) than exclusive responding.

The unit price resulting from exclusive responding was used as a reference point to categorize the non-exclusive packages in terms of their "efficiency". In this context, efficient packages are response combinations that resulted in unit prices equal or lower than exclusive responding. Inefficient packages are those that resulted in unit prices higher than exclusive responding. Efficient packages are labelled as "satisficing", expressing the assumption that the completion of these trials produced "good enough" trade-offs between the fixed volume of reinforcement and either (a) the physical effort of responding exclusively in one wheel, or (b) the physical effort of switching but having to emit less wheel-spins. Satisficing packages were further sub-categorized as exclusive, intermediary, and maximizing. Maximizing packages are the ones in which the terminal link initiated with the lowest possible number of responses allowed in this contingency. Intermediary packages are those in which switching between wheels resulted in a unit price above maximizing, but below exclusive packages. Exclusive packages are those in which the subject responded exclusively on one schedule, and thus, paid a fixed unit price established by the contingency. Package categorization is summarized in Table 5.

Table 5: Response Package Categorization

Experimental Conditions	Unit Price range (wheel-spins per 1 cc of sucrose)	Package Categories	
14 – 6 and 6 - 14	53 - 62	Satisficing	Maximizing
	63 – 69		Intermediary
	70		Exclusive
	71 – 102	Inefficient	
21 – 9 and 9 - 21	80 - 90	Satisficing	Maximizing
	91 – 104		Intermediary
	105		Exclusive
	106 – 155	Inefficient	
28 – 12 and 12 - 28	113 - 118	Satisficing	Maximizing
	119 - 139		Intermediary
	140		Exclusive
	141 - 197	Inefficient	

A working hypothesis in our study is that if a pattern of recurrent choices of satisficing or maximizing patterns can be identified, they can be attributed to (a) the fact that the response of switching between wheels became a function of either the “signals” of LED illumination and extinguishment, or the number of responses emitted in each schedule (a tandem schedule); or (b) that they are due to random choices. To estimate the chances of alternative (b), a mathematical analysis compared 250 random selection of packages that would be reinforced in each experimental condition. It showed that if reinforced packages were selected randomly, about 69% would be inefficient, and 31% would be satisficing. Table 6 compares the percentage of satisficing and inefficient packages actually observed and the estimations from this random model. The numbers within brackets are the standard deviations from the random samples. Except for subject S2 in Phases 14-6 and 6-14, all other observed percentages are significantly above the random percentages. In short, the comparison suggests that subjects were *not* choosing packages at random, but instead, they were actively selecting satisficing packages.

Table 6: Average percentage of observed and random satisficing packages

		Satisficing and inefficient package average distribution	
Phases	Subject	Observed percentages Satisficing - Inefficient	Random analysis (n=250) Satisficing - Inefficient
14-6 & 6-14	S1	58 - 42%	30 - 70% [±4%]
	S2	34 - 66%	
	S3	65 – 35%	
	S4	54 – 46%	
	S5	44 – 66%	
21-9 & 9-21	S1	60 - 40%	35 - 65% [± 4%]
	S2	49 - 51%	
	S3	63 - 37%	
	S4	66 - 34%	
	S5	61 – 39%	
28-12 & 12-28	S1	53 - 47%	31 - 69% [± 3%]
	S2	54 - 46%	
	S3	58 – 42%	
	S4	62 – 38%	
	S5	40 – 60%	

Figure 11 is an overview of the contingency, composed of four smaller figures. In all graphs, the x-axis shows responses on the mixed schedule and the y-axis is the number of responses in the FR schedule. Figure 11.A. shows where each package category will appear in the results. The white trapezoid is the satisficing area. The points (x, 0) and (0, y), where the trapezoid touches both axis, correspond to exclusive packages. Points located inside this area are intermediary and maximizing packages. Inefficient packages are located above the satisficing area. Packages located in the striped "lost" area were insufficient to complete a trial.

Figure 11.B focus on the consequences that the mixed schedule would produce during a trial. Packages located in the light-gray areas, labelled "Lost WS", are those in which the subject emitted some responses in the mixed schedule but switched wheels before earning tokens. Packages located in the dark-gray areas, labeled "token losses" are those in which the subject earned some tokens in the positive component of the mixed schedule, lost some of them in the negative component, and switched to the FR schedule before recovering these tokens. The two black circles are the two maximizing packages allowed in this contingency, marked as x_1 and x_2 They would be formed only if the subject emitted a number of responses in the mixed schedule (exactly x_1 or x_2), and then immediately switched to the FR schedule. Figure 11.C lists all response packages that would initiate the terminal link. Figure 11.D. overlaps 11.A, 11.B, and 11.C. Empty circles are inefficient packages. The circled horizontal lines are inefficient packages that ended with permanent token losses (dark-grey areas of Figure 11.B). The two black circles are maximizing packages. Gray circles are intermediary packages, located in the overlap between the satisficing area from Figure 11.A and the "Lost WS" bars from Figure 11.B.

This figure offers an overview, like a "contingency map", that helps to identify whether the subject's choices formed molar choice patterns, and to hypothesize about the organizing principle of such patterns. In other words, this “map” is a connection between the observed choices and the two molar EBA models of maximization and satisficing.

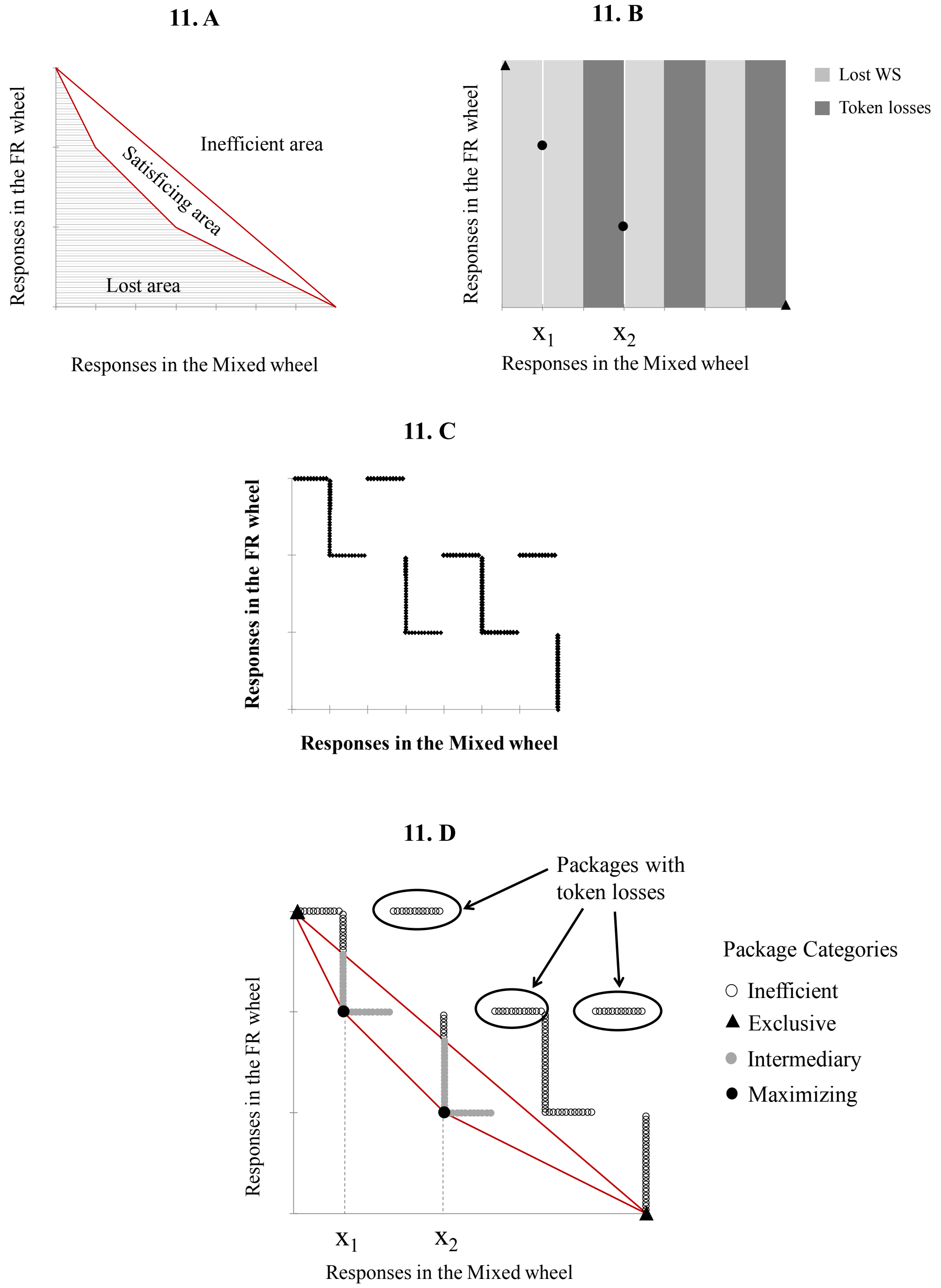


Figure 11: Graphical description of the contingency. Figure 11.A. shows three general areas of “lost responses”, satisficing and inefficient packages. Figure 11.B. marks areas in which the packages would have lost wheel-spins, or would have ended with token losses. Figure 11.C, show all packages that would initiate the terminal link. Figure 11.D. overlaps all others.

Figure 12 shows all observed satisficing packages in terms of exclusive and non-exclusive packages (maximizing and intermediary) in the two most-extreme unit price ranges, that is, on Phases 14-6 / 6-14 (lowest range), and 28-12 / 12-28 (highest range). Subjects names are listed in the right-side column. For 4 out of 5 subjects, the increase in unit price range produced a clear transition in the composition of satisficing packages. When in the lower unit price range (14-6/ 6-14) subjects S1, S2, S3, and S5 produced 88, 27, 179, and 118 exclusive packages, respectively. These numbers fell to 14, 0, 141, and 15 in the higher unit price range (28-12/ 12-28). The opposite tendency happened with non-exclusive packages, which were less selected in the lower unit price range (25, 78, 60, and 91 trials respectively) than in the higher unit price range (98, 142, 180, and 98 trials, respectively). Subject S4 showed the same tendencies in terms of non-exclusive packages, with an increase from 59 trials in the lowest price ranges to 121 in the highest price ranges. Different from the others, this subject showed a smaller fall in the number of exclusive packages, from 160 to 131 trials. Also differently, he maintained his preference for exclusive packages during Phases 28-12/ 12-28.

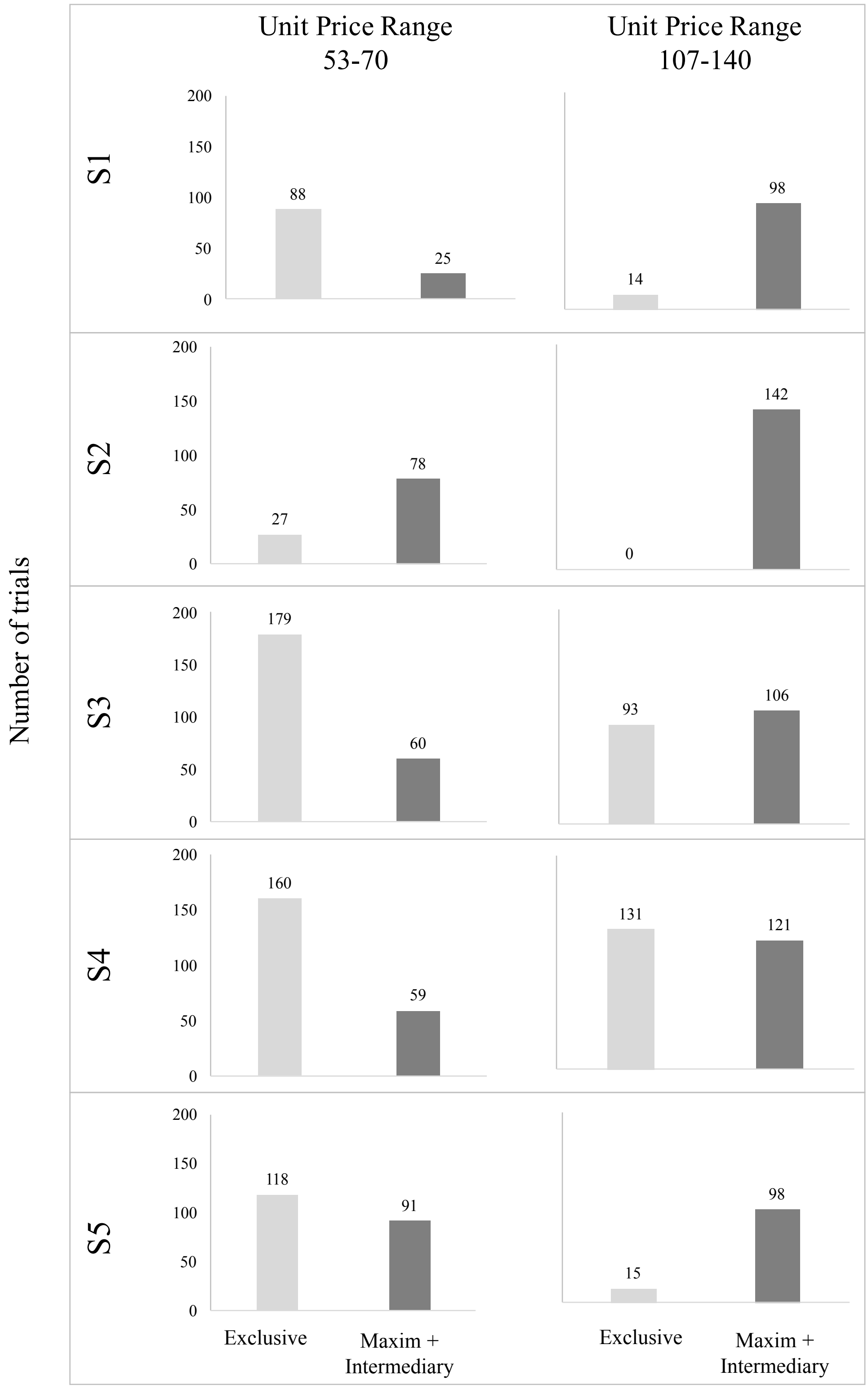


Figure 12: number of satisficing packages in the phases with the lowest (left graphs) and highest unit price ranges (right graphs). Columns in light gray are exclusive packages; darker grays are non-exclusive packages (sum of maximizing and intermediary).

Maximizing Analysis of the Results

Packages that attended one of the following criteria were categorized as maximizing:

- With enough responses on the mixed schedule to produce only three tokens, plus enough responses on the FR schedule to produce four tokens, plus three wheel-spin responses on either schedule.
- With enough responses on the FR schedule to produce only two tokens, plus enough responses on the mixed schedule to produce four tokens (that is, three tokens in the positive component, two removals in the negative component, followed by three more tokens in the positive component), plus three wheel-spins on either schedule.

These packages would be positioned on the black circles (x_1 or x_2 points) on Figure 11.D. Table 7 compares the observed percentage of maximizing packages and the percentages of packages predicted by the random model. The shaded gray cells emphasize the occasions in which the observed percentages were significantly above the predictions from the random model.

Table 7: Average percentage of observed and random maximizing packages

Phases	Subject	Observed percentages	Random analysis (n=250)
14-6 & 6-14	S1	14%	15% [±3%]
	S2	28%	
	S3	12%	
	S4	17%	
	S5	12%	
21-9 & 9-21	S1	14%	16% [± 2%]
	S2	24%	
	S3	17%	
	S4	13%	
	S5	21%	
28-12 & 12-28	S1	24%	13% [± 2%]
	S2	22%	
	S3	10%	
	S4	11%	
	S5	14%	

Satisficing Analysis of the Results

The satisficing analysis was based on the package categorization exposed in Table 5, and the contingency analysis illustrated in Figure 11. Figures 13-17 show the observed packages in all phases and conditions. There are three larger graphs for each subject, plotting all packages formed under the three unit price ranges. The percentage in the upper left part of these larger graphs is the proportion of observed satisficing packages (extracted from Table 6). These large graphs have the same axis scale to facilitate the observation of the effects of unit price manipulation. The smaller graphs on the left side of the figures, segment the same data in terms of the two conditions, FR-Mix and Mix-FR. These axis scales differ by phase. The vertical gridlines are where responses in the mixed schedule would result in packages with permanent token losses.

In general, raising unit price range from Phases 14-6 / 6-14 to Phases 21-9 / 9-21 increased the efficiency of package selection. The percentage of satisficing packages is larger in Phases 21-9/ 9-21 than in 14-6/ 6-14 for most subjects, except for S3, who produced similar percentages in both phases (65% and 63%). The second increase in unit price range, from Phases 21-9 / 9-21 to 28-12 / 12-21 did not have the same effect. The percentage of satisficing packages decreased for subjects S1, S3, S4, and S5 from 60%, 63%, 66%, and 61% to 53%, 58%, 62%, and 40%, respectively. This suggests that package formation was a function of unit prices, but not in a linear way. When the ranges were too low or too high, satisficing packages were chosen less frequently. The higher percentage was found at the middle unit price range.

A comparison between Figure 11.D and the larger (phase) graphs from Figures 13-17 reveals a reduction in packages situated in the inefficient area, and a concentration in the areas closer to four critical points: the two exclusive and the two maximizing packages. A recurrent form in the large graphs resembles a letter "L". They are formed by series of packages that form vertical and horizontal lines. Vertical lines are the result of packages with the same number of responses on the mixed schedule, and various numbers on the FR schedule. They suggest that responses were strongly under the control of the mixed schedule, i.e. of the illumination and removal of tokens. Horizontal lines are packages with a limited number of responses in the FR schedule, and a wide range of responses in the mixed schedule.

Some of the vertical and horizontal lines connect at the points where the two maximizing packages are located. For examples, see subjects S1, S3 and S4 in Phases 21-9 / 9-21. These "L" forms might derive from packages in which the subjects "missed" the exact switching point that would form a maximizing package, either by giving too many responses in the FR schedule (vertical lines) or too many responses on the mixed schedule (horizontal lines). Another common feature in most larger (phase) graphs are vertical lines connected to the points of exclusive responding, that is, (0,y) and (x,0). Examples are subjects S3 and S4 in the 28-12 / 12-28 phase. They derive from trials in which the subjects started responding in one wheel, but abandoned it before they were reinforced with any token, switched, and completed the trial by working the full requirement on the other wheel.

A general strategy for analyzing the larger graphs is to consider that the "shorter" the vertical and horizontal lines, the higher the probability of forming satisficing packages. For instance, subject S1 form "shorter" lines in Phase 21-9 / 9-21 than in Phase 28-12 / 12-28, which coincides with the fact that the proportion of 60% satisficing packages in Phases 21-9/ 9-21 is larger than the proportion of 53% in Phases 28-12 / 12-28.

The smaller graphs provide more details about how these large patterns were formed. When subjects S1 (Figure 13) and S3 (Figure 15) were in the FR-Mix condition of the three phases, their packages form vertical lines, located exactly in between the token loss gridline, meaning that these packages ended with no token losses. When these subjects were on the Mix-FR conditions, their graphs form many horizontal lines and some vertical lines. The token loss gridlines are frequently “touched”, meaning that there were many packages that ended with permanent token losses. So, whenever the mixed schedule was on the left wheel, subjects S1 and S3 chose more satisficing packages. Subject S4 (Figure 16) had an inverse side bias, and showed the exact opposite tendency: he formed horizontal lines under FR-Mix conditions and vertical lines under the Mix-FR conditions. So, the “L” patterns that appear in the larger (phase) graphs from subjects S1, S3, and S4 result from the overlap of two very distinct tendencies: vertical lines in one condition and horizontal lines in the other.

This did not happen with subjects S2 and S5, who had weak side biases. Their smaller (condition) graphs do not show inverted tendencies of vertical and horizontal lines. On the contrary, all of their smaller graphs show “L” forms, no matter the condition they were in. The only exception is when subject S5 (Figure 17) forms horizontal lines in the FR-Mix condition of Phase 28-12. It might be relevant that, by that time, S5 was favoring the left wheel, similar to S4.

To sum up the results from Figures 13-17, the smaller (condition) graphs show that each subject had a distinct tendency for package selection, correlated with side biases. The larger (phase) graphs suggest that they all showed similar tendencies of selecting more satisficing packages as a function of unit price range, with a higher selection in Phases 21-9 / 9-21.

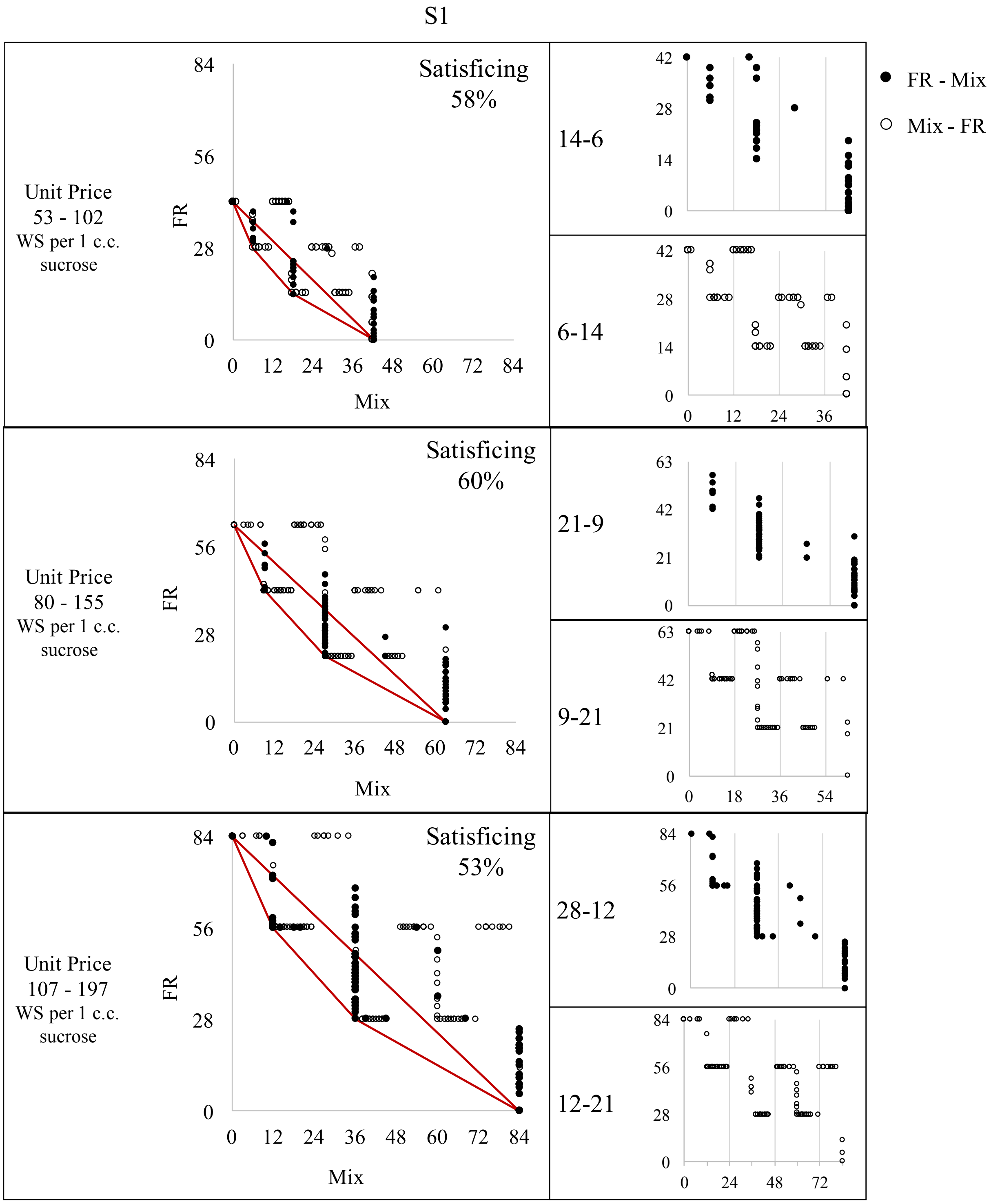


Figure 13: Distribution of response packages from subject S1 across three unit price ranges and six experimental conditions (FR-Mix and Mix-FR). The abscissas show the number of responses in the mixed schedule; the ordinates show the same information for the FR schedule. The large graphs have the same scale, and the smaller graphs have their scales adapted to the condition’s specific limits.

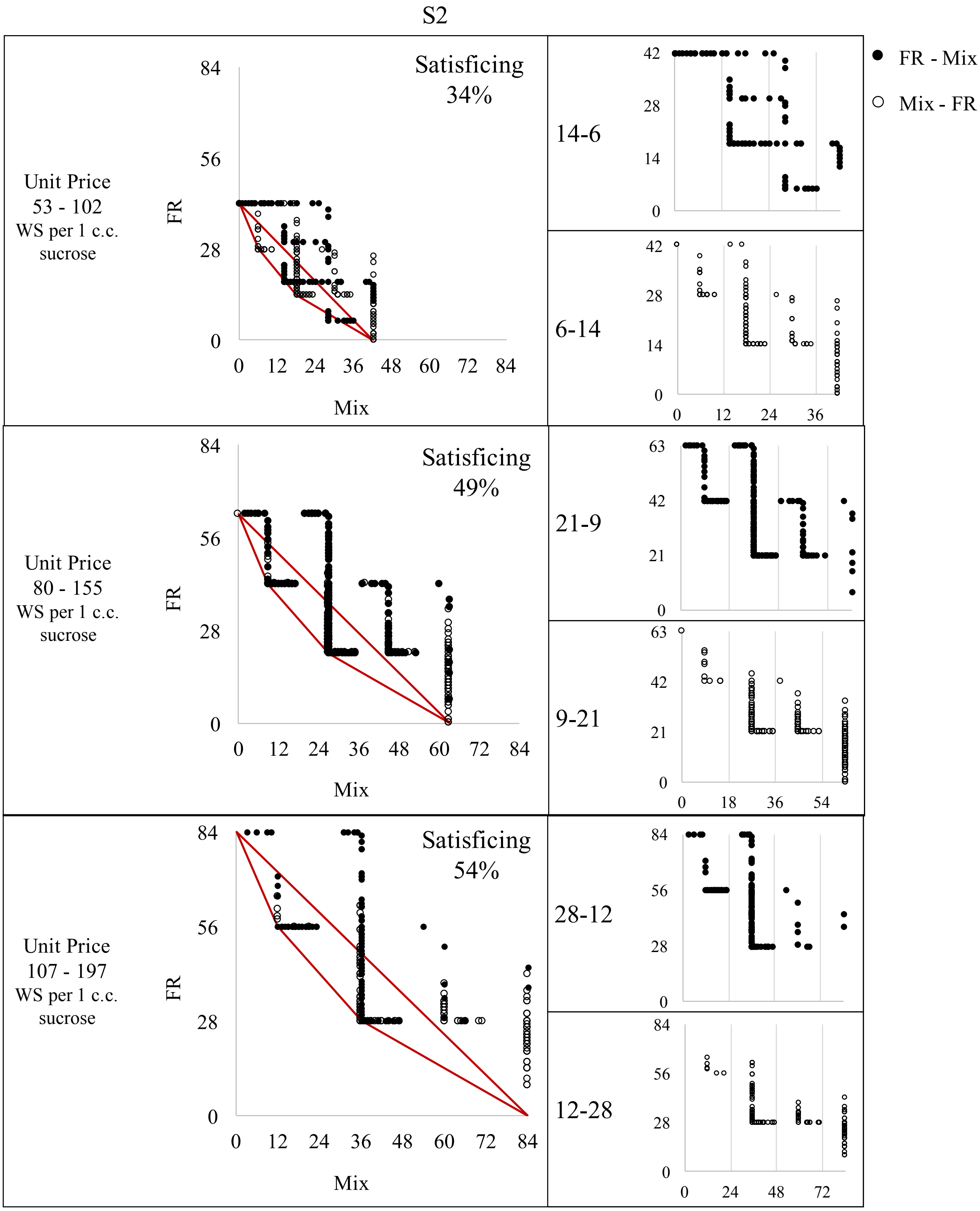


Figure 14: Distribution of response packages from subject S2 across three unit price ranges and six experimental conditions (FR-Mix and Mix-FR). The abscissas show the number of responses in the mixed schedule; the ordinates show the same information for the FR schedule. The large graphs have the same scale, and the smaller graphs have their scales adapted to the condition's specific limits.

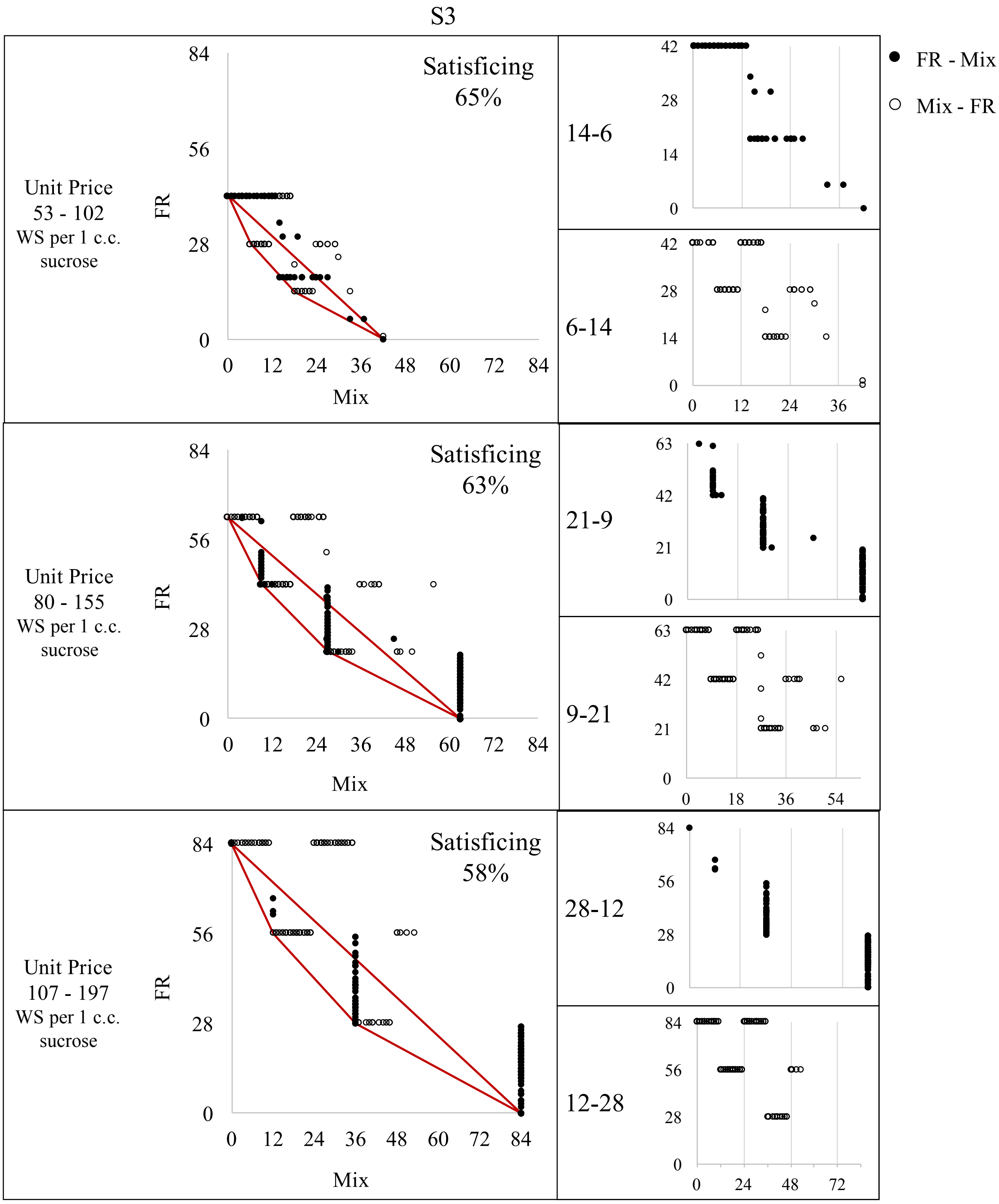


Figure 15: Distribution of response packages from subject S3 across three unit price ranges and six experimental conditions (FR-Mix and Mix-FR). The abscissas show the number of responses in the mixed schedule; the ordinates show the same information for the FR schedule. The large graphs have the same scale, and the smaller graphs have their scales adapted to the condition's specific limits.

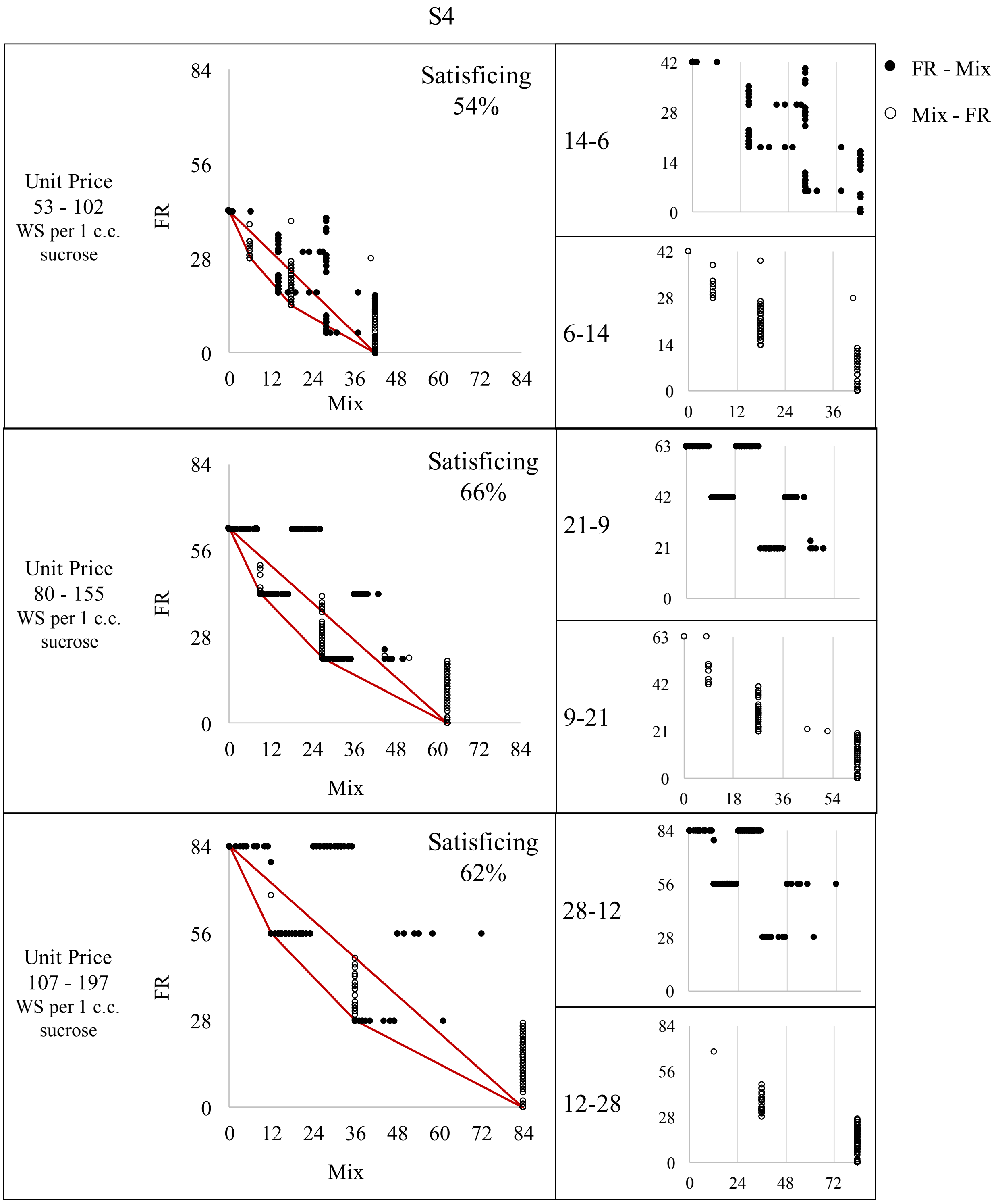


Figure 16: Distribution of response packages from subject S4 across three unit price ranges and six experimental conditions (FR-Mix and Mix-FR). The abscissas show the number of responses in the mixed schedule; the ordinates show the same information for the FR schedule. The large graphs have the same scale, and the smaller graphs have their scales adapted to the condition's specific limits.

S5

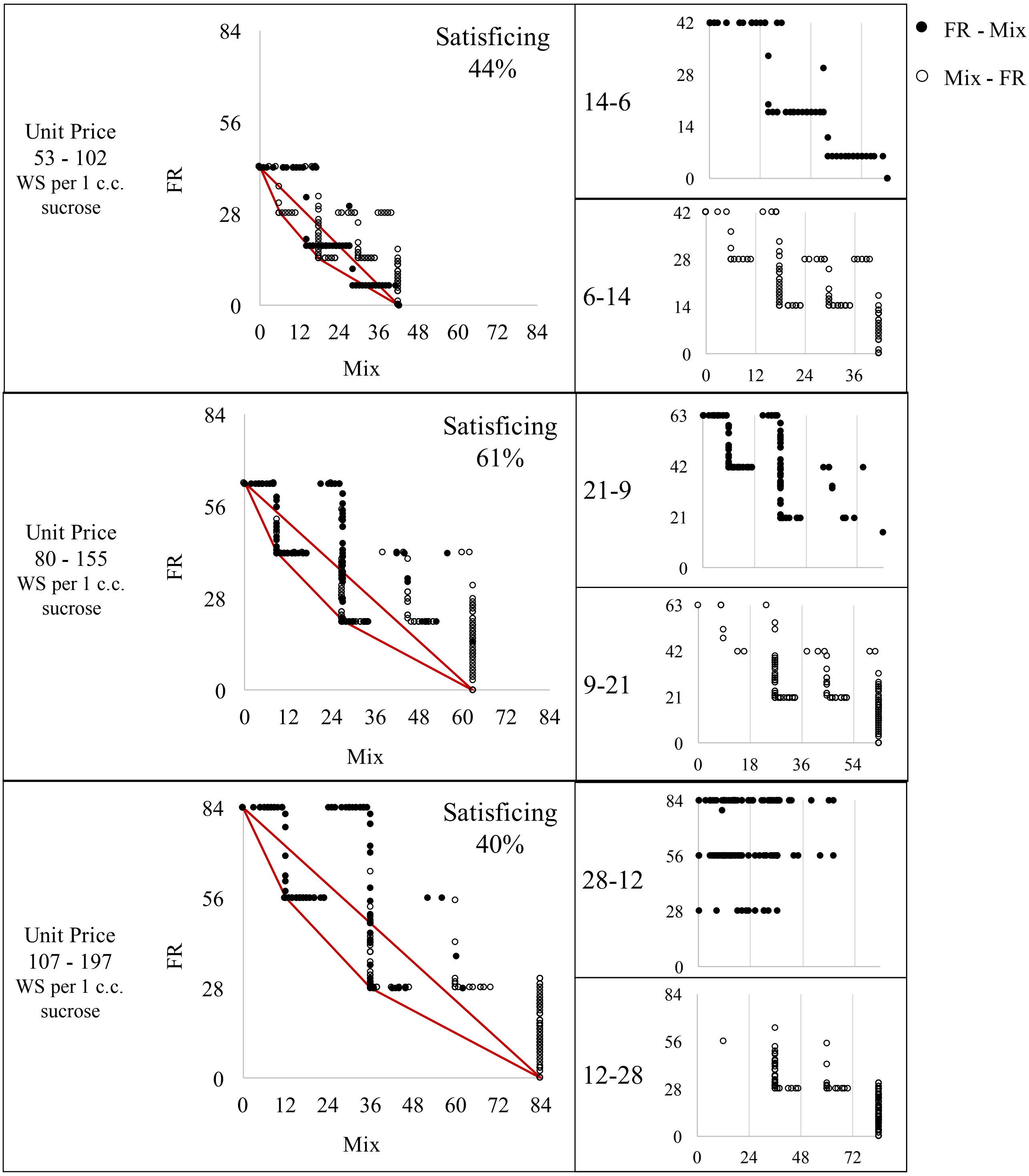


Figure 17: Distribution of response packages from subject S1 across three unit price ranges and six experimental conditions (FR-Mix and Mix-FR). The abscissas show the number of responses in the mixed schedule; the ordinates show the same information for the FR schedule. The large graphs have the same scale, and the smaller graphs have their scales adapted to the condition's specific limits.

Figure 18 shows the observed percentage of each package category per phase and condition. The horizontal lines mark the percentage of satisficing packages that would be expected if subjects were choosing packages at random. These random limits are 69%, 65%, and 70% for phases 14-6 / 6-14, 21-9 / 9-21, and 28-12 / 12-28, respectively. The percentage of satisficing packages exceeds these random limits in most sessions, suggesting that there was an organizing rule guiding choice selections beyond random pickings.

The kind of satisficing packages that prevailed per phase - maximizing, intermediary, or exclusive - changed with unit price ranges. In the lower range (14-6 and 6-14) subjects S1, S3, S4, and S5 chose more exclusive packages (the light-gray bars) and only small percentages of the other two categories. Subject S2 chose the three categories equally in these phases. As unit price ranges increased, they show a gradual reduction in the percentage of exclusive packages, and increases in the percentage of intermediary and maximizing packages. This suggests that increases in unit price ranges produced a refinement in the selection of satisficing packages towards packages with lower unit prices. It is unclear, however, if this selection is moving towards an increase in maximizing packages (black bars) or towards a stabilization of intermediary packages (dark-gray bars).

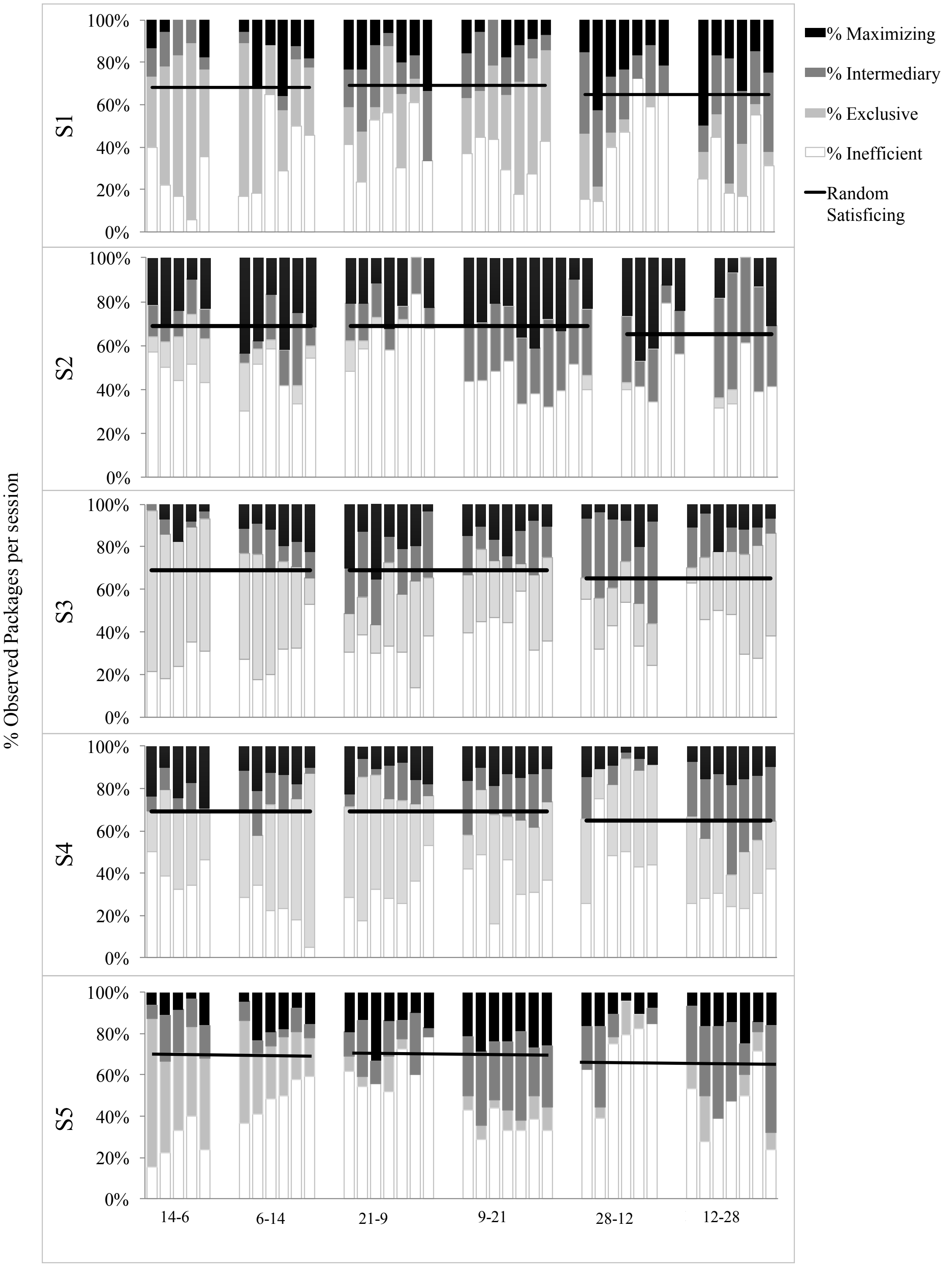


Figure 18: Percentage of maximizing (black bars), intermediary (dark gray), exclusive (light gray) and inefficient (empty) packages per session in all experimental phases and conditions. The horizontal lines are the percentage of satisficing packages (maximizing, intermediary, and exclusive) that would occur if packages were selected randomly. The number of sessions per condition differs by subject, as condition changes depended on the subject achieving consumption stability.

Table 8 compares the descriptive accuracy of each of the three models of choice used in this investigation. The melioration model had a good predictive accuracy at either the lower unit price ranges or the higher ranges for three out of five subjects (S1, S4, and S3) and a good accuracy for subject S3 in one of the lower unit price range conditions (6-14). In contrast, the maximization model had a poor performance describing the choices of four out of five subjects, but was the best model to predict the choices of subject S2, who was exactly the one that completely evaded the melioration model. The satisficing model was the one that captured the larger percentage of choices among the three models, but it also performed poorly in describing the choices of subject S2 in the two lower unit price ranges. So, it seems that the maximization model was not a good model of choice for the present experiment in general, but it captured the performance of one specific subject that would be considered an outlier in the other models. That result supports the proposition of complementarity among the models, as each one seems to capture behavioral patterns established by some subjects, but not from every existing subject. It does not seem like a stretch to imagine that different human beings interacting outside of the laboratory might establish of different functional relations, even if all subjects have been submitted to similar environmental contingencies.

Table 8: Comparative descriptive accuracy of choice models

Subject / Model	S1	S2	S3	S4	S5
Melioration	6-14 21-9 28-12	-	6-14	All except 14-6 & 28-12	6-14 14-6 12-28
Maximizing	28-12 12-28	All phases	-	-	21-9 9-21
Satisficing	All phases	28-12 12-28	All phases	All phases	All phases

General Discussion of the Models

The results of the maximizing analysis exposed in Table 7 does not make a strong case in favor of the validity of using this model in our experiment in general, but this model captured the behavioral patterns of one subject, S2, better than the other two models. One distinguishing characteristic of S2 was his weak side bias, which could have accounted for him being more adaptive to the experimental manipulations. He shared this characteristic with S5, with whom the maximizing model also showed a good predictive accuracy in Phase 21-9/ 9-21. So, maximizing might not be a viable predictive model for all subjects in our experimental situation, but it was a good predictor of choices from subjects with weak biases. Maybe these subjects have greater flexibility to adapt to changing environmental constraints than the ones with stronger biases. Subjects S1 and S5 achieved a percentage of maximizing packages above what would be expected if they were selecting at random, but only in the higher unit price ranges: Phase 28-12/ 12-28 for S1, and 21-9/ 9-21 for S5. This suggests that a more demanding environment might have induced these subjects to search for "better" packages, i.e. for packages that minimize the ratio of wheel-spins per trial, while a less demanding situation did not induce such a search. If confirmed, this would indicate that maximizing might be a good model to describe choices under more stringent contingencies.

These comments on the maximizing model are aligned with a general account of maximizing in the economic view. There is plenty experimental data showing that not all individual subjects maximize, but that some actually do. One recurrent argument from a traditional (non-behavioral) economic approach is that the maximization theory is more adequate to predict tendencies from large populations, but it is not necessarily applicable to every single individual. One popular theory in traditional economics states that as people interact in the marketplace, those who are able to maximize would achieve better results and become more successful than their peers, who will gradually become less competitive and be excluded from that marketplace. In other words, when subjects are in direct competition among themselves, the marketplace would select "maximizers" and eliminate those who cannot achieve such patterns of choice. It is possible that all subjects were capable of forming maximizing packages, but the number of sessions was not sufficient to train them all in the precise responses that resulted in these packages. They were the result of a very refined functional relation between switching and token removal. It is also possible that some subjects could be trained to maximize, while others could not, no matter the number of sessions. Future studies might consider using a higher number of sessions per condition to verify if more subjects would start selecting maximizing packages, and/or other manipulations that can increase maximization.

The melioration analysis in Table 4 suggests that this model provided accurate descriptions for the choices of three subjects S1, S4, and S5. It should be emphasized that under condition 6-14, melioration produced good predictions for 4 out of five subjects (except S2). Also of notice is the fact that the inferred N value for the moving average analysis were relatively small, between N=2 and N=4. These results might be complementary to those gathered by Herrsntein et all. (1993). In that study, they concluded that melioration and maximization were functionally related to the width of the averaging window, and that melioration was more likely to occur when the window was small. Consonant with that conclusion, our deducted values of N were small *and* melioration provided a better fit than maximization for most subjects.

Table 8 shows that the satisficing analysis had the best descriptive power in this experiment, for most phases and subjects. Satisficing packages (i.e. maximizing *and* intermediary *and* exclusive) accounted for more than 50% of choices, except for subject S2 in

Phases 14-6/ 6-14 and 21-9/ 9-21 (34% and 49%, respectively) and subject S5 in Phases 14-6/ 6-14 and 28-12/ 12-28 (44% and 40%). Once again, these are exactly the two subjects whose choices were better described by maximization.

It is possible to attribute the better performance of the satisficing model to the nature of the present experimental contingency. Different from other EBA investigations on concurrent choices, our experiment did not establish any punishment for switching between wheels (COD), and thus, did not induce exclusive preferences for one schedule or the other. Freed from this constraint, the subjects actively combined both schedules and produced various assorted packages. This complexity might have provided a better approximation to out-of-the-laboratory reality of choices, but it also imposed challenges to the quantitative analyses of the results. The majority of trials in the present study were completed by non-exclusive packages in which the subjects earned tokens in *both* schedules, so there is no precise way to attribute the terminal reinforcement to one schedule or the other. The impossibility of directly linking each reinforcement to one specific schedule prevented the use of the matching equation or similar kinds of analyses that compare relative responding to relative reinforcement. These calculations demand another type of experimental procedure, with a COD in place. The satisficing theory was built exactly to account for complex situations, where multiple layers of values are involved, and clusters of preference might form. So, it might not come as a surprise that the satisficing model provided a better description of the present pattern of complex choices.

Figure 12 shows that different kinds of satisficing packages were selected as a function of unit price ranges. At low unit prices, exclusive packages were chosen more often than non-exclusive (intermediary and maximizing). The exact opposite happened at higher unit price ranges, with a higher frequency of intermediary and maximizing packages. It is possible to recall the concept of dynamically-changing aspirational levels, and hypothesize about the reasons for these observations. Simon (1956; 1978; 1990) suggested that previous experiences and changing environmental conditions would affect the aspirational level, either by expanding or shrinking the threshold criteria for which alternative would compose the cluster of “good enough” options. As the experimental constraints became more stringent, intermediary and maximizing packages were picked more frequently, suggesting a change in the selection criteria or aspirational level.

As a final note, the present experiment created a complex set of conditions that (supposedly) more closely resemble the ones in which repeated choices are made outside of the laboratory. One risk of arranging this contingency was that the results could become too “polluted”, with too many variables, to allow for valid and accurate descriptions. This did not happen here. All three choice models – maximization, melioration and satisficing – provided good explanations at some levels of observation for some subjects. This can lead to (at least) two possible directions for future investigations. One would be to examine que question “how can we change the present procedure, so that the accuracy of one model or the other would be increased?”. This would help identifying the variables that “tipped the scale” towards one model or the other. Another line of inquiry would be to compare the results of the present experiment to patterns of choices that happen in non-controlled situations, like with humans in the marketplace. The first investigative venue shows an inclination to the inquisitive framework of a behavioral analyst; the second might be a more inspiring investigation to an economist. Both would be of interest to EBA research, reflecting the rich pluralism of this area.

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