Essays in Behavioral Economics

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DIRECTORS DE LA TESI

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To my family.

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Abstract

This thesis comprises three chapters on topics in behavioral and experimental economics. In the first chapter, I show formally that, in a limited attention framework, the choices made by a decision maker who considers at least two available alternatives under sequential elimination are consistent with preference maximization, whereas this is not necessarily the case under the direct procedure. Furthermore, I implement a randomized controlled experiment, which finds causal evidence that sequential elimination leads to an economically meaningful improvement in individual consistency, especially for subjects with low cognitive ability. The second chapter studies the impacts of visual and auditory strategies on consumer behavior in mobile advertising by a novel data set of two large-scale randomized field experiments. The third chapter implements a randomized controlled experiment and finds causal evidence that providing auditory descriptions of decisions, compared to visual descriptions, leads to severe impairment in economic rationality.

Resum

Aquesta tesi consta de tres capítols sobre temes d'economia conductual i experimental. En el primer capítol, mostro formalment que, en un marc d'atenció limitada, les eleccions fetes per un decisor que considera almenys dues alternatives disponibles sota eliminació seqüencial són coherents amb la maximització de preferències, mentre que això no és necessàriament el cas en el procediment directe. A més, implemento un experiment controlat aleatoritzat, que troba proves causals que l'eliminació seqüencial condueix a una millora econòmicament significativa de la consistència individual, especialment per a subjectes amb baixa capacitat cognitiva. El segon capítol estudia els impactes de les estratègies visuals i auditives en el comportament dels consumidors a la publicitat mòbil mitjançant un nou conjunt de dades de dos experiments de camp aleatoris a gran escala. El tercer capítol implementa un experiment controlat aleatoritzat i troba proves causals que proporcionar descripcions auditives de decisions, en comparació amb descripcions visuals, condueix a un greu deteriorament de la racionalitat econòmica.

Preface

This thesis contains three chapters on analyzing behavioral economic issues through experiments.

In the first chapter, I investigate the impact of sequential elimination, in which individuals eliminate alternatives sequentially until only one survives, on individual consistency with preference maximization. First, I develop a limited attention framework incorporating the evidence from marketing and psychology that individuals consider at least two alternatives when choosing among multiple alternatives. I show that sequential elimination improves individual consistency compared to the direct procedure, where individuals choose directly from a menu. The explanation is intuitive: one of the best alternatives in a menu survives every elimination, either by not being considered or by beating the other alternatives in the set of considered alternatives. Then, I implement an experiment to test empirically whether sequential elimination facilitates consistency. Subjects are randomly assigned to a risky decision-making task involving one of the two procedures. I measure consistency by the number of violations of the Generalized Axiom of Revealed Preference (GARP), a necessary and sufficient condition for preference maximization (Afriat, 1967; Varian, 1982, 1983). I find causal evidence that sequential elimination leads to an economically meaningful improvement in individual consistency, especially for subjects with low cognitive ability. In addition, the experiment includes a third treatment where subjects are allowed to select either the direct procedure or sequential elimination. My analysis suggests that most of the subjects with low cognitive ability choose sequential elimination over the direct procedure. The experiment also reveals a negative relationship between cognitive ability and risk aversion, overall and especially under sequential elimination. Finally, I discuss the policy implications of the results.

The second and third chapters are joint papers with Fadong Chen. In the second chapter, we exploit a novel data set of two large-scale randomized field experiments to investigate the impacts of two behavioral strategies on consumer behavior in mobile advertising. The first experiment investigates a visual strategy that adds a red dot containing a random number to an icon linking consumers to advertising games (i.e., games containing advertisements for products) on a weather app. We find that the visual strategy increases consumers' visits to advertising games. The second experiment provides sound effects to advertising games as an auditory strategy. Our analysis shows that the auditory strategy has a persistent positive impact on the consumers' visits to advertisements in the games. We discuss potential mechanisms that could account for the results. Our findings suggest that behavioral strategies altering payoff-irrelevant attributes can enhance individual attention and behavior at relatively low costs, which may be relevant to many real-world settings.

In the third chapter, we examine the impact of perceptual descriptions of decisions on economic choice behavior. We conduct a controlled laboratory experiment that randomly assigns subjects to make decisions under one of the two treatments: (1) the visual description treatment in which they can only see each option serially; (2) the auditory description treatment in which they can only hear each option serially. We find that subjects in the auditory description treatment reveal a significantly lower level of economic rationality compared to those in the visual description treatment in terms of both the number of GARP violations and the severity measured by Afriat (1972)'s Critical Cost Efficiency Index. This indicates that deciding by hearing could lead to substantial welfare losses. Moreover, subjects spend significantly more time in the auditory description than in the visual description treatment. Finally, auditory descriptions result in less risk-averse choices than visual descriptions; this is especially significant for females. Our results raise a concern about welfare loss in choice contexts where auditory descriptions play a major role.

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Chapter 1

INDIVIDUAL RATIONALITY UNDER COGNITIVE LIMITATIONS: THE EFFECT OF SEQUENTIAL ELIMINATION

1.1 Introduction

There is broad evidence that individual choices are inconsistent with preference maximization (e.g., Choi et al., 2007; Echenique et al., 2011; Choi et al., 2014; Carvalho et al., 2016; Dean and Martin, 2016). The evidence suggests substantial welfare issues that deserve attention from economists and policymakers. In particular, individual inconsistency may be fundamentally caused by cognitive limitations (Simon, 1955; Burks et al., 2009; Rustichini, 2015), which could be difficult to overcome by public policy. In other words, there is a severe concern about the welfare of a considerable proportion of the population, especially of those with relatively low cognitive ability, plausibly including the elderly (Abaluck and Gruber, 2011, 2016).[1] Despite the wealth of research on individual inconsistency, few studies have addressed the crucial question of how to improve individual consistency under cognitive limitations.

I provide the first study on whether a simple *choice procedure* can improve individual consistency under cognitive limitations. According to prior research, a primary consequence of cognitive limitations may be *limited attention*, which postulates that people only consider a limited set of available alternatives (Eliaz and Spiegler, 2011; Masatlioglu et al., 2012; Dean et al., 2017; Lleras et al., 2017).[2] Following this strand of literature, I study a decision maker (DM) with a rational preference relation and limited attention. Importantly, I assume the minimum property of limited attention that the DM considers at least two alternatives when faced with a menu of multiple alternatives, based on the converging evidence from experiments (Krajbich and Rangel, 2011; Reutskaja et al., 2011) and the field (Honka et al., 2017; Barseghyan et al., 2021).

Since Simon (1955), the notion of choice procedures has been acknowledged for its fundamental role in shaping choice behavior (e.g., Simon, 1976; Aumann, 2008; Salant, 2011). Drawing on this notion, I develop a formal framework of limited attention to examine the DM's choice consistency in two choice procedures. One is the *direct procedure*, where the DM chooses directly from the menu. Limited attention may cause choice inconsistency in this procedure due to the DM overlooking the best alternatives on the menu. This leads me to the investigation of *sequential elimination*, in which the DM eliminates alternatives sequentially until only one survives. This procedure has been studied widely in marketing, psychology—and more recently,—economics.[3] It has been shown to reduce choice overload (Besedeš et al., 2015) and to encourage people to consider more alternatives (Huber et al., 1987; Yaniv and Schul, 1997, 2000; Sokolova and Krishna, 2016). Building on the established evidence, I present the first research on

[1]Evidence from the cognitive sciences suggests that normal aging may cause cognitive decline in the elderly due to brain degradation (Hedden and Gabrieli, 2004; Bishop et al., 2010).

[2]See also stochastic choice models of limited attention, e.g., Manzini and Mariotti (2014), Brady and Rehbeck (2016), Caplin et al. (2019), Cattaneo et al. (2020), and Dardanoni et al. (2020).

[3]See Section 1.1.1 for the literature review of sequential elimination.

the role of sequential elimination in improving individual consistency.

I show that the DM makes choices consistent with preference maximization under sequential elimination. An intuitive explanation for this result is that one of the best alternatives in a menu survives in every elimination, either by not being considered or by beating the other alternatives in the set of considered alternatives. In effect, sequential elimination decomposes a potentially complex (preference) maximization problem into an equivalent sequence of elimination subproblems, each of which is manageable to solve. Based on these results, I formulate the main hypothesis in this paper, which is that individuals make choices with a higher level of consistency under sequential elimination than under the direct procedure. In addition, the cognitive-ability interpretation of limited attention implies another key hypothesis; namely, that sequential elimination especially improves the consistency of individuals with low cognitive ability.

To test the hypotheses, I implement an experiment involving risky decision problems, each representing a list of portfolio options from a unique budget line. Each option rewards one of two amounts of money with equal probability. In the experiment, subjects are randomly assigned to one of the three choice procedure treatments: (1) *Direct Procedure*; (2) *Sequential Elimination*; and (3) *Free Procedure*, where subjects are allowed to select one of the first two procedures.[4] Cognitive ability is expressed as IQ scores obtained from the International Cognitive Ability Resource (ICAR) test (Condon and Revelle, 2014). Consistency is measured by the number of Generalized Axiom of Revealed Preference (GARP) violations; GARP is a necessary and sufficient condition for choices to be consistent with preference maximization (Afriat, 1967; Varian, 1982, 1983).[5] More GARP violations indicates a lower level of consistency. The hypotheses can be tested causally by comparing the numbers of GARP violations in the first two treatments. In addition, I compute the number of first-order stochastic dominance (FOSD) violations, which are defined as choosing an option over another that

[4]Henceforth, where initially capitalized, the terms Sequential Elimination and Direct Procedure refer to the respective treatments in the experiment; otherwise, they refer to their respective general meanings.

[5]I discuss other consistency measures in Section 1.3.1.1. See also Apesteguia and Ballester (2015) and Halevy et al. (2018) for detailed discussion of consistency measures.

offers better outcomes without additional risk. FOSD violations, while not implying GARP violations, are typically regarded as mistakes. GARP is the minimal criterion for economic rationality, and FOSD complements GARP in decision-making under risk. Lastly, the Free Procedure helps provide insights into individual preference for sequential elimination.

The main experimental results show that Sequential Elimination reduces GARP violations by almost 76% (with statistical significance approaching conventional levels) and FOSD violations by almost 63% (with statistical significance) compared to the Direct Procedure. Furthermore, I find that Sequential Elimination leads to a statistically significant and economically substantial (over 94%) reduction in the number of GARP violations by low-IQ subjects (i.e., those with below-or-equal-to-median IQ scores) compared to the Direct Procedure. There is no evidence that Sequential Elimination affects the consistency of high-IQ subjects (i.e., those with above-median IQ scores). Nevertheless, the reduction in the number of FOSD violations committed by high-IQ subjects under Sequential Elimination relative to the Direct Procedure (almost 97%) is statistically significant. Most importantly, these results provide causal evidence in favor of the hypotheses, thereby narrowing the gap in the literature on improving economic rationality.

I present three other experimental results that contribute to the literature on choice procedures. First, in the Free Procedure, subjects with lower cognitive ability are more likely to select Sequential Elimination than those with higher cognitive ability. This provides empirical evidence for the role of cognitive ability in determining individual preference for choice procedures in the context of decision-making under risk. Second, the experiment explores another choice procedure, choice revision, which has been shown to reduce choice inconsistency with a few normative axioms (e.g., FOSD), but not including GARP (MacCrimmon, 1968; Gaudeul and Crosetto, 2019; Benjamin et al., 2020; Breig and Feldman, 2020; Nielsen and Rehbeck, 2020). I find evidence that choice revision corresponds to fewer FOSD violations but not with fewer GARP violations, thus adding to the literature that examines choice revision. Third, the experiment reflects an overall negative relationship between cognitive ability and risk aversion, in line with the main findings of prior studies (Burks et al., 2009; Dohmen et al., 2010; Benjamin et al., 2013; Falk et al., 2018). Further analysis indicates that this relationship is significant under Sequential Elimination but not under the Direct Procedure. This result connects the literatures on choice procedures and risk preferences by suggesting the role of choice procedures in revealing risk preferences.

This paper gives rise to important policy implications. In particular, sequential elimination may boost individuals' economic rationality by mitigating the impacts of limited attention. Arguably, this procedure is easy and low-cost to implement in a variety of real-world decision problems, e.g., bank loans or health insurance choices involving meaningful consequences. Moreover, it can be implemented with a reasonably high degree of flexibility. My analysis suggests that individuals with low cognitive ability tend to use sequential elimination when available. Thus, policymakers can offer sequential elimination as an optional procedure and support individuals in using their preferred procedures. Finally, and taken together, the present findings highlight the importance of choice procedures in welfare policies.

1.1.1 Related Literature

This paper contributes to the literature on limited attention (Eliaz and Spiegler, 2011; Masatlioglu et al., 2012; Dean et al., 2017; Lleras et al., 2017), which postulates the direct procedure whereby the DM directly chooses from a limited set of alternatives on a menu, known as the *consideration set*. Recently, Dardanoni et al. (2020) explicitly model consideration set sizes as a result of cognitive heterogeneity in a stochastic choice framework. I build on this literature by proposing the minimum property of limited attention, which finds firm support in evidence from economics and the cognitive sciences. For example, eye-tracking studies find that subjects attend to at least two alternatives most of the time (Krajbich and Rangel, 2011; Reutskaja et al., 2011). Field data also suggest that most individuals form consideration sets containing at least two alternatives (Honka et al., 2017; Barseghyan et al., 2021). Notably, Cowan (2001), drawing on a survey of studies from the cognitive sciences, suggests that the attention span of normal adult humans stretches beyond the processing of two alternatives. By exploiting the minimum property, I open up the possibility of reducing inconsistency by means of a particular choice procedure, i.e., sequential elimination.

Sequential elimination originates from the marketing and psychology literatures, where it is postulated that individuals use it to simplify decision problems involving criteria, e.g., certain aspects of the alternatives (Tversky, 1972) or environmental cues (Gigerenzer and Todd, 1999; Todd and Gigerenzer, 2000). Recently, it has received growing attention in economics. Masatlioglu and Nakajima (2007) propose a model of choice by elimination where the DM eliminates all alternatives that are dominated by some other alternatives in the menu. Inconsistency may arise in this model when the DM chooses the alternatives that are not comparable to any of the others on the menu. Further studies postulate that the DM may eliminate alternatives sequentially based on multiple acyclic relations (Manzini and Mariotti, 2007), a checklist of desirable properties (Mandler et al., 2012), or a particular order of binary comparisons (Apesteguia and Ballester, 2013). A central premise of the models above is that the DM may not be intrinsically endowed with one well-behaved preference relation over all alternatives. In contrast and importantly, this paper's premise is that the DM compares all alternatives based on a rational preference relation, which can be revealed by means of sequential elimination.

Several experimental studies provide evidence in support of the benefits of sequential elimination for improving decision-making. In the economics literature, Besedeš et al. (2015) find that sequential decision-making reduces choice overload. Specifically, they study a choice procedure known as the "sequential tournament", where subjects make choices from several rounds of smaller menus randomly separated from a larger one. The cited authors find that subjects are more likely to choose the option with the highest payment likelihood in the sequential tournament than when faced with many at once (i.e., the direct procedure). Marketing and psychology studies show that the elimination process leads to more alternatives being considered (Huber et al., 1987; Yaniv and Schul, 1997, 2000; Sokolova and Krishna, 2016). The general idea of sequential elimination is widely recommended in practice, e.g., career decisions (Gati et al., 1995), managerial decision making (Stroh et al., 2003), patient counseling (Zikmund-Fisher et al., 2011), and criminal identification (Pica and Pozzulo, 2017). The present paper contributes to this strand of literature by examining the effect of sequential elimination on economic rationality.

This paper is also part of the literature strand that investigates the determinants of economic rationality. For example, Harbaugh et al. (2001) find that senior students are more consistent than junior students. List and Millimet (2008) find that individual consistency is facilitated by market experience. Burks et al. (2009) show a positive association between cognitive skills and consistency. Abaluck and Gruber (2011) find that elders tend to make inconsistent choices in the Medicare Part D program; moreover, if they had made consistent choices, they might have achieved a markedly higher level of welfare (about 27%). Choi et al. (2014) find that female, low-income, low-education, and older households have, on average, lower levels of economic rationality in a representative sample of over 2000 Dutch households. Dean and Martin (2016) find that households of retirement age are more consistent than younger households, using scanner data on 977 representative households in Denver. However, Echenique et al. (2021) find that younger people (i.e., aged 16-34) comply with rationality more than older people (i.e., aged 65+) based on the datasets from Choi et al. (2014), Carvalho et al. (2016), and Carvalho and Silverman (2019). Kim et al. (2018) exploit a randomized controlled field experiment involving the introduction of an education program for female students in a Malawian secondary school. They find causal evidence of education's impact on improving economic rationality, which operates partially through enhancing cognitive ability. Banks et al. (2019), on the other hand, find no evidence of education effects in a sample of people who have been affected by a policy on compulsory schooling in England. Despite growing interest in the literature, little is known about the effects of choice procedures on individual consistency. I fill this gap in the literature by proposing a simple theoretical framework, and, most importantly, by providing causal evidence from a randomized controlled experiment.

The rest of the paper proceeds as follows. Section 1.2 presents the framework with which I derive the hypothesis. Section 1.3 describes the details of the experimental design. Section 1.4 provides the experimental results. Finally, Section 1.5 discusses the implications of the results and concludes.

1.2 Framework

Let $x \in \mathbb{R}^k_+$ be an alternative representing a bundle of k goods. Consider a finite data set $D = \{c^i, M^i\}_{i=1}^n$, where M^i is a finite menu of distinct alternatives and a DM chooses c^i from M^i. Let $X = \cup_{i=1}^n M^i$ be the set of all available alternatives and $\mathcal{X}$ be the set of all nonempty subsets of X. Let $\succeq$ be a complete, transitive, and monotone preference relation over X.[6]

In this paper, I assume that when faced with a menu M, the DM pays attention to a limited set of alternatives on the menu, $\gamma(M)$, known as the consideration set. Importantly, the DM's limited attention satisfies the *minimum property*, i.e., he pays attention to at least two alternatives when M comprises multiple alternatives. Formally, a *consideration set mapping* γ assigns to every $M \in \mathcal{X}$ a subset of M such that $|\gamma(M)| \geq \min\{|M|, 2\}$. A consideration set mapping is said to be a *full consideration* if for all $M \in \mathcal{X}$, $\gamma(M) = M$.

1.2.1 The Direct Procedure

I propose that under the direct procedure, the DM chooses an alternative that is preferred to all the others in his consideration set within a menu. The following definition is adapted from Masatlioglu et al. (2012).

[6]A preference relation $\succeq$ is monotone if $x \geq y$ implies $x \succeq y$ and $x > y$ implies $x \succeq y$ but not $y \succeq x$.

Definition 1. The data set $D = \{c^i, M^i\}_{i=1}^n$ is generated by the direct procedure if there exist a preference relation $\succeq$ and a consideration set mapping γ such that for all i, $c^i \in \{x \in \gamma(M^i) | x \succeq y \; \forall y \in \gamma(M^i)\}$. Further, D is generated by the direct procedure with full consideration if γ is a full consideration.

I examine choice consistency by GARP, a necessary and sufficient condition for a data set D to be rationalized by a preference relation. The number of GARP violations gives an exact measure of the deviation of the DM's choices from preference maximization. More GARP violations indicate a lower level of consistency with preference maximization. I formally introduce GARP in the present setting by adapting Cosaert and Demuynck (2015)'s axiom of revealed preference for finite choice sets. For any pair of choices c^i and c^j, I denote that $c^i R^* c^j$ if there exists $x \in M^i$ such that $x \geq c^j$. In words, for any pair of choices, the first is revealed preferred to the second if the first menu contains an alternative that is weakly greater than the second choice. I also denote that $c^i R c^j$ if there exists some sequence $i, h, g, ..., m, j$ such that $c^i R^* c^h$, $c^h R^* c^g, ..., c^m R^* c^j$. That is, R is the transitive closure of R^*.

Definition 2 (GARP)**.** The data set $D = \{c^i, M^i\}_{i=1}^n$ satisfies the *Generalized Axiom of Revealed Preference* if for any pair of choices c^i and c^j, $c^i R c^j$ implies there exists no $x \in M^j$ such that $x > c^i$.

Unless the DM considers every available alternative under the direct procedure, his choices do not necessarily satisfy GARP, as the following example shows. Consider two menus, $M^1 = \{x, y, z\}$ and $M^2 = \{u, v, w\}$ with $z > u$ and $w > x$. Suppose that the DM's preferences are described by $z \succeq w \succeq x \succeq u \succeq v \succeq y$ and his consideration sets are $\gamma(M^1) = \{x, y\}$ and $\gamma(M^2) = \{u, v\}$. Consequently, the DM's choices from M^1 and M^2 under the direct procedure are $c^1 = x$ and $c^2 = u$. We have that $c^1 R c^2$ but there exists $w \in M^2$ such that $w > c^1$, violating GARP.

How may GARP violations depend on the size of consideration sets under the direct procedure? Consider a different case where the DM has full consideration. In this case, his choices under the direct procedure are $\tilde{c}^1 = z$ and $\tilde{c}^2 = w$, satisfying GARP. The DM pays attention to more alternatives as compared to the previous case. Intuitively, the number of GARP violations (weakly) decreases in the expansion of consideration sets, because the DM would not make worse choices by attending to additional alternatives. In fact, it is equivalent for a data set to be generated by the direct procedure with full consideration and to be rationalized by standard preference maximization.

The following remark summarizes the above discussion, which will be useful later for the formulation of the hypothesis.

Remark 1. *Let $D = \{c^i, M^i\}_{i=1}^n$ and $\tilde{D} = \{\tilde{c}^i, M^i\}_{i=1}^n$ be two data sets, the following statements are true:*

(i) D does not necessarily satisfy GARP if D is generated by the direct procedure.

(ii) The number of GARP violations in D is weakly greater than that in $\tilde{D}$ if D ($\tilde{D}$, respectively) is generated by the direct procedure with a preference relation $\succeq$ and a consideration set mapping γ ($\tilde{\gamma}$, respectively) such that $\tilde{\gamma}(M^i) \supseteq \gamma(M^i)$ for all i.

(iii) D satisfies GARP if D is generated by the direct procedure with full consideration.

1.2.2 Sequential Elimination

Remark 1 implies that the DM may miss the best alternatives under the direct procedure by not giving the menu full consideration. This paper's proposal for addressing this problem is to study sequential elimination, in which the DM eliminates alternatives sequentially until only one survives, i.e., the choice.

To illustrate sequential elimination, consider again that the DM is confronted with M^1. Under this procedure, he goes through two rounds of elimination to select a alternative from M^1. In the first round, he eliminates $e_1^1 = y$, leaving the menu to be $M^1 \backslash \{y\} = \{x, z\}$. In the second round, the DM confronts $\{x, z\}$ as a "new" menu, from which he eliminates $e^1_2 = x$, leaving the menu to be $M^1 \backslash \{y, x\} = \{z\}$ representing his choice under sequential elimination.

Formally, $E = \{e^i, M^i\}_{i=1}^n$ is an *elimination* data set, where e^i is a sequence of alternatives $e^i = (e^i_1, ..., e^i_{|M^i|}) \in \prod_{r=1}^{|M^i|} \mathbb{R}^k_+$ such that $\bigcup_{r=1}^{|M^i|}\{e^i_r\} = M^i$. The sequence e^i fully describes an elimination behavior of the DM with the interpretation that when confronted with a non-singleton menu M^i, he eliminates $e^i_1, ..., e^i_{|M^i|-1}$ sequentially, and finally chooses $e^i_{|M^i|}$ from M^i. For all i and $r = 1, .., |M^i|$, let E^i_r denote the remaining menu before the jth round of elimination by $E^i_r = \bigcup_{s=r}^{|M^i|}\{e^i_s\}$. I propose the following model of sequential elimination with limited attention.

Definition 3. The data set $D = \{c^i, M^i\}_{i=1}^n$ is generated by sequential elimination if there exist a preference relation $\succeq$, a consideration set mapping γ, and an elimination data set $E = \{e^i, M^i\}_{i=1}^n$ such that for all i and $r = 1, ..., |M^i|$,

(i) $e^i_r \in \gamma(E^i_r)$.

(ii) $\{x \in \gamma(E^i_r) | x \succeq e^i_r, x \neq e^i_r\} \neq \emptyset$ if $|E^i_r| \geq 2$.

(iii) $c^i = e^i_{|M^i|}$.

Definition 3 (i) and (ii) state that the DM eliminates an alternative from the consideration set if he prefers another alternative in this set. In other words, despite limited attention, the DM compares at least two alternatives according to his preferences in every elimination. The last condition relates an elimination data set to a choice data set by imposing the final remaining alternative to be the choice.

The following proposition formally establishes the consistency of the choice behavior under sequential elimination. All proofs are in Appendix 1.6.1.

Proposition 1. *Let D be a data set. D satisfies GARP if and only if D is generated by sequential elimination.*

Proposition 1 shows that the DM always makes choices consistent with preference maximization under sequential elimination. Thanks to the minimum property, one of the best alternatives survives in every elimination, according to one or other of the following two cases. One is that the DM does not consider this alternative, which remains on the menu. The other is that he considers this alternative, which beats all the others in the consideration set. Instead of confronting a taxing problem, the DM sequentially solves an equivalent sequence of elimination subproblems, each of which requires arguably lower cognitive costs.

Note that Remark 1 and Proposition 1 imply that it is impossible to distinguish whether a data set is generated by the direct procedure with full consideration or by sequential elimination with the same preference relation. This poses no problem here, given that this paper focuses precisely on individuals whose choices violate GARP under the direct procedure.

1.2.3 Testable Implications

In light of Remark 1 and Proposition 1, a preference maximizer with limited attention satisfying the minimum property would make consistent choices under sequential elimination but would not necessarily do so under the direct procedure, unless applying full consideration. I take the premise that a sufficiently large portion of the population can be described as preference maximizers with limited attention satisfying the minimum property. Although the proportion of the population applying full consideration is unclear, it may, to some degree, be inferred by taking into account cognitive ability. An individual's cognitive capacity (i.e., his total endowment of usable mental resources) could limit his attention to the alternatives (Kahneman, 1973). Thus, I argue that individuals with low cognitive ability may attend to fewer alternatives than those with high cognitive ability.

Taking these factors together, I reason that the population may behave in accordance with the implication of Remark 1 and Proposition 1, and more so in the case of those with low cognitive ability. In other words, I expect the following hypotheses to be true:

Hypothesis 1. *Individuals make choices with a higher level of consistency (i.e., fewer GARP violations) under sequential elimination than under the direct procedure.*

Hypothesis 2. *Individuals with low cognitive ability make choices with a higher level of consistency (i.e., fewer GARP violations) under sequential elimination than under the direct procedure.*

There exist two possibilities such that the hypotheses might not be true in a given sample. The first possibility is that the sample contains a sufficient number of individuals with a high enough level of cognitive ability to apply full consideration. As a result, these individuals may make consistent choices irrespective of the choice procedure, and the sequential elimination effect may not be significant. This possibility can be verified by observing that individual choices are highly consistent overall, particularly for those members of the sample with high cognitive ability. The second possibility is that a large fraction of the sample consists of individuals who are intrinsically inconsistent (e.g., Gilboa and Schmeidler, 1989; Ok, 2002; Gilboa et al., 2010). In this case, I expect to observe a low level of consistency in individual choices under both choice procedures.

1.3 Experimental Design

Figure 1.1 presents a global view of the experimental design. After starting the experiment, subjects are randomly assigned to one of the three treatments, Direct Procedure, Sequential Elimination, or Free Procedure. Subjects are first asked to make economic decisions under their assigned choice procedures. They are then asked to complete cognitive ability tests. Finally, they are requested to complete a survey on additional information, including individual attitudes towards consistency and demographics. The details of the experimental design are discussed below.

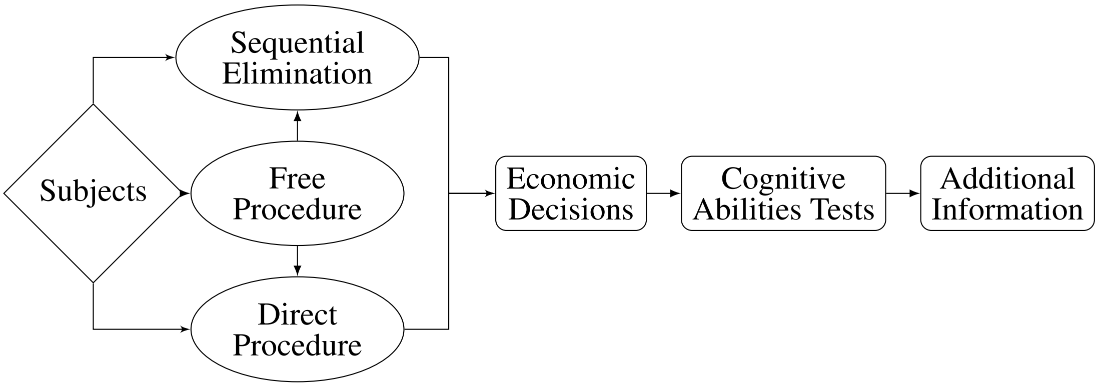


Figure 1.1: A Global View of the Experiment

1.3.1 Main Design

1.3.1.1 Measuring Consistency

Individual choice consistency with preference maximization is measured based on twenty risky decision problems adapted from Kim et al. (2018). Each decision problem comprises eleven randomly ordered *options* from a budget line with a unique price and endowment combination. An *option* (x_1, x_2) rewards x_1 or x_2 tokens with equal probability. There is also one decision problem to check comprehension.[7] In addition, there is a choice revision design, the motivation and the details of which will be explained shortly in Section 1.3.2.1.

Consistency is measured as the number of GARP violations in choices.[8] GARP is the minimal criterion for economic rationality. The number of GARP violations indicates the degree to which choices can be rationalized by a preference relation, which does not need to be objectively optimal. As a complement to GARP violations, the number of first-order stochastic dominance (FOSD) violations in choices is also computed.[9] FOSD is proposed in decision theory as a fundamental criterion for rationality

[7]The comprehension check problem comprises nine options: (11, 11), (22, 22), (33, 33), (44, 44), (55, 55), (66, 66), (77, 77), (88, 88), (99, 99). Subjects are identified as having failed the comprehension check if they did not choose (99, 99).

[8]See Appendix 1.6.2 for a graphical illustration of a GARP violation in this setting.

[9]FOSD violations are computed by assuming a symmetric preference for the two values of options.

in decision-making under risk (Quiggin, 1990; Wakker, 1993) and has been widely applied in experiments as a measure of decision-making quality (Choi et al., 2014; Carvalho et al., 2016; Kim et al., 2018; Banks et al., 2019). By committing a FOSD violation, subjects forgo an option that yields better outcomes than their choices, with no additional risk. That is, a larger number of FOSD violations signals a lower level of economic rationality.

In robustness checks, consistency is additionally measured by the number of strong axiom of revealed preference (SARP) violations (Rose, 1958), the HoutmanâMaks (HM) index (Houtman and Maks, 1985), and the critical cost efficiency index (CCEI, Afriat, 1972), as proposed by the literature. SARP differs from GARP by excluding indifference between alternatives in the preferences. The HM index finds the minimal removal of the observations such that the rest are consistent. The CCEI considers the minimal wealth change such that choices are consistent.[10] Similarly, more SARP violations, a higher HM index, or a higher CCEI indicate a lower level of consistency.

1.3.1.2 Experimental Treatments

In every decision problem, the left-hand side of the screen shows a vertical list of options, labeled "Options". Under the Direct Procedure, subjects are asked to click on their selected options sequentially and place them in a box labeled "Choice List" which appears on the right-hand side of the screen.[11] They are not allowed to move any option from the Choice List back to the Options list. Subjects are asked to choose an option from the Choice List box once it contains all their options. Under Sequential Elimination, subjects are asked to eliminate options sequentially and put them into a box labeled

To be specific, subjects commit a FOSD violation if they choose an option (x_1, x_2) when there exists another option (y_1, y_2) in the same problem such that $y_2 > x_1$ and $y_1 > x_2$.

[10] CCEI assumes that choices are made from linear budget sets. It is not sensitive to the total number of GARP violations, which is the paper's main interest.

[11] See Appendix 1.6.3 for screenshots of all treatments and other designs of the experiment. Under the Direct Procedure, subjects are instructed to "examine" them by clicking on them. Under each treatment, subjects are given a trial problem; specifically, Free Procedure subjects are given a trial problem with the two procedures randomly ordered.

"Trash" on the right-hand side of the screen. Subjects can move any option from the Trash box back to the Options list by clicking on it. Subjects are asked to choose one option by leaving it as the only remaining option on the Options list. These designs minimize the differences in presentation and numbers of clicks between the Direct Procedure and Sequential Elimination. Thus, the difference in choice behavior between the two treatments enables precise testing of the hypothesis. In the Free Procedure, subjects are asked to select either one of the Direct Procedure and Sequential Elimination as their choice procedures. The Free Procedure treatment enables the investigation of individual preference for sequential elimination. Is there any demographic factor that might affect procedure preferences? More importantly, are those with lower cognitive ability—who are arguably prone to limited attention— more likely to adopt sequential elimination than those with a higher level?

1.3.1.3 Measuring Cognitive Ability

Cognitive ability is expressed as IQ scores derived from the ICAR test. Specifically, subjects are required to complete five matrix reasoning and five three-dimensional rotation questions, both of which are considered the primary measure of problem-solving and reasoning abilities (Nisbett et al., 2012). The number of correct answers (i.e., an integer between 0 and 10) provides the test score. The experiment also includes tests of selective attention and working memory capacity, which are related to the notion of limited attention.[12] Selective attention is measured by the Stroop test (Stroop, 1935), where subjects are presented with a word, say, GREEN, printed in the same or a different color, say, red, and asked to name the colors in which the words are printed. Working memory capacity is measured by the Sternberg test (Sternberg, 1966), where subjects see a sequence of numbers presented singly and are asked to remember them. After a few

[12]See Appendix 1.6.3 for the details of the cognitive ability tests. The tests are implemented via the platform of Henninger et al. (2022). Selective attention refers to the differential processing of simultaneous information sources (Johnston and Dark, 1986). Working memory capacity refers to the capacity for "temporary storage and manipulation of the information" (Baddeley, 1992). Oberauer (2019) reviews the close relationship between working memory and attention.

numbers have been shown, there is a brief pause, and a test number appears. Subjects are asked to answer whether the test number was included in the sequence previously shown. At the end of a trial, subjects are asked to recall the entire sequence of numbers previously shown.

1.3.2 Other Details of the Experimental Design

1.3.2.1 Choice Revision

It is important to know whether sequential elimination is more effective than other procedures. There is an emerging literature on the choice revision procedure, i.e., the procedure gives individuals a chance to revise choices (Gaudeul and Crosetto, 2019; Benjamin et al., 2020; Breig and Feldman, 2020; Nielsen and Rehbeck, 2020). They document cases of individual choices being revised to comply with axioms of normative decision theory, e.g., FOSD, but not with GARP. Based on this evidence, it is possible that people reduce their GARP violations by revising their choices, although the possibility appears to be unexplored. The present experiment includes a choice revision design with a view to exploring this hypothesis. More importantly, the comparison between the effects of choice revision and sequential elimination may aid interpretation of the latter.

Specifically, subjects are asked to make decisions for two identical blocks of decision problems, Blocks A and B, each containing the set of decision problems described in Section 1.3.1.1. Subjects are not informed of the identical nature of the two blocks until they enter Block B. The decision problems are ordered randomly within each block and independently between them. In a Block B problem, subjects may either alter the choice they made in the respective problem in Block A by clicking on a different option or keep their Block A choice by clicking on a button.[13] Subjects are informed that

[13]The literature has employed different choice revision designs. The one used in this study is similar to that used in Gaudeul and Crosetto (2019) and Yu et al. (2021), where subjects are asked whether they want to revise their choices without further instructions. This design is, furthermore, comparable to sequential elimination in that it too is without normative axioms.

they will have to choose one block for payment (referred to as the *payment block*), from which one decision problem is randomly drawn for the payoff.[14] Thus, the two blocks are equally incentive-compatible. Subjects are labeled as having revised their choices if they alter their choices from Block A to Block B, and then choose Block B for payment.

1.3.2.2 Attitude towards Consistency

The literature points out that, in some individuals, inconsistency of choices is deliberate (e.g., Kahneman, 2003; DellaVigna, 2009). Consequently, this study accounts for the possible impact of individual attitudes towards consistency on choice consistency. Subjects are presented with a scenario which includes the presence of the attraction effect (Huber et al., 1982); a common behavioral phenomenon which violates consistency with preference maximization (Tversky and Simonson, 1993). Subjects are asked to rate how at ease they are with the scenario on a scale of 0 (least at ease) to 10 (most at ease). This rating provides an indicator of individual attitudes towards consistency, i.e., the higher the rating, the less negative the attitude towards inconsistency.

1.3.3 Experimental Procedure

Subjects were recruited from the Prolific survey pool and the experiment was conducted online between May 31, 2020, and June 1, 2020, using the Qualtrics survey platform. They could withdraw from the experiment at any time with no need for justification. Their earned tokens were converted to money after the experiment. Each subject received £3 as a participation fee for completing the experiment. There was an additional payment of up to £14.6 depending on the economic decisions and the performance in cognitive ability tests. Subjects received their payoffs three days after the experiment via Prolific. The average completion time for the experiment was 42 minutes, and the average payout was £8.14.

[14] Evidence from Agranov and Ortoleva (2017) suggests that individuals may deliberately make different choices when faced with repetitive problems. Requiring subjects to choose the payment block avoids this issue, as each problem is unique to subjects in terms of providing incentives.

The main analysis is based on a sample of 223 subjects (50.2% female) and 73-75 observations per treatment.[15] The sample subjects are plausibly younger and more educated than the population on average. The mean age is approximately 24, and 75% of the subjects are aged between 18 and 25. All subjects have completed at least secondary education. Specifically, 57% of the subjects are currently in undergraduate education, and 39% have completed at least undergraduate education. By design, demographics and cognitive ability are balanced across the Direct Procedure and Sequential Elimination. To examine the hypotheses, subjects are categorized into two groups based on cognitive ability: (1) low-IQ subjects, whose IQ scores are lower than or equal to the sample median; (2) high-IQ subjects, whose IQ scores are higher than the sample median.[16] Table 1.1 presents the breakdown of subjects by treatment and IQ. In the Free procedure, 32 (82%) of the low-IQ subjects and 17 (47.2%) of the high-IQ subjects choose Sequential Elimination.

Table 1.1: Breakdown of Observations

Treatment / IQ Group	Direct Procedure	Sequential Elimination	Free Procedure
Low-IQ Subjects	34 (45.3%)	40 (54.8%)	39 (52%)
High-IQ Subjects	41 (54.7%)	33 (45.2%)	36 (48%)
Total	75 (100%)	73 (100%)	75 (100%)

[15] A total of 253 subjects (53.1% female) were recruited. All subjects speak English as their first language and could complete the experiment only once. 30 subjects who had failed the comprehension check in the first block were filtered out. Appendix 1.6.4 gives the histograms of demographics and cognitive ability for the overall sample and per treatment.

[16] The sample median IQ score is 4, the mean is about 4.74, and the standard deviation is about 2.47. In the sample, the IQ scores range from 0 to 10, with 3 and 6 being the first and third quantiles, respectively. Note that low-IQ (high-IQ, respectively) subjects identically match those with IQ scores lower than (higher than, respectively) the sample mean IQ score.

1.4 Experimental Results

1.4.1 Main Results

This section examines the hypotheses by analyzing the observed differences between the Direct Procedure and Sequential Elimination. I present descriptive statistics and perform regression analysis to test for treatment effects. The negative binomial regression is used to estimate the sequential elimination effect on GARP and FOSD violations because of their count data nature (Cameron and Trivedi, 2013).[17]

I start by discussing the evidence for Hypothesis 1. Figure 1.2(a) shows that the average numbers of GARP violations under Sequential Elimination and the Direct Procedure are roughly 4.3 and 5.9, respectively. This indicates that Sequential Elimination leads to a reduction of about 27% in the number of GARP violations on average when compared with the Direct Procedure, in line with Hypothesis 1. In addition, Figure 1.3(a) depicts that the cumulative distribution of GARP violations under the Direct Procedure almost (first-order) stochastically dominates that under Sequential Elimination, except on the extreme right tails of the distributions. That is, a subject is more likely to commit more GARP violations under the Direct Procedure than under Sequential Elimination.

Table 1.2 presents the estimation results.[18] Column (1) indicates that Sequential Elimination reduces the number of GARP violations by nearly 4.5 as compared with

[17]Nonlinear regressions are widely applied in economics for nonnegative integer data, e.g., R&D patents (Karkinsky and Riedel, 2012; Acemoglu et al., 2016), conflicts and wars (Glick and Taylor, 2010; Crost et al., 2014), level-k reasoning (Camerer et al., 2004), and revealed preference analysis (Choi et al., 2014). Cameron and Trivedi (2013) recommend the Poisson, negative binomial, and zero-inflated negative binomial models for count data. Appendix 1.6.6 reports the model selection procedure. The negative binomial model is selected based on the Akaike information criterion, Bayesian information criterion, likelihood ratio test, and Vuong Test.

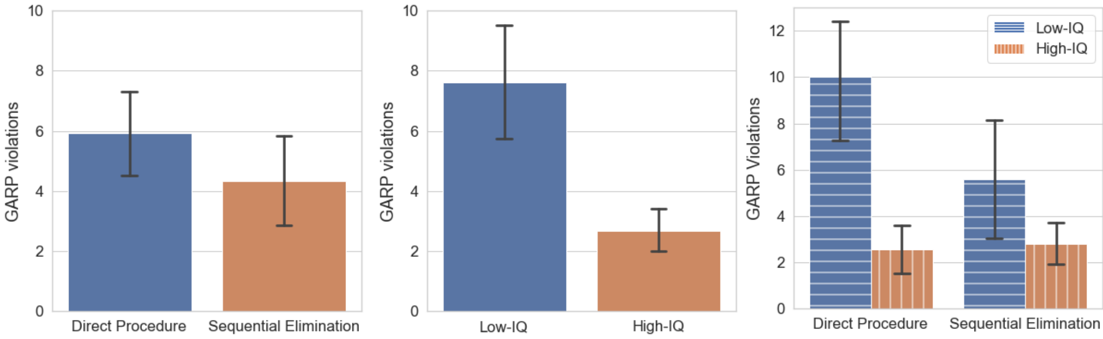
[18]Table 1.2 presents results from the negative binomial regressions, including an interaction between Sequential Elimination and High-IQ, in the form of average marginal effects. P-values of the Sequential Elimination effect (for low-IQ, high-IQ subjects, and overall) are computed based on the null hypothesis that the number of GARP (FOSD) violations under Sequential Elimination is larger than or equal to that under the Direct Procedure. The regressions are reported in the original form in Appendix 1.6.6.

the Direct Procedure ($p = 0.07$). Closely approaching the statistical significance, the impact of Sequential Elimination is economically meaningful: it improves consistency by almost 76% relative to the Direct Procedure. The same column shows a positive and statistically significant relationship between high-IQ and consistency ($p = 0.01$), in line with previous studies (e.g., Burks et al., 2009; Cappelen et al., 2020). Indeed, high-IQ subjects are very consistent, both overall (see Figure 1.2(b)), and per treatment (see Figure 1.2(c)). Taken together, these results suggest that the impact of sequential elimination in improving consistency operates mainly through its effect on low-IQ subjects, which leads to the following discussion on Hypothesis 2.

Figure 1.2(c) shows that the occurrence of GARP violations among low-IQ subjects is approximately 44.2% lower, on average, under Sequential Elimination than under the Direct Procedure (5.58 vs. 10 GARP violations, respectively), thus supporting Hypothesis 2. Furthermore, Figure 1.3(b) displays that the cumulative distribution of GARP violations by low-IQ subjects under the Direct Procedure strongly (first-order) stochastically dominates that under Sequential Elimination, except on the extreme right tails of the distributions. Column (1) in Table 1.2 indicates that Sequential Elimination reduces by over 9.4 the number of GARP violations ($p = 0.04$) among low-IQ subjects as compared with the Direct Procedure.[19] This reduction is substantial (over 94%) relative to their average of 10 GARP violations under the Direct Procedure. The treatment effect on low-IQ subjects is more pronounced than the overall treatment effect, thus confirming that the former is the key driver of the latter. The results demonstrate the effect of sequential elimination on individuals with low cognitive ability, thus lending support to Hypothesis 2.

Besides consistency, Table 1.2 depicts the effect of sequential elimination on FOSD violations in Column (2). Overall, Sequential Elimination corresponds to a decrease in the number of FOSD violations by 0.5 ($p = 0.01$), approximately 63% of the aver-

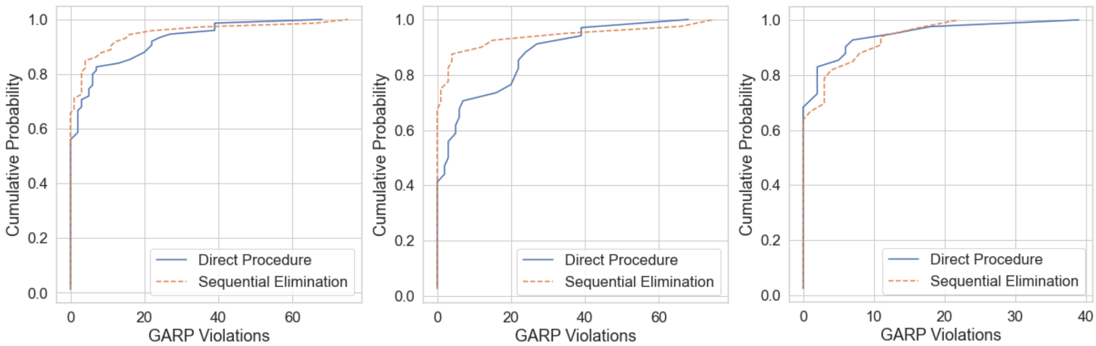
[19]For robustness checks, see Appendix 1.6.5, which reports nonparametric tests of treatment effects, other specifications of the estimation, and estimations on other consistency measures. The robustness checks reveal comparable treatment effects on SARP violations, HM index, and CCEI for low-IQ subjects ($p = 0.04$, $p = 0.11$ and $p = 0.14$), although not all are significant at the conventional levels.



(**a**) By Treatment (**b**) By IQ (**c**) By Treatment×IQ

Figure 1.2: Means of GARP Violations by Treatment and by IQ

Notes: Error bars indicate the standard error of means.



(**a**) Overall Sample (**b**) Low-IQ Subjects (**c**) High-IQ Subjects

Figure 1.3: Cumulative Distributions of GARP Violations by Treatment and by IQ

age 0.8 FOSD violations under the Direct Procedure. There is no significant difference in FOSD violations between low-IQ and high-IQ subjects. In contrast to what was observed for GARP violations, no significant treatment effect on FOSD violations by low-IQ subjects can be seen. High-IQ subjects, on the other hand, show 0.9 (almost 97%, $p = 0.02$) fewer FOSD violations under Sequential Elimination than under the Direct Procedure (on average about 0.93 FOSD violations). This finding provides empirical support for the idea that individuals with high cognitive ability can benefit from sequential elimination in decision-making.

Table 1.2: Determinants of Economic Rationality

	(1) GARP Violations	(2) FOSD Violations
Sequential Elimination	-4.480*	-0.515**
	(3.045)	(0.215)
-Low-IQ Subjects	-9.409**	-0.226
	(5.246)	(0.233)
-High-IQ Subjects	0.799	-0.917**
	(1.302)	(0.434)
Age	-0.456*	-0.064***
	(0.253)	(0.024)
Female	0.885	0.170
	(2.138)	(0.177)
Education	-1.232	0.212
	(1.339)	(0.133)
High-IQ	-7.300**	0.145
	(2.900)	(0.211)
Selective Attention	-0.283	-0.030
	(0.373)	(0.031)
Working Memory	-0.357	-0.045
	(0.500)	(0.051)
Response Time (Minutes)	-0.491**	0.012
	(0.229)	(0.020)
Attitude towards Inconsistency	-0.840	0.021
	(0.511)	(0.033)
N	148	148

Standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

In conclusion, the experimental results provide causal evidence of the role played by sequential elimination in increasing economic rationality, as indicated by the improvement in individual consistency (especially among individuals with low cognitive ability) and the reduction in FOSD violations (especially among individuals with high cognitive ability).

1.4.2 Other Factors of Economic Rationality

The literature has documented that demographics (i.e., age, education, and gender) have diverse effects on economic rationality, as reviewed in Section 1.1.1. A partial explanation for this lies in the differences in sample characteristics and choice settings between studies. The present sample of primarily young and educated subjects is arguably unique in comparison to those used in other studies. Thus, an examination of the effects of demographics on economic rationality in this sample may enhance our understanding of their impact.

I found some considerable results for the demographical variables. Table 1.2 shows that higher age is associated with higher economic rationality (i.e., fewer GARP and FOSD violations), in line with Dean and Martin (2016), but not with Choi et al. (2014) or Echenique et al. (2021). The effect of age on economic rationality possibly varies by age group. On the one hand, normal aging can cause cognitive decline; although the evidence also suggests that this is not a substantial problem for young people (Plassman et al., 1995; Aartsen et al., 2002; Rönnlund et al., 2005).[20] On the other hand, age may contribute to the accumulation of knowledge required for decision-making (Eberhardt et al., 2019). That is, the marginal returns of aging probably outweigh its marginal costs in the young population, thereby resulting in the positive association between age and economic rationality observed in the sample. The education and gender effects are not significant, in line with Banks et al. (2019), and in contrast to Choi et al. (2014) and Kim et al. (2018). This suggests that, at high education levels, the marginal returns to education on consistency may be low, intuitively in line with the hypothesis that marginal returns to education diminish as education levels increase (Harris, 2007; Agüero and Beleche, 2013). Conclusions from other studies are based on measures of economic rationality, which may differ according to their research motivations. More research is

[20]Eberhardt et al. (2019) find that older age is associated with with more experience-based knowledge, and fewer negative emotions surrounding financial decisions. Findings from the cognitive sciences also suggest that cognitive decline may begin after age 50 or later (Plassman et al., 1995; Aartsen et al., 2002; Rönnlund et al., 2005).

needed to evaluate the various implications of demographic factors on different measures of economic rationality.

Lastly, this section examines response times, an emerging topic in economics (e.g., Woodford, 2014; Fudenberg et al., 2018; Baldassi et al., 2020), and recently as related to revealed preference analysis (Alós-Ferrer et al., 2021). Table 1.2 shows that longer response times are associated with fewer GARP violations ($p = 0.03$).[21] That is, slow decisions are more likely to reveal preferences consistent with preference maximization than fast decisions. This is in line with the well-known trade-off between slow decisions and higher accuracy (Fitts, 1966; Wickelgren, 1977). Importantly, the results contribute evidence to the vital role of response times in the revelation of individual preferences.

1.4.3 Individual Preference for Sequential Elimination

This section focuses on the Free Procedure treatment to analyze the determinants of individual preference for sequential elimination. Table 1.3 presents the results from probit and logit regressions, where the probability of choosing Sequential Elimination is regressed on demographics and cognitive ability.[22] A positive association is observed between the probability of choosing Sequential Elimination and education. Although further research is needed to determine the main channel of this association, it could indicate that sequential elimination presents a potential challenge to people with relatively low educational attainments. Importantly, over 82% of the low-IQ subjects choose Sequential Elimination, as shown in Appendix 1.6.4. The probability of choosing Sequential Elimination decreases, *ceteris paribus*, as IQ ($p = 0.04$ in probit and $p = 0.03$ in logit), working memory ($p = 0.07$ in probit and $p = 0.05$ in logit), or selective attention ($p = 0.13$ in probit and $p = 0.17$ in logit) increase, although the last of these is not significant at the conventional levels. In other words, subjects with lower cognitive

[21] Appendix E reports that subjects spend more time in Sequential Elimination than in the Direct Procedure, however, there is no strong evidence that the effects of response times depend on choice procedures.

[22] Table 1.3 presents results from the probit and logit regressions in the form of average marginal effects. The regressions are reported in their original form in Appendix 1.6.6.

ability are more likely to use sequential elimination than those with higher cognitive ability.

Table 1.3: Determinants of Preference for Sequential Elimination

	Probability of Choosing Sequential Elimination	
	(Probit)	(Logistic)
Age	-0.004	-0.004
	(0.007)	(0.007)
Female	0.110	0.115
	(0.094)	(0.096)
Education	0.114***	0.111**
	(0.044)	(0.044)
IQ	-0.042**	-0.042**
	(0.020)	(0.020)
Selective Attention	-0.025	-0.024
	(0.016)	(0.018)
Working Memory	-0.038*	-0.038*
	(0.020)	(0.020)
Attitude towards Inconsistency	0.003	0.00339
	(0.019)	(0.021)
N	75	75

Standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

In fact, the negative association between cognitive ability and the choice of Sequential Elimination is strong. Only 18% (seven) low-IQ subjects choose the Direct Procedure over Sequential Elimination. This plausible under-sampling of low-IQ subjects in the Direct Procedure hinders me from examining the effect of sequential elimination when the sample is restricted to Free Procedure subjects.

All in all, the evidence suggests that individuals with low cognitive ability—the central interest of this paper—may tend to use sequential elimination. This could be crucial for policy evaluation. However, due to the constraints of the present study, I here cannot validate sequential elimination's impact in the context where subjects freely determine the choice procedure. The conclusion from this section is that there is a need for further investigation in this context.

1.4.4 Choice Revision

This section explores the effects of choice revision. In brief, the resulting evidence shows that choice revision has some potential to reduce FOSD violations as aligned with other studies, but not necessarily GARP violations. This result complements the existing research on choice revision by evaluating its effect in relatively complex decision-making tasks without explicitly presenting the normative axioms.

Table 1.4 shows the estimation of choice revision effect.[23] As shown in Column (1), there is no sound evidence to show that choice revision improves individual consistency overall, whether conditioned on IQ or treatment groups.[24] To some degree, this reveals the limited effect of choice revision in mitigating inconsistency. Column (2) indicates that choice revision corresponds to an overall reduction of 0.42 FOSD violations ($p = 0.04$), that is, approximately 61% fewer than among non-revisers (on average, about 0.69 FOSD violations). The significance of this effect holds when restricted to the low-IQ subjects under Sequential Elimination ($p = 0.03$). Collectively, these results indicate that choice revision may complement sequential elimination to further improve economic rationality in low-IQ individuals by reducing their FOSD violations.

Benjamin et al. (2020), Breig and Feldman (2020), and Nielsen and Rehbeck (2020) show choice revision to have a stronger effect in shifting choices towards normative axioms than observed in the present study. Those studies present the normative

[23]Table 1.4 presents results from the negative binomial regressions, where the triple interaction between Choice Revision, high-IQ, and Sequential Elimination is included. The results are reported in the form of average marginal effects. P-values of choice revision effect are computed based on the null hypothesis that the number of GARP (FOSD) violations of subjects who revise is larger than or equal to that of subjects who do not revise. This estimation is based on the sample of subjects who passed the comprehension check in the payment block. GARP violations in the table are calculated based on choices from the payment block. The complete table and the regression estimates appear in their original form in Appendix 1.6.6.

[24]This is further corroborated by testing its sensitivity to other specifications, as reported in Appendix 1.6.5.

axioms in primarily binary choice tasks. In contrast, this study uses eleven-options choice tasks without presenting axioms. Considering the contrast, it is possible that choice revision's effect may hinge on the comprehensive design of the procedure and complexity of choice settings. This discussion sheds light on the further question of the robustness of choice revision effects across contexts.

Table 1.4: Effects of Choice Revision on Economic Rationality

	(1) GARP Violations	(2) FOSD Violations
Choice Revision	-1.833	-0.42**
	(2.849)	(0.244)
-Low-IQ Subjects under the Direct Procedure	-4.665	-0.612
	(7.004)	(0.647)
-High-IQ Subjects under the Direct Procedure	-3.182	0.085
	(2.695)	(0.467)
-Low-IQ Subjects under Sequential Elimination	3.487	-0.610**
	(3.804)	(0.331)
-High-IQ Subjects under Sequential Elimination	-5.078	-0.207
	(6.182)	(0.251)
N	151	151

Standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Control variables not shown in this table: Age, Female, Education, IQ, Selective Attention, Working Memory, and Attitude towards Inconsistency.

1.4.5 Risk Preferences

This section presents the analysis of risk preferences under the expected utility model using the coefficient of relative risk aversion (CRRA) revealed from the subjects' choice data.[25] Before stating the results, it is worth mentioning that, although the literature tends to find a negative relationship between cognitive ability and risk aversion

[25]CRRA coefficients are estimated using the code packages from Halevy et al. (2018). Based on the CRRA form of the expected utility model, the estimation recovers parameters using nonlinear least squares. The histogram of the CRRA revealed in the experiment is given in Appendix 1.6.4, where it can be seen that 80% of the values range from 0 to 4.7.

(Burks et al., 2009; Oechssler et al., 2009; Dohmen et al., 2010; Benjamin et al., 2013; Dohmen et al., 2018), this relationship cannot always be replicated and sometimes even becomes positive (Mather et al., 2012; Tymula et al., 2012; Andersson et al., 2016).[26] Specifically, Andersson et al. (2016) argue that the effect of cognitive ability on risk preferences may operate through the channel of decision-making mistakes. Recall the theoretical prediction that individuals may err due to limited attention under the Direct Procedure but not under Sequential Elimination. Also, the existing studies primarily derive their results from simple choice settings, i.e., most decisions comprise of two or three options (e.g., Oechssler et al., 2009; Andersson et al., 2016). Thus, the following analysis contributes to the discussion by examining the relationships between cognitive ability and risk preferences under the two procedures in non-simple choice settings.

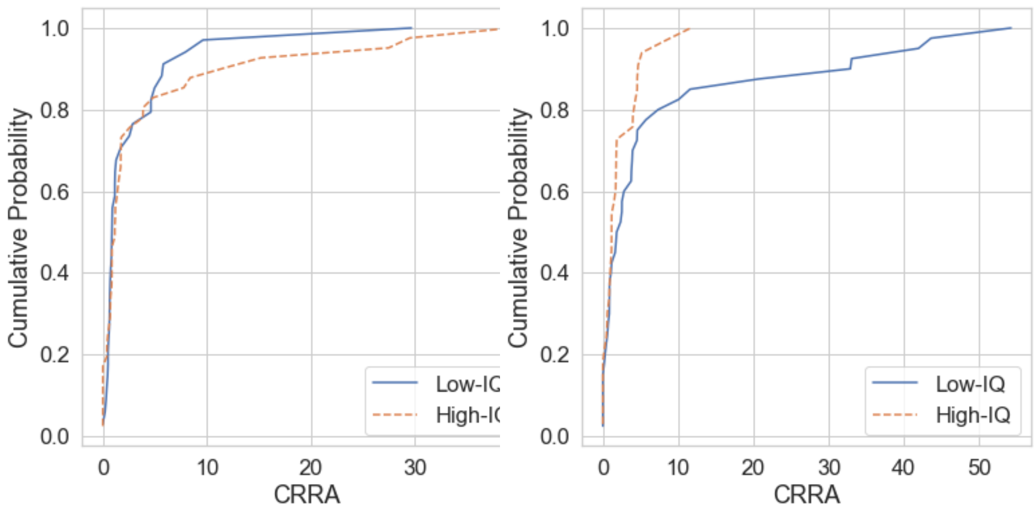
Table 1.5 presents the estimation results based on two specifications.[27] In Column (1), CRRA is directly regressed on IQ and a complete set of explanatory variables. Coinciding with early reported findings, overall, there is a negative impact of IQ on CRRA ($p = 0.09$). No other factor, including sequential elimination, appears to be associated significantly with risk aversion. Conjecturally, the sequential elimination effect may depend on cognitive ability, based on the previous results showing its heterogeneous effects on consistency.

The estimation in Column (2) incorporates the interaction between IQ and Sequential Elimination. Verifying the conjecture, the association between IQ and CRRA is significant ($p = 0.04$) under Sequential Elimination but not under the Direct Procedure. Further, this association is stronger under Sequential Elimination than overall. This is also confirmed by the distinction in cumulative CRRA distributions between the low-IQ

[26]Dohmen et al. (2018) suggest that the nonsignificant relationships in Mather et al. (2012) and Tymula et al. (2012) may be due to small sample size and measurement error. Andersson et al. (2016) find a positive relationship in a multiple-price list (MPL) where there are more opportunities to err towards the risky option. They argue that the choice errors cause an underestimation of risk aversion.

[27]Table 1.5 Column (2) reports the average marginal effects based on the linear regression, which includes an interaction term between IQ and Sequential Elimination in addition to the specification reported in Column (1). The complete table and the regression estimates appear in their original form in Appendix 1.6.6.

and high-IQ subjects is sharpest under Sequential Elimination (Figure 1.4(b)), where that of the low-IQ subjects almost stochastically dominates that of the high-IQ subjects. Under the Direct Procedure (Figure 1.4(a)), in contrast, there is no evident distinction between the two groups in this respect.



(a) The Direct Procedure **(b)** Sequential Elimination

Figure 1.4: Cumulative Distributions of Estimated CRRA by Treatment and by IQ

These results may be driven by the present choice setting comprising eleven options. The choices made by low-IQ subjects under the Direct Procedure may not fully reveal their risk preferences, potentially as a result of mistakes caused by limited attention, as would be consistent with Andersson et al. (2016). In other words, the complexity of the choice task may be determinant in the revelation of risk aversion.

In short, the findings in this section complement the existing evidence for the negative relationship between cognitive ability and risk aversion. This relationship is confirmed under sequential elimination, where choice consistency is theoretically established and empirically supported by the previous results of this study. Crucially, these findings raise the question of whether the robustness of this relationship holds for complex choice settings.

Table 1.5: Determinants of Risk Preferences

	(1)	(2)
	Coefficient of Relative Risk Aversion	
IQ	-0.397*	-0.358
	(0.230)	(0.227)
-Under the Direct Procedure		0.071
		(0.320)
-Under the Sequential Elimination		-0.799**
		(0.397)
Sequential Elimination	2.010	2.063
	(1.619)	(1.628)
N	148	148

Standard errors in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Control variables not shown in this table: Age, Female, Education, Selective Attention, Working Memory, Response Time, and Attitude towards Inconsistency.

1.5 Discussion

1.5.1 Policy Implications

Policymakers and institutions can implement sequential elimination in a wide range of contexts to mitigate the impact of limited attention and improve individual welfare. For example, field evidence indicates that individuals have difficulty in making decisions for retirement plans (Sethi-Iyengar et al., 2004; Thaler and Benartzi, 2004) and bank loans (Bertrand et al., 2010), which typically involve a large number of options. Public policy can promote sequential elimination at a relatively low cost, e.g., by providing it on a governmental website where people choose retirement plans or by regulating it to be installed on banking websites where consumers choose loan plans. More broadly, sequential elimination might be flexibly applied to numerous meaningful contexts across a person's life cycle—spanning from education, through career, to retirement decisions—where often the options are complex, and most people long for the “best” choice.

Upon improvement of individual consistency, sequential elimination may complement policymaking based on economic predictions drawn from the premise of rationality. In light of the present results on risk preferences, sequential elimination may help exploit information on individual preferences. Perhaps, this presents an alternative approach that could enhance policymaking based on revealed preferences by incorporating the emerging behavioral findings of human limitation (e.g., Bernheim and Rangel, 2007, 2009). Importantly, sequential elimination needs not be implemented in a paternalistic fashion. Individuals can be allowed to opt out of making decisions under sequential elimination at no cost. The Free Procedure’s analysis suggests that individuals with limited attention are likely to use the procedure based on their preferences. The non-paternalistic approach of implementing sequential elimination inflicts little or no harm on individuals; thus, it is a desirable advantage in institutional design (Thaler and Sunstein, 2003).

In light of my theoretical framework, it is sufficient for individuals to consider only two alternatives in every elimination to achieve consistency. It may be efficient for less cognitively constrained individuals to eliminate more than one alternative at a time. In effect, the procedure works as long as each round of elimination remains within the individualâs cognitive ability. Further study is required to evaluate variations in sequential elimination due to individual heterogeneity.

1.5.2 Concluding Remarks

This paper has shown that sequential elimination—a well-known choice procedure, especially in the cognitive sciences (Tversky, 1972; Todd and Gigerenzer, 2000)—improves individual consistency with preference maximization under cognitive limitations. This paper develops a formal framework to identify the role of sequential elimination in improving individual consistency. Causal evidence for a sequential elimination effect is obtained for subjects participating in a randomized controlled risky decision-making experiment. This effect is statistically significant and economically substantial for individuals with low cognitive ability. The existing literature on the gap between low cognitive ability and choice consistency is enriched by the identification of theoretical and empirical conditions under which this gap narrows. This paper may offer a new insight into the ways in which choice procedures can influence individual consistency with preference maximization, which poses one of the major challenges to neoclassical economics.

Finally, beyond decision-making under risk, it would be desirable to test the robustness of sequential elimination in different choice domains, such as consumer goods, intertemporal choice, and altruistic choice. Notably, field research into the effect of sequential elimination presents a promising line of research.

1.6 Appendix

1.6.1 Proof of Proposition 1

Let $D = \{c^i, M^i\}_{i=1}^n$ be a data set. Consider the following conditions:

[1] D satisfies GARP.

[2] D is rationalizable by sequential elimination.

[3] There exists a preference relation $\succeq$ over X such that for all i, $c^i \in \{x \in M^i | x \succeq y \; \forall y \in M^i\}$.

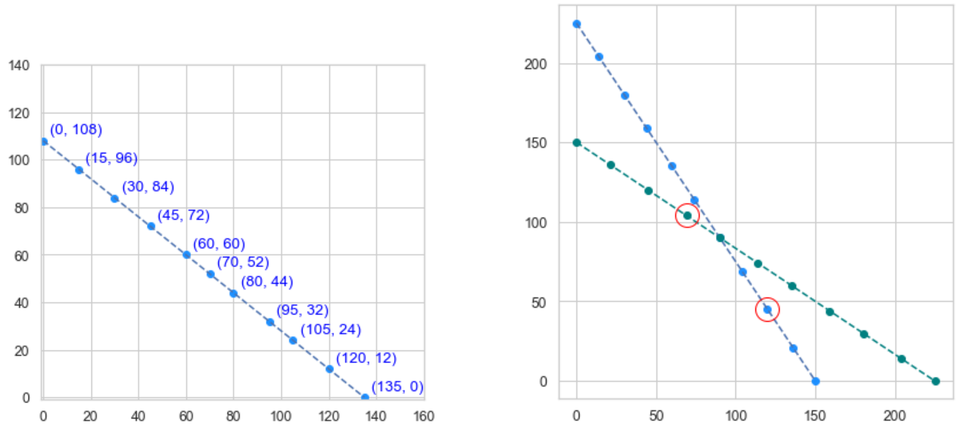
By a theorem of Cosaert and Demuynck (2015), we have that [1] if and only if [3]. Hence in the following proof, I show equivalently that [2] if and only if [3].

[3] implies [2]. Suppose that [3] is true. Define $\gamma(M) = M$ for all $M \in \mathcal{X}$. Given $D = \{c^i, M^i\}_{i=1}^n$, define $E = \{e^i, M^i\}_{i=1}^n$ such that for all i: if $|M^i| \geq 2$, then $e^i = (e_1^i, ..., e_{|M^i-1|}^i, c^i)$ with $\bigcup_{r=1}^{|M^i|}\{e_r^i\} = M^i$; if $|M^i| = 1$, then $e^i = (c^i)$. For all i and $r = 1, ..., |M^i|$, we have $e_r^i \in \gamma(E_r^i)$ (Definition 3 (i)); $c^i \in \{x \in \gamma(E_r^i) | x \succeq e_r^i, x \neq e_r^i\} \neq \emptyset$ if $|E_r^i| \geq 2$ (Definition 3 (ii)); and $c_i = e_{|M^i|}^i$ (Definition 3 (iii)). Thus, D is rationalizable by sequential elimination.

[2] implies [3]. Suppose that [2] is true. Let $\succeq$, γ, and $E = \{e^i, M^i\}_{i=1}^n$ be the preference relation, consideration set mapping, and elimination data set that satisfy the conditions in Definition 3. Suppose by contradiction that there exists some $j \in \{1, ..., n\}$ such that $c^j = e_{|M^j|}^j \notin \{x \in M^j | x \succeq y \; \forall y \in M^j\}$. Since $\succeq$ is complete and transitive, $\{x \in M^j | x \succeq y \; \forall y \in M^j\} \neq \emptyset$. Then there must exist some $r \in \{0, ..., |M^j - 1|\}$ such that $e_r^j \in \{x \in M^j | x \succeq y \; \forall y \in M^j\}$ and $\{x \in E_r^i | x \succeq e_r^i, x \neq e_r^i\} = \emptyset$. This implies $\{x \in \gamma(E_r^i) | x \succeq e_r^i, x \neq e_r^i\} = \emptyset$, which is a contradiction to Definition 3 (ii). Therefore, we have that for all i, $c^i \in \{x \in M^i | x \succeq y \; \forall y \in M^i\}$.

1.6.2 Details of the Experimental Design

1.6.2.1 Illustrations of the Experimental Setting



(a) A Decision Problem **(b)** A GARP Violation

Figure 1.5: Graphical Illustrations of a Decision Problem and a GARP Violation

Notes: As illustrated in Figure 1.5(a), each budget line represents a menu of options in the experiment. The red circles indicate a pair of choices from these menus that violate GARP. In Figure 1.5(b), the red circles indicate a pair of choices from these menus that violate GARP.

1.6.3 Instructions in the Experiment

1.6.3.1 Introduction

Welcome to our study on decision-making.

The study consists of three sections. In Section 1, you will make a series of economic decisions. In Section 2, you will participate in some cognitive tasks. In Section 3, you will be asked to imagine yourself in some hypothetical scenarios and answer a few questions related to those scenarios. Detailed instructions will be provided at the beginning of each section.

You will receive £3 as a participation fee for completing the study. You will also earn an additional payment of up to £14.6 depending partly on your decisions and partly on chance. You will be paid within 3 working days after completing the study.

Please pay careful attention to the instructions. During the study, we will speak in terms of experimental tokens instead of pounds. The sum of tokens you earn in the experiment will be converted to pounds at the following rate:

25 tokens= £1

Important: Once you have moved on to the next question, you cannot go back and change your choice. Do not close the web browser at any time!

1.6.3.2 Experimental Section 1

Section 1 consists of two blocks, Blocks A and B. Each block consists of 21 decision problems that share a common format. An example of the decision problem will be provided at the beginning of each block.

In each decision problem, you will be asked to choose **one** option out of multiple options. An option [X, Y] indicates that you will earn either X tokens or Y tokens with **the same** probability. For instance, the option [24, 32] indicates that you will earn 24 tokens with probability 50% and 32 tokens with probability 50%.

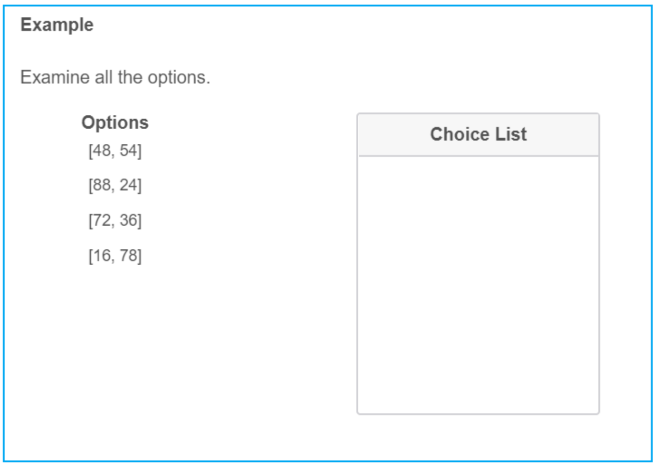
In each decision problem, you are encouraged to examine all options and should choose only one option that you prefer. There is no right and wrong answer to each decision problem. We are interested in studying your preferences.

We use the following method to determine your payment in Section 1: At the end of Section 1, you will be asked to make a choice between Blocks A and B for your payment. At the end of the experiment, one of the 21 problems from the block you choose will be drawn at random. Each problem has **the same** probability of being drawn. You will earn tokens according to your choice in this randomly drawn problem.

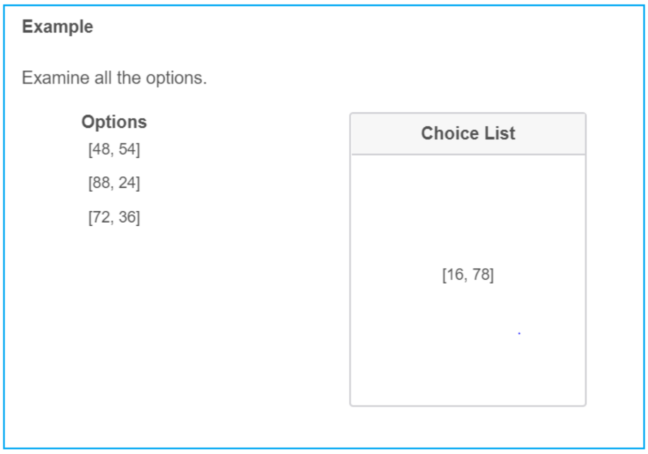
You will earn real money, depending on your decisions. Please make careful decisions.

The Direct Procedure (Block A)

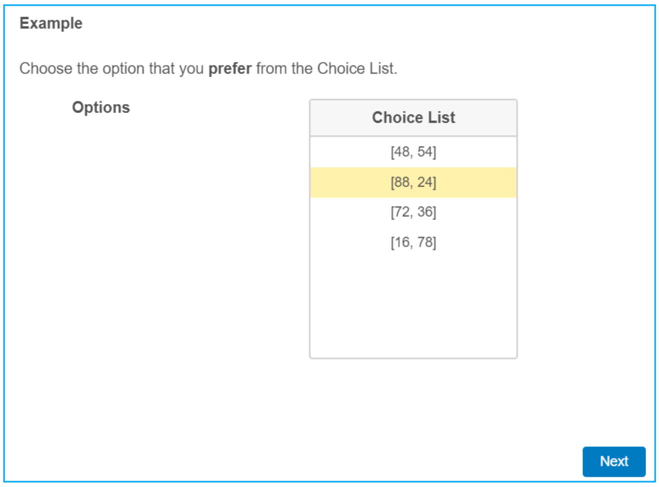
In this block, you will participate in 21 decision problems. You will make decisions by a procedure called "**sequential examination**". You will be asked to sequentially examine, one by one, options by clicking on them. Then you will be asked to choose only **one** option that you **prefer**. Below, you can see an example of sequential examination:



For instance, if you have examined the option [16, 78], you can click on it. It will then be moved to the "**Choice List**".



You should examine all the options by clicking on them. Then you can choose the option that you prefer from the "**Choice List**" by clicking on it. Your final choice will be highlighted in yellow. For instance, in the screen below, your choice is [88, 24].



You should click on “Next” to confirm your choice and proceed to the next problem.

Regarding payment, suppose that you choose [88, 24] by sequential examination. If you are paid according to this choice, you would receive 88 tokens with 50% probability and 24 tokens with 50% probability.

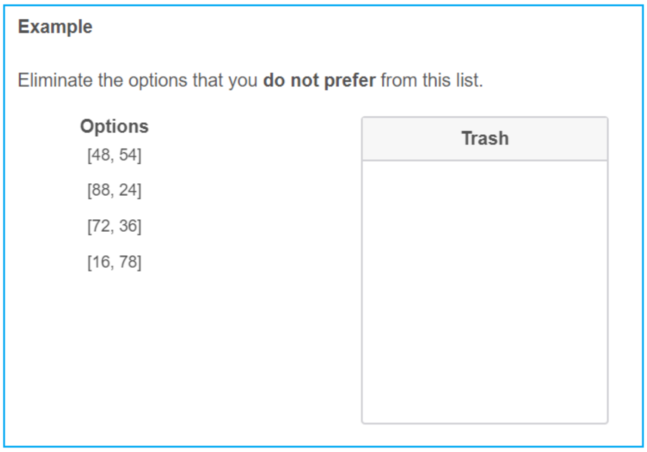
To familiarize you with the decision problems, you will have a practice problem. It will not affect your payment. Then you will be asked to complete all the problems.

Important: Once you have clicked on “**Next**”, you cannot go back and change your choice.

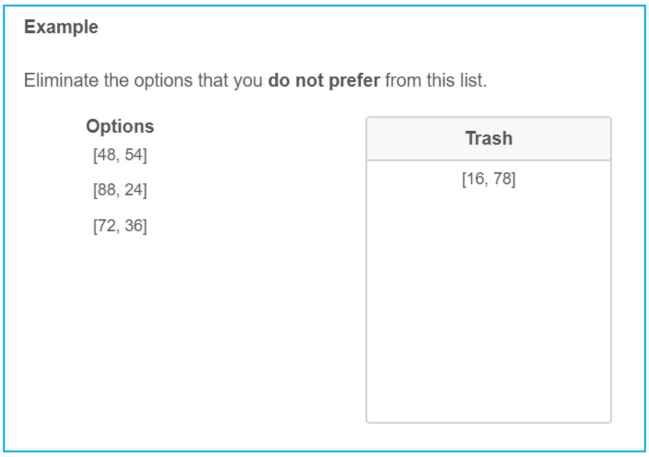
Sequential Elimination (Block A)

In this block, you will participate in 21 decision problems. You will make decisions by a procedure called "**sequential elimination**". You will be asked to sequentially eliminate, one by one, the options that you do not prefer by clicking on them, until only **one** option remains. The **last remaining option** is your **choice** in the decision problem.

Below, you can see an example of sequential elimination:

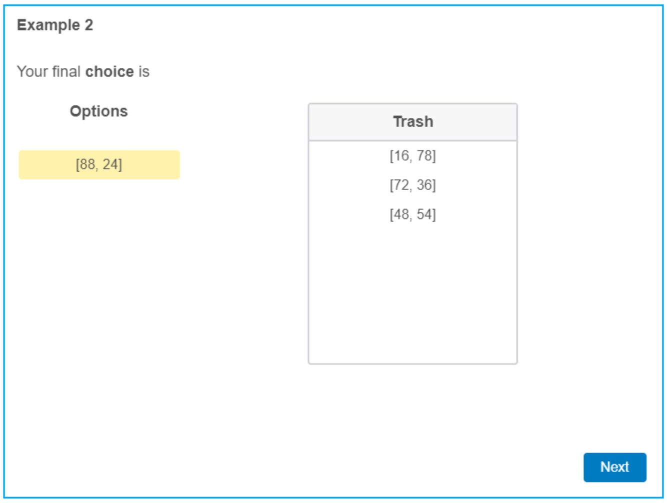


For instance, if you eliminate [16, 78] by clicking on it, it will be moved to the "**Trash**".



Note that you can **recover** the options in the Trash by clicking on them. For example, if you click on [16, 78] in the Trash, it will be moved back to the “Options”.

Regarding your choice, you should eliminate options until only **one** option remains. For instance, in the screen below, supposed that you have eliminated [16, 78], [72, 36] and [48, 54]. As a result, the **last remaining** [88, 24] is your final **choice** in this problem. Your final choice is highlighted in yellow.



You should click on “Next” to confirm your choice and proceed to the next problem.

Regarding payment, suppose that you choose [88, 24] by sequential elimination. If you are paid according to this choice, you would receive 88 tokens with 50% probability and 24 tokens with 50% probability.

To familiarize you with the decision problems, you will have a practice problem. It will not affect your payment. Then you will be asked to complete all the problems.

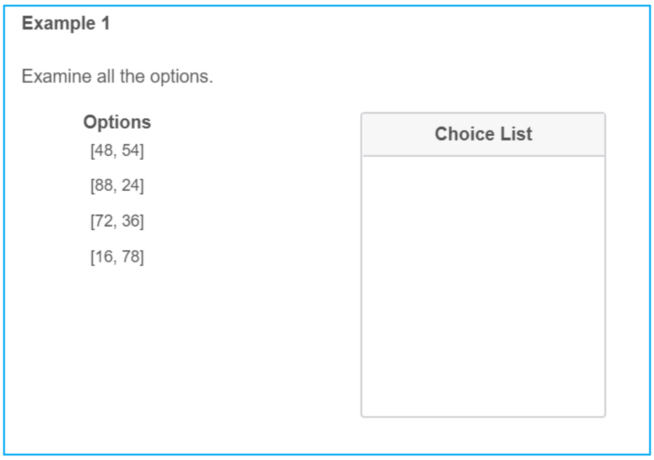
Important: Once you have clicked on “Next”, you **cannot** go back and change your choice.

The Free Procedure (Block A)

First, you have to make a choice between two choice procedures: sequential examination and sequential elimination. The two procedures will be explained below with examples. Then you will participate in 21 decision problems using the procedure chosen by you.

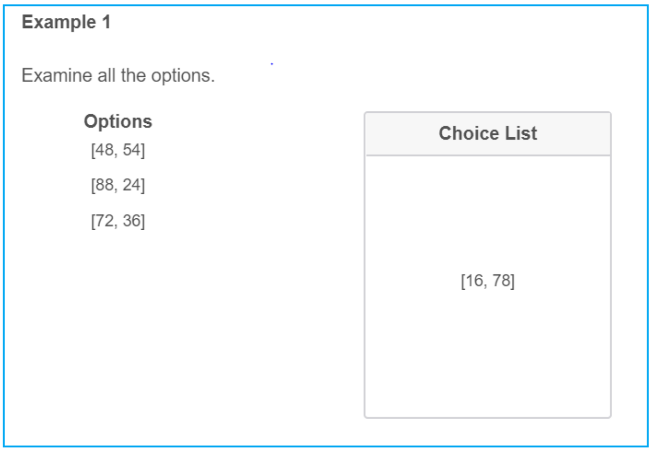
1) **Sequential Examination**: You will be asked to sequentially examine, one by one, options by clicking on them. Then you will be asked to choose only **one** option that you **prefer**.

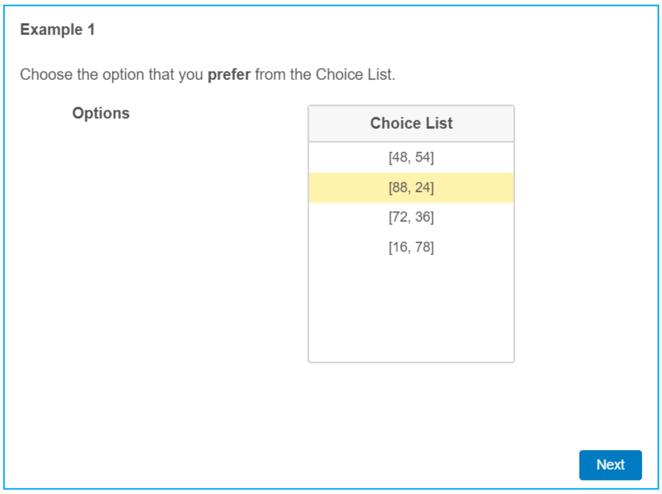
Below, you can see an example of sequential examination:



For instance, if you have examined the option [16, 78], you can click on it. It will then be moved to the "**Choice List**".

You should examine all the options by clicking on them. Then you can choose the option that you prefer in the "**Choice List**" by clicking on it. Your final choice will be highlighted in yellow. For instance, in the screen below, your choice is [88, 24].



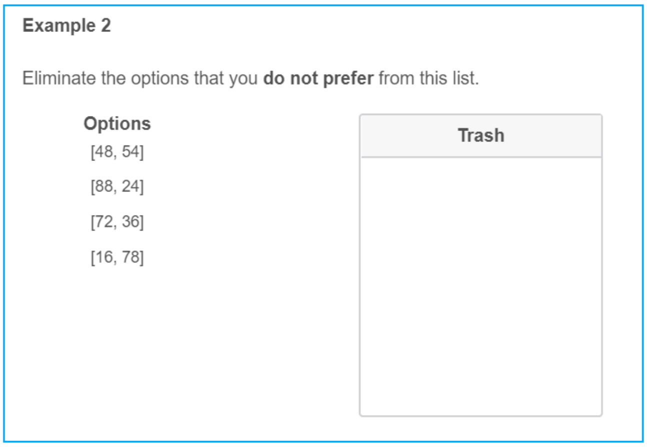


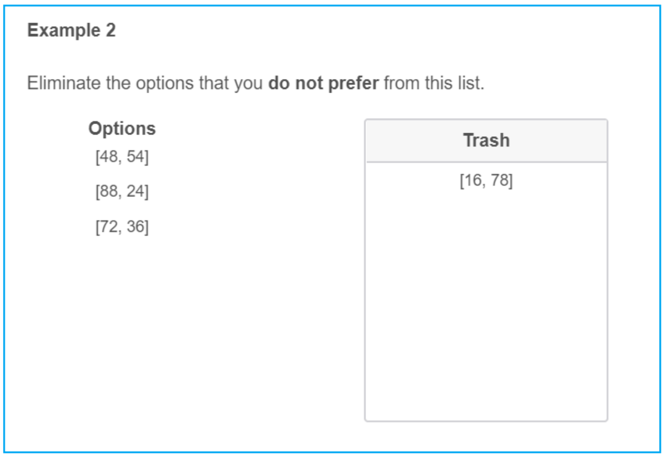
You should click on “Next” to confirm your choice and proceed to the next problem.

2) **Sequential Elimination**: You will be asked to sequentially eliminate, one by one, the options that you do **not prefer** by clicking on them, until only one option remains. The **last remaining option** is your **choice** in the decision problem.

Below, you can see an example of sequential elimination:

For instance, if you eliminate [16, 78] by clicking on it, it will be moved to the “**Trash**”.

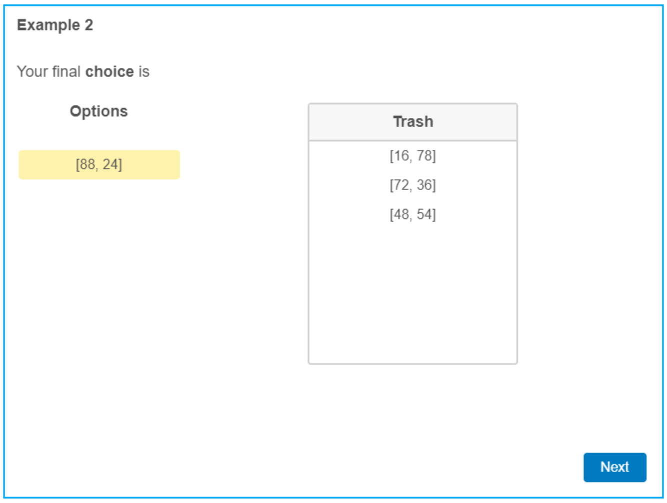




Note that you can **recover** the options in the Trash by clicking on them. For example, if you click on [16, 78] in the Trash, it will be moved back to the "Options".

Regarding your choice, you should eliminate options until only **one** option remains. For instance, in the screen below, supposed that you have eliminated [16, 78], [72, 36] and [48, 54]. As a result, the **last remaining** [88, 24] is your final choice in this problem. Your final **choice** is highlighted in yellow.

You should click on "Next" to confirm your choice and proceed to the next problem.



Regarding payment, suppose that you choose [88, 24] by sequential examination or sequential elimination. If you are paid according to this choice, you would receive 88 tokens with 50% probability and 24 tokens with 50% probability.

To familiarize you with the decision problems, you will have a practice problem for each procedure. It will not affect your payment. Then you will be asked to choose a procedure and complete all the problems.

Important: Once you have clicked on “Next”, you **cannot** go back and change your choice.

The Free Procedure: Procedure Selection

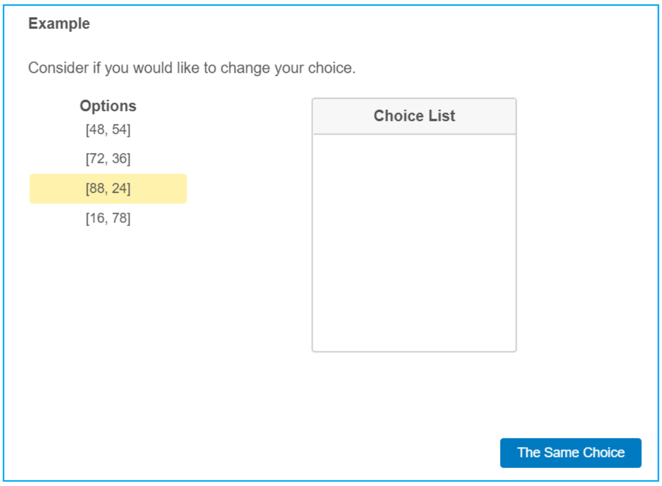
Please indicate which procedure that you would like to use in Section 1.

- The Direct Procedure
- Sequential Elimination

The Direct Procedure (Block B)

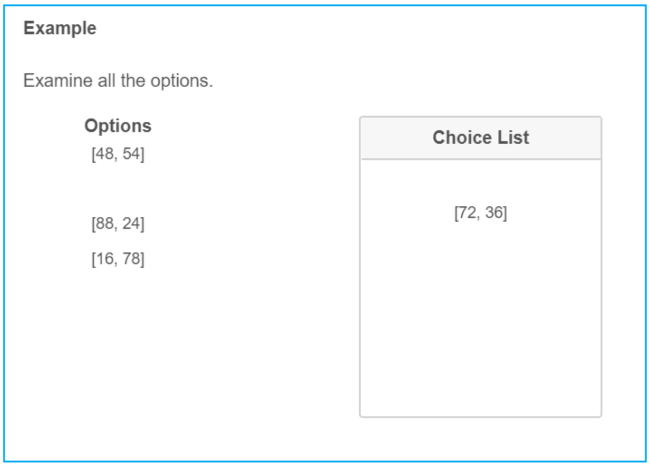
In this block, you will confront the **same** 21 decision problems as those in Block A. You will see your choice from the corresponding problem in Block A highlighted in yellow. You will be asked to consider if you would like to change you choice.

Below, you can see an example of Block B problem:



You can choose the same option as you chose in the corresponding problem in Block A by clicking on “The Same Choice”. For instance, if you click on “The Same Choiceâ in this problem, your choice is [88, 24] and you will proceed to the next problem directly.

If you want to change your choice, you can click on **any** option on the list. Then you can start again the sequential examination. For instance, if you click on [72, 36], you will see the screen below.



Regarding payment, suppose that this time you choose [48, 54]. If you are paid according to this choice, you would receive 48 tokens with 50% probability and 54 tokens with 50% probability.

To familiarize you with the decision problems, you will have a practice problem. It will not affect your payment. Then you will be asked to complete all the problems.

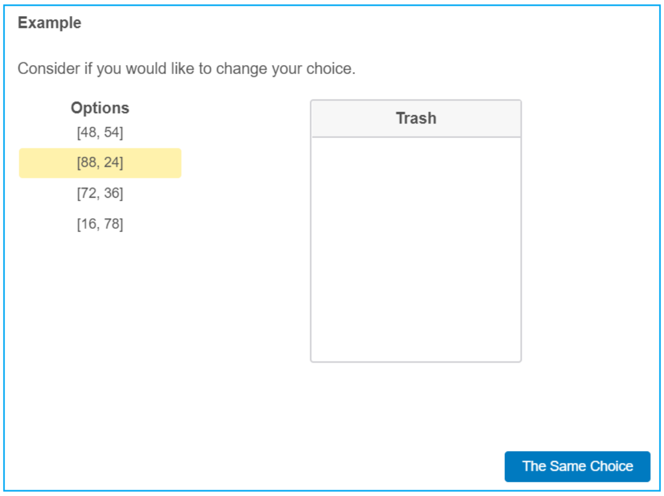
Remember that we will ask you to choose between Blocks A and B for payment at the end of Section 1.

Important: Once you have clicked on "Next", you **cannot** go back and change your choice.

Sequential Elimination (Block B)

In this block, you will confront the **same** 21 decision problems as those in Block A. You will see your choice from the corresponding problem in Block A highlighted in yellow. You will be asked to consider if you would like to change you choice.

Below, you can see an example of Block B problem: You can choose the same



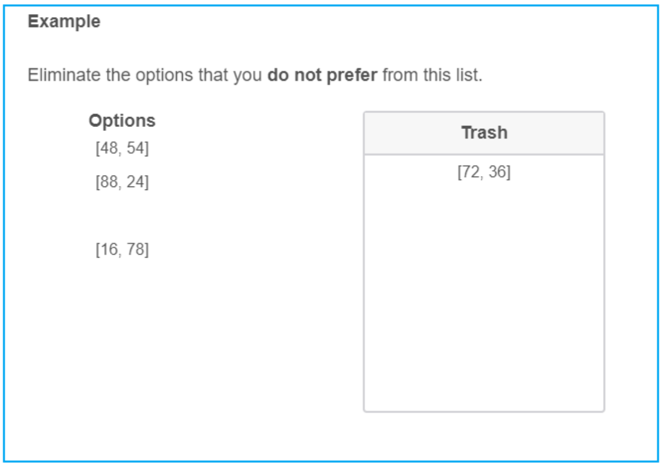
option as you chose in the corresponding problem in Block A by clicking on “The Same Choice”. For instance, if you click on “The Same Choiceâ in this problem, your choice is [88, 24] and you will proceed to the next problem directly.

If you want to change your choice, you can click on **any** option on the list. Then you can start again the sequential elimination. For instance, if you click on [72, 36], you will see the screen below.

Regarding payment, suppose that this time you choose [48, 54]. If you are paid according to this choice, you would receive 48 tokens with 50% probability and 54 tokens with 50% probability.

To familiarize you with the decision problems, you will have a practice problem. It will not affect your payment. Then you will be asked to complete all the problems.

Remember that we will ask you to choose between Blocks A and B for payment at the end of Section 1.



Important: Once you have clicked on "Next", you **cannot** go back and change your choice.

Payment Block Selection

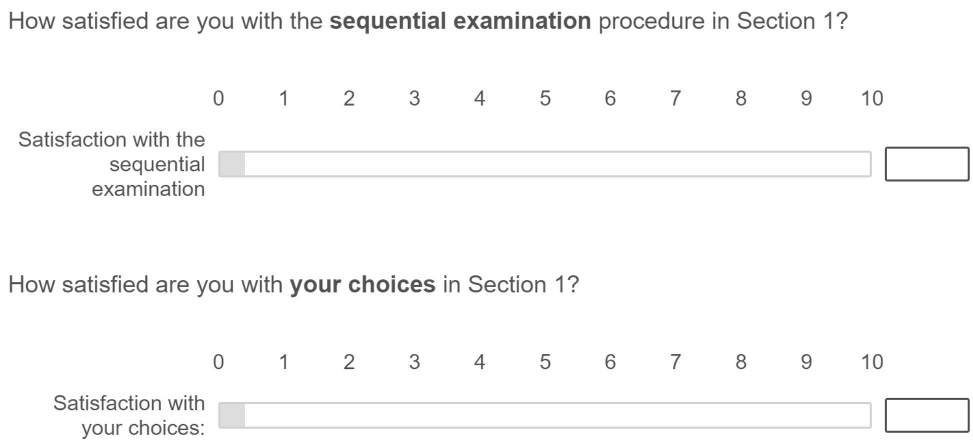
Please indicate that which block you would like to choose for your payment in Section 1.

- Block A
- Block B

Individual Satisfaction (The Direct Procedure)

Now, we would like to understand how satisfied you are with the decisions you made in Section 1.

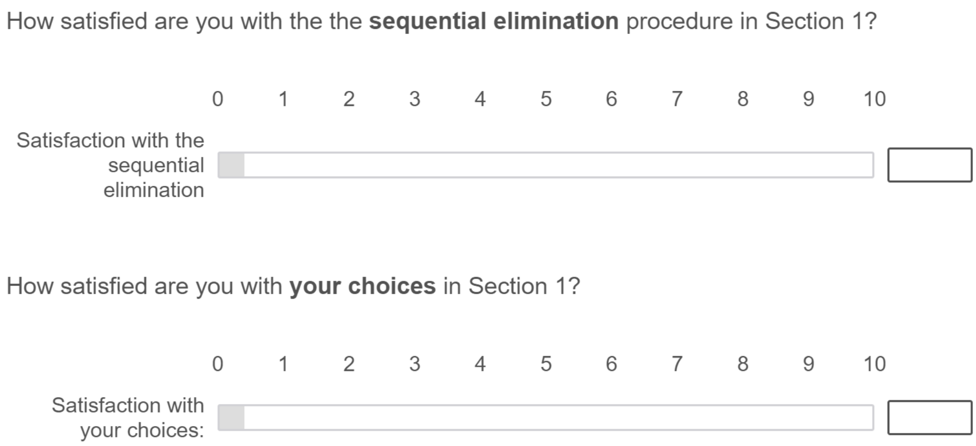
A rating of 0 means that you are not satisfied at all. A rating of 10 means that you cannot be more satisfied. Please select the number between 0 and 10 that best describes how you feel about the sequential examination procedure and your choices in Section 1.



Individual Satisfaction (Sequential Elimination)

Now, we would like to understand how satisfied you are with the decisions you made in Section 1.

A rating of 0 means that you are not satisfied at all. A rating of 10 means that you cannot be more satisfied. Please select the number between 0 and 10 that best describes how you feel about the sequential elimination procedure and your choices in Section 1.



1.6.3.3 Screenshots of Treatments

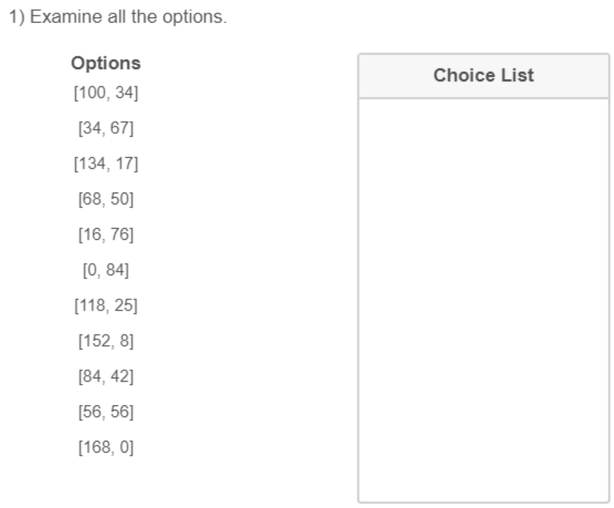


Figure 1.6: The Direct Procedure, a Subject Enters a Decision Problem

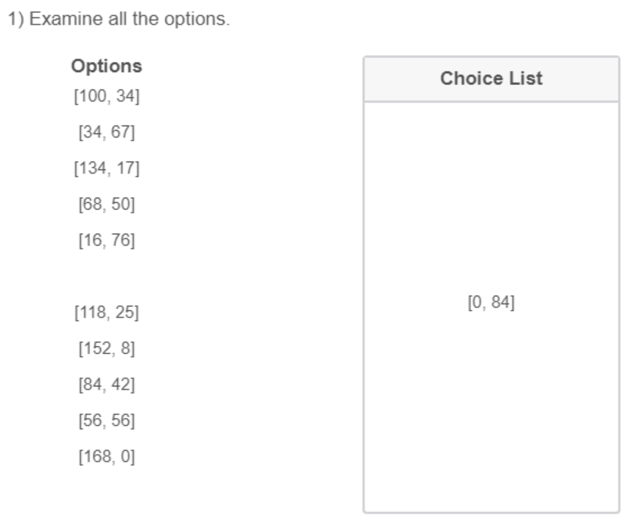


Figure 1.7: The Direct Procedure, a Subject Clicks on an Option

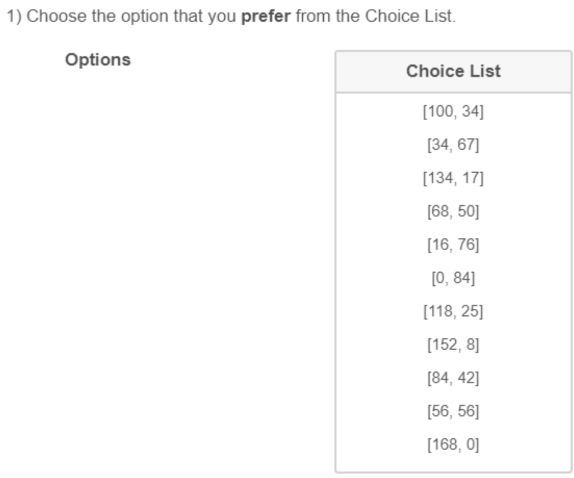


Figure 1.8: The Direct Procedure, a Subject Has Clicked on All Options

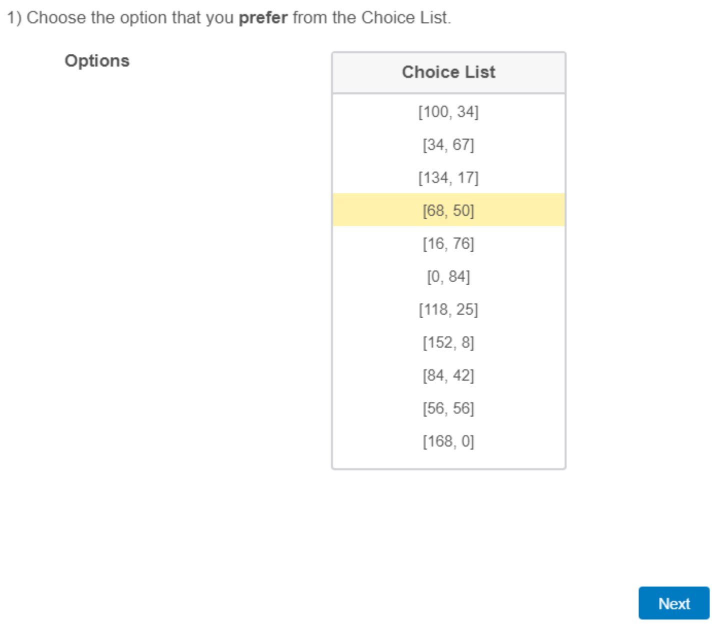


Figure 1.9: The Direct Procedure, a Subject Chooses an Option in the Choice List

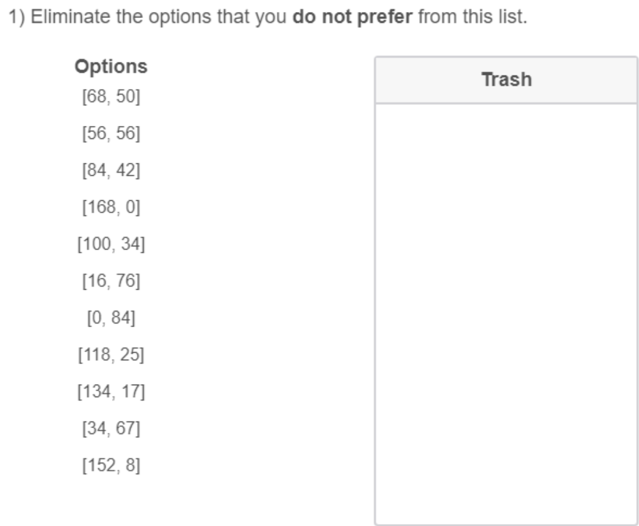


Figure 1.10: Sequential Elimination, a Subject Enters a Decision Problem

Figure 1.11: Sequential Elimination, a Subject Eliminates an Option

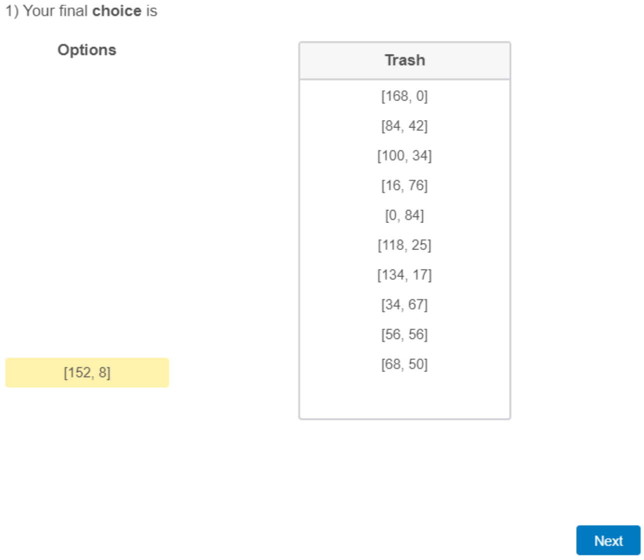


Figure 1.12: Sequential Elimination, a Subject Has Eliminated All But One Options

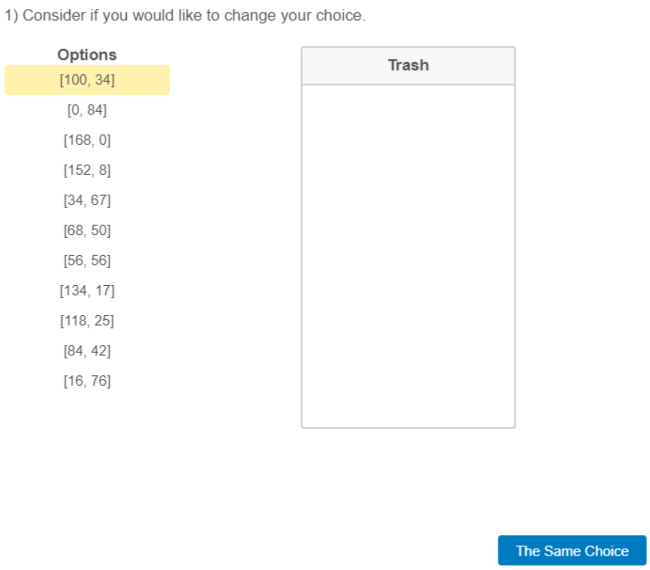


Figure 1.13: Choice Revision (Block B), a Subject Enters a Decision Problem

1.6.3.4 Experimental Section 2

This section has three cognitive tasks. Your payment in this section will depend on your performance in the three tasks. Each task has a different number of questions. At the end of the experiment, the computer will randomly draw three questions from all the tasks with equal probability. For each correct answer to the random three questions, you will receive 25 tokens.

Task 1 (ICAR)

In this task, you are asked to answer ten questions. Five of them are about matrix reasoning and the other five are about three-dimensional rotation. There is a right answer to each question. You can have at most twelve minutes in this task.

Please indicate which is the best answer to complete the figure below.

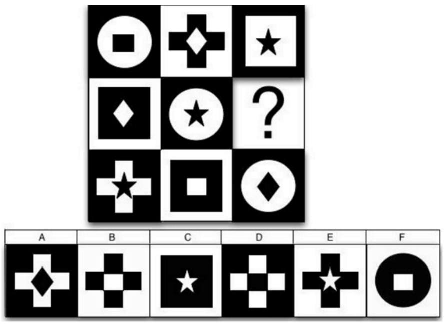


Figure 1.14: ICAR, Matrix Reasoning Problem

Please indicate which is the best answer to complete the figure below.

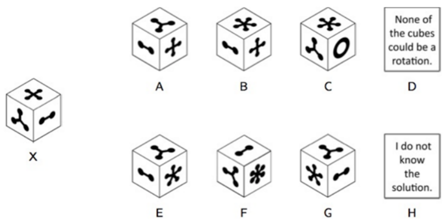


Figure 1.15: ICAR, Three-dimensional Rotation Problem

Task 2 (Stroop Task)

This task measures your concentration. In each round, you are asked to **identify the color of the word shown on the screen**. The word itself is irrelevant â you can safely ignore it. To indicate the color of the word, please use the keys **r**, **g**, **b** and **o** for red, green, blue and orange, respectively. A plus sign will be shown before each word, please keep your eyes on the plus sign. You will have only two seconds in each round.

Figure 1.16: Stroop Task

Task 3 (Sternberg Task)

This task measures your working memory. In each round, you are asked to memorize a sequence of digits. The length of this sequence can vary from four to eight digits. After the presentation, we will ask you to indicate whether a certain digit was included in the sequence. Please press **y** if you think that the digit was in the sequence. If not, please press **n**. If your decision is correct, you will see a green circle. Otherwise, you will see a red circle. Then we will ask you to type in the entire sequence.

Figure 1.17: Sternbeg Task, Memorization Phase

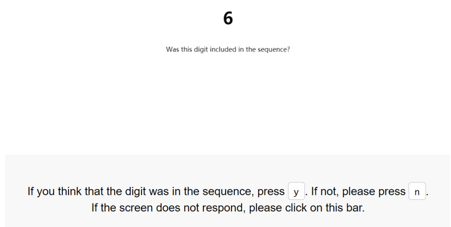


Figure 1.18: Sternbeg Task, Recall Phase

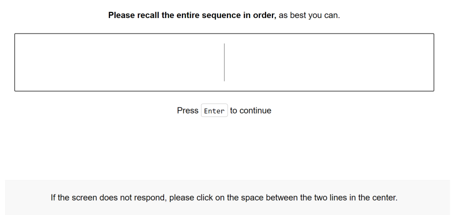


Figure 1.19: Sternbeg Task, Recall Phase

1.6.3.5 Experimental Section 3

In this section, you will also be asked to imagine yourself in three hypothetical scenarios and answer a few questions related to those scenarios. There are no right or wrong answers to those questions, simply answer based on your feeling.

Attitude towards Inconsistency

Imagine that you are at a cinema and wish to buy some popcorn. The cinema sells small tubs of popcorn for £3 and large ones for £7. Suppose that you choose the small one. Now consider a different situation. The cinema sells small tubs for £3, medium ones for £6.50 and large ones for £7. This time you choose the large one.

In the first case, you prefer the small size to the large. In the second case, your choice suggests the opposite. How at ease do you feel with your choices? Please rate how at ease you feel on the scale provided. A rating of 0 means that you are not at all at ease with one or more of your choices and would really like to make changes. A rating of 10 means that you could not be more at ease and have no wish to change anything.

Sunk Cost Fallacy

Imagine that you have spent £50 on a ticket for concert A and £100 on a ticket for concert B. You really prefer A to B, but you have discovered that the two concerts are to take place exactly at the same time on the same day. You cannot obtain a refund or sell the tickets. Which concert would you go to?

- Concert A
- Concert B

Non-Consequentialism

Imagine two trips you may make this summer. You plan Trip 1 by yourself. Someone plans Trip 2 for you. The plans for both trips are the same. You will visit the same places, take the same photos and enjoy the same foods. In other words, you will enjoy the same experiences on both trips. Which trip do you prefer to go to?

- Trip 1
- Trip 2
- I am indifferent between the two trips.

1.6.4 Descriptive Statistics of the Sample

1.6.4.1 Demographics

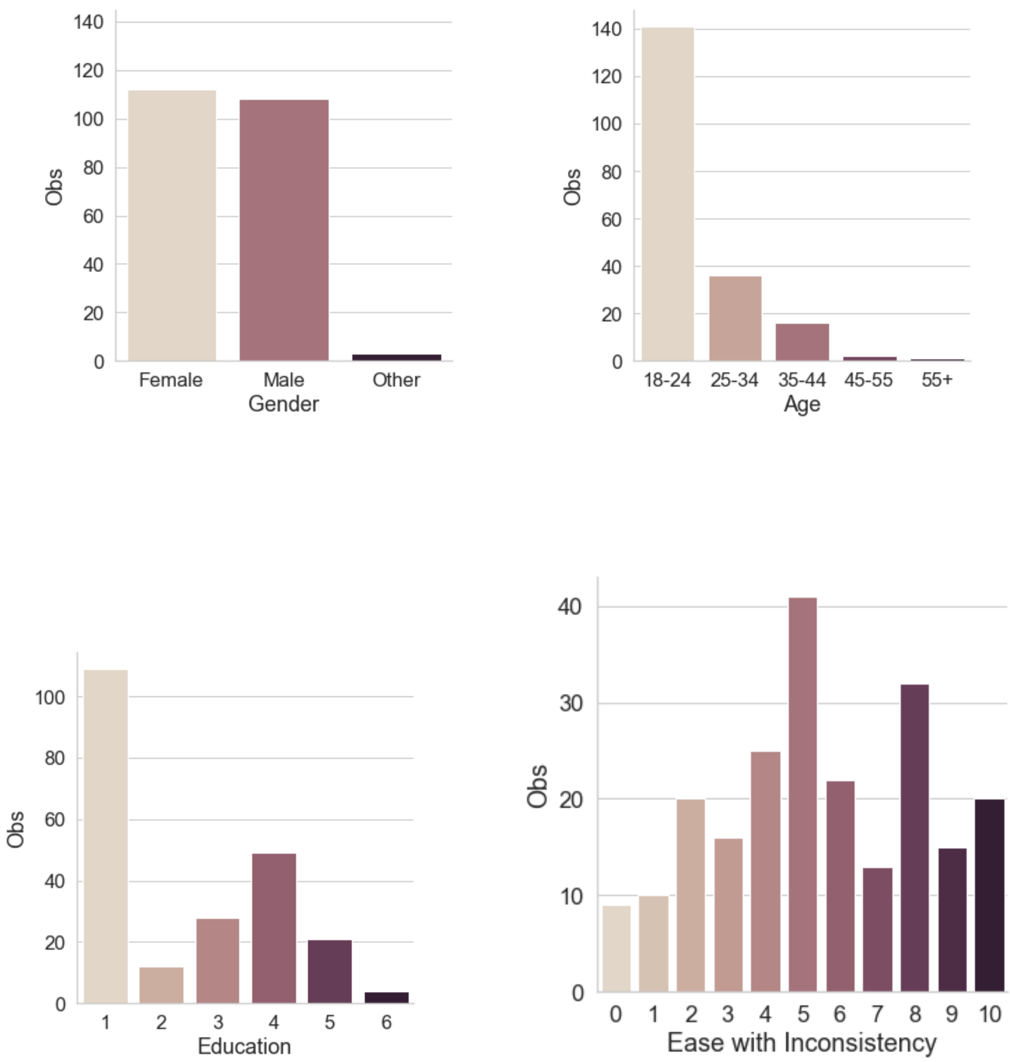


Figure 1.20: Histograms of Demographics (Overall Sample)

Notes: The variable *education* takes a numeric value defined as follows: 0="No Qualifications", 1="High school diploma/A-levels" or "Secondary education (e.g., GED/GCSE)", 2="Technical/community college", 3="Undergraduate degree (BA/BSc/other)", 4="Graduate degree (MA/MSc/MPhil/other)", 5="Doctorate degree (PhD/other)".

1.6.4.2 Cognitive Ability

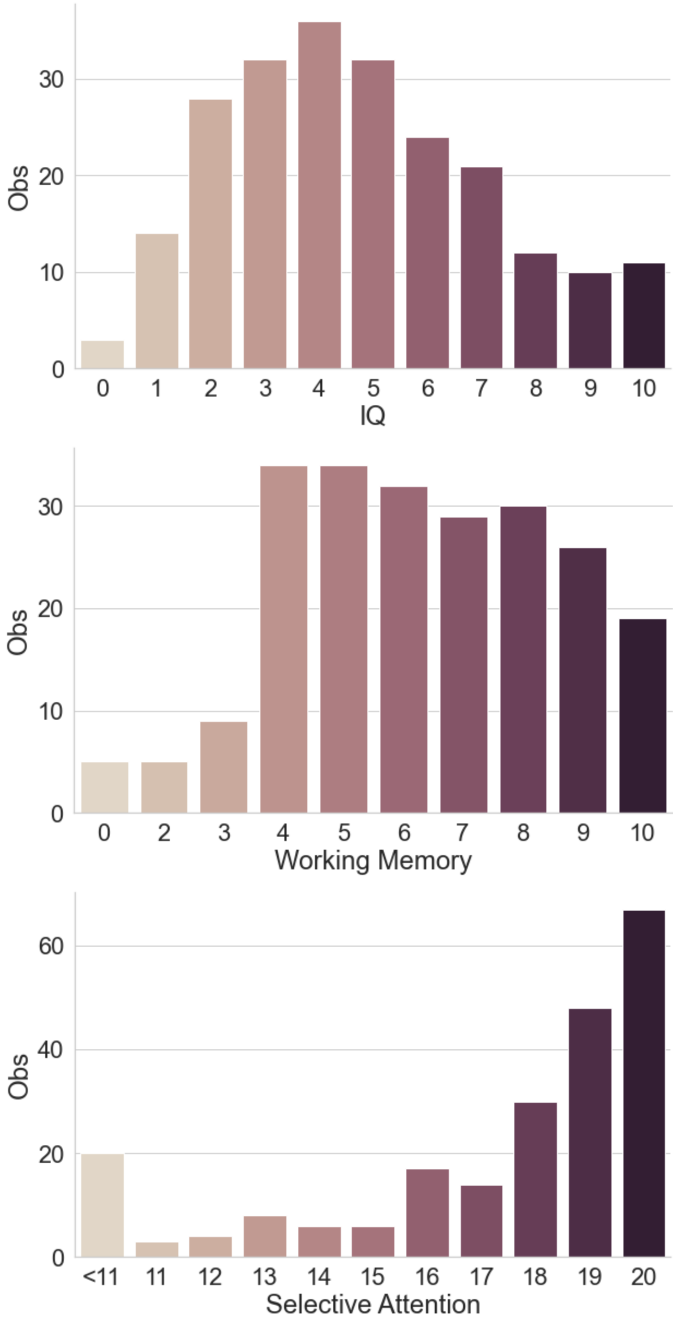


Figure 1.21: Histograms of Cognitive Ability (Overall Sample)

1.6.4.3 Balance Checks

Table 1.6: Descriptive Statistics and Balance

Variable	Direct Procedure	Sequential Elimination	Difference
Age (years)	23.147	24.712	1.566
	(5.082)	(8.259)	(1.124)
Female	0.520	0.507	-0.013
	(0.503)	(0.503)	(0.083)
Education (highest completed level)	1.973	2.000	0.027
	(1.150)	(1.190)	(0.192)
IQ	4.907	4.562	-0.345
	(2.291)	(2.560)	(0.399)
Selective Attention	17.173	16.616	-0.557
	(3.411)	(4.192)	(0.627)
Working Memory	6.213	6.096	-0.117
	(2.164)	(2.328)	(0.369)
Attitude towards Inconsistency	5.800	5.329	-0.471
	(2.899)	(2.911)	(0.478)
Observations	75	73	148

Standard errors in parentheses.

Table 1.7: Detailed Breakdown of Observations

IQ Group \ Treatment	Direct Procedure	Sequential Elimination	Direct Procedure (Free)	Sequential Elimination (Free)
Low-IQ Subjects	34 (45.3%)	40 (54.8%)	7 (26.9%)	32 (65.3%)
High-IQ Subjects	41 (54.7%)	33 (45.2%)	19 (73.1%)	17 (34.7%)
Total	75 (100%)	73 (100%)	26 (100%)	49 (100%)

1.6.4.4 Economic Rationality

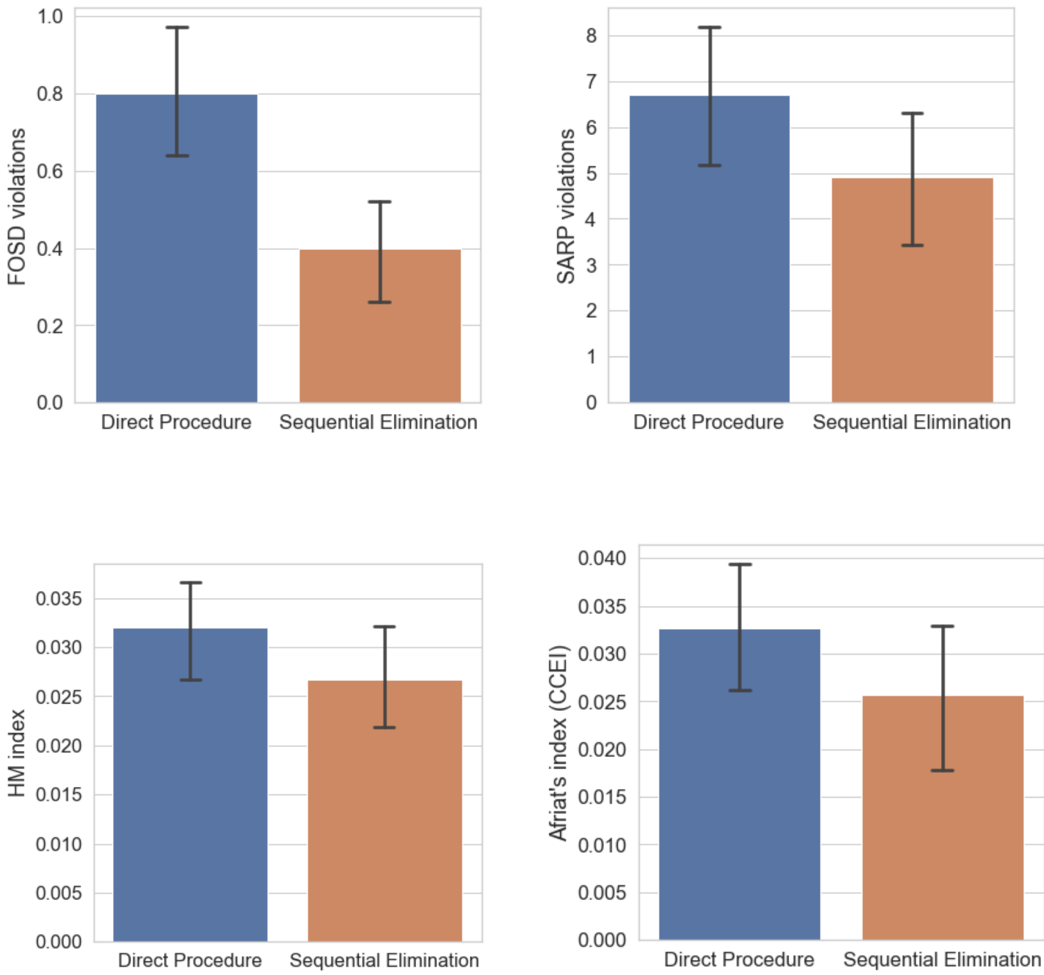


Figure 1.22: Means of Economic Rationality Measures by Treatment (1)

Notes: Error bars indicate the standard error of means.

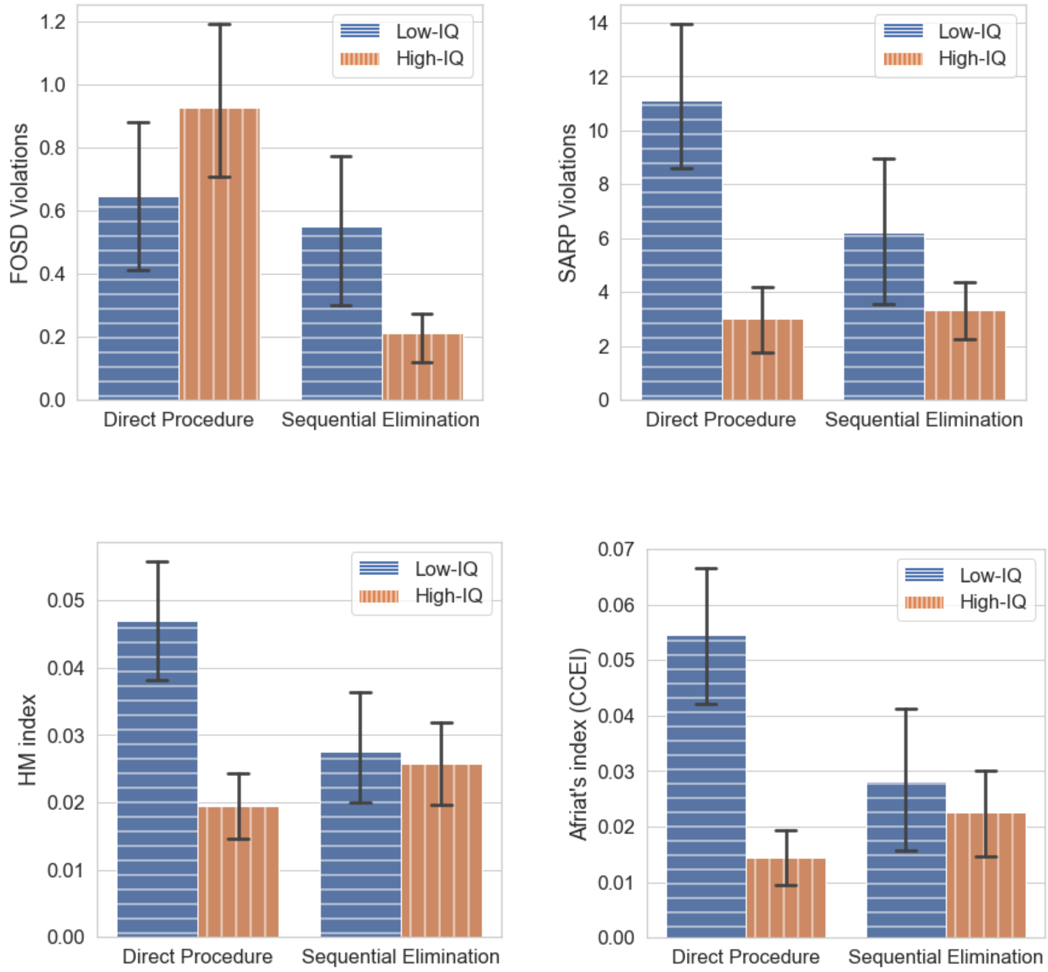


Figure 1.23: Means of Economic Rationality Measures by Treatment (2)

Notes: Error bars indicate the standard error of means.

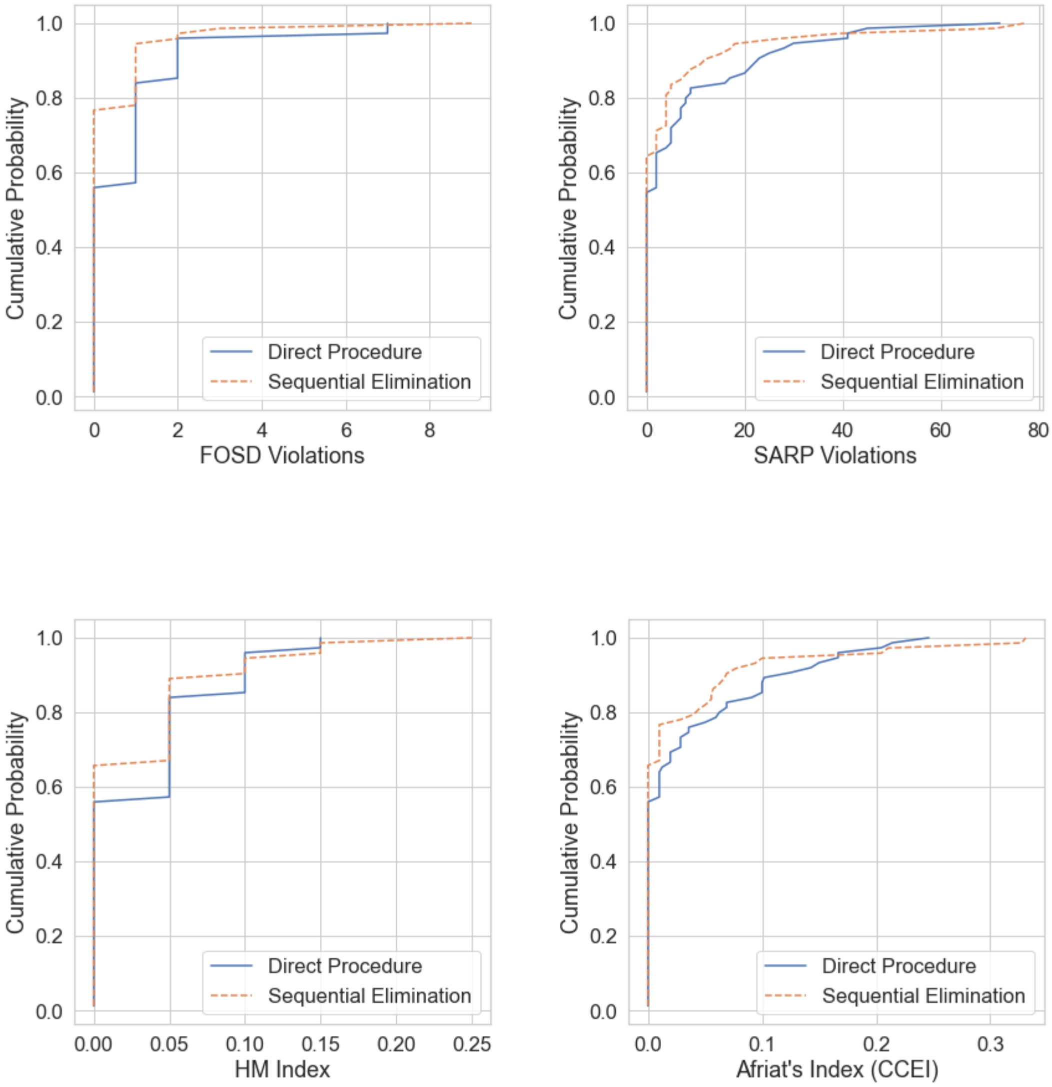


Figure 1.24: Cumulative Distributions of of Economic Rationality Measures by Treatment

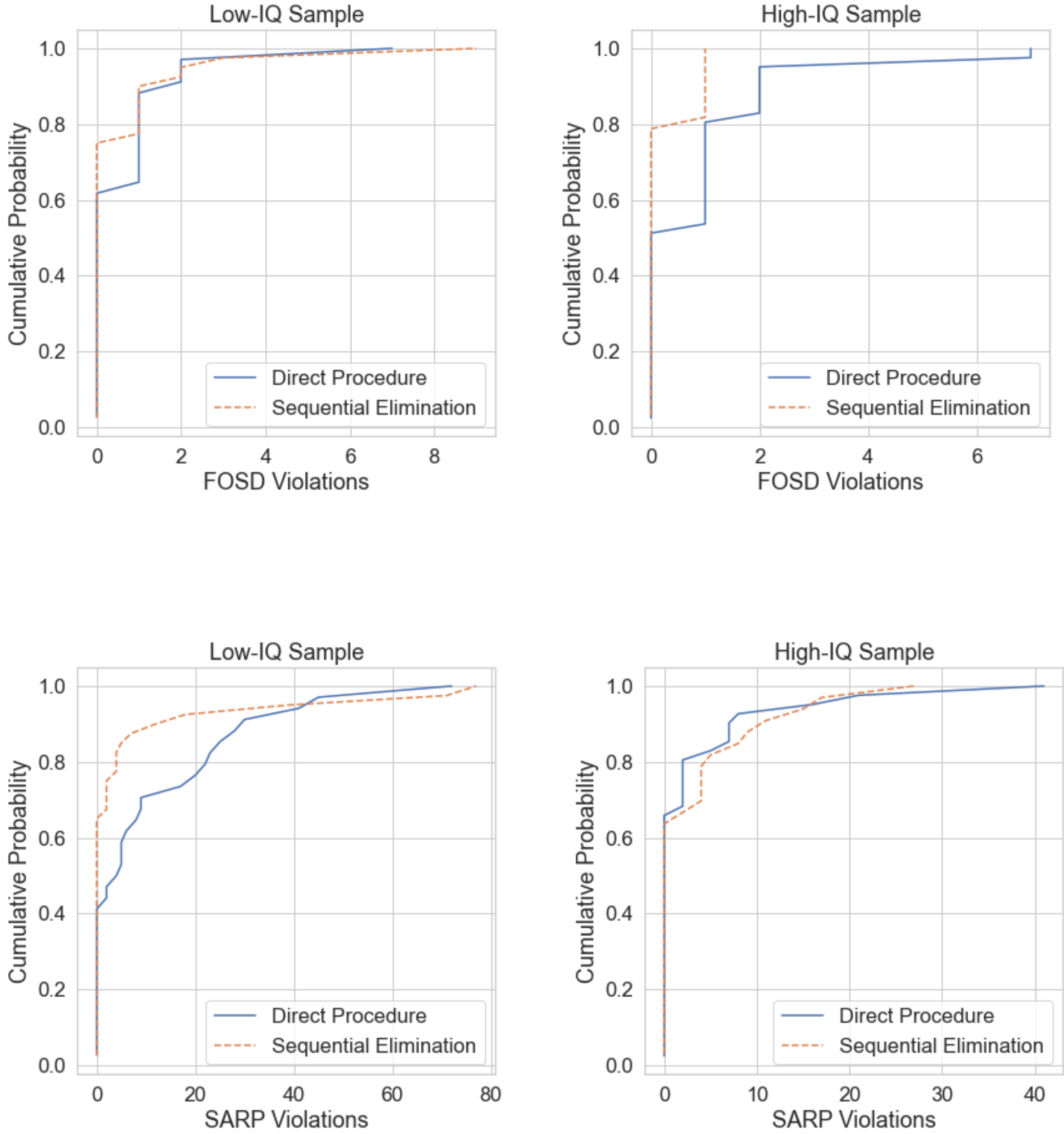


Figure 1.25: Cumulative Distributions of of Economic Rationality Measures by Treatment and by IQ (1)

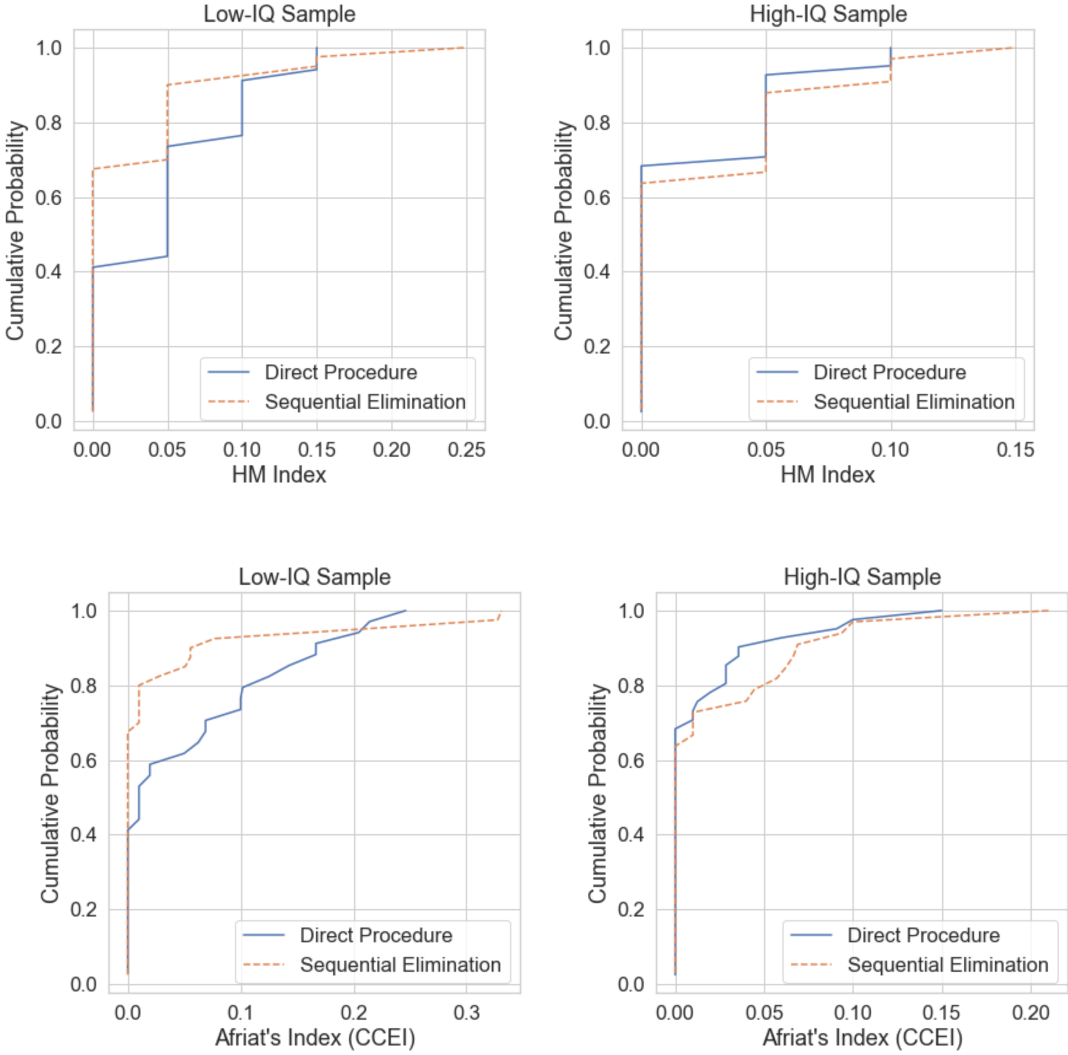


Figure 1.26: Cumulative Distributions of of Economic Rationality Measures by Treatment and by IQ (2)

1.6.4.5 Risk Preferences

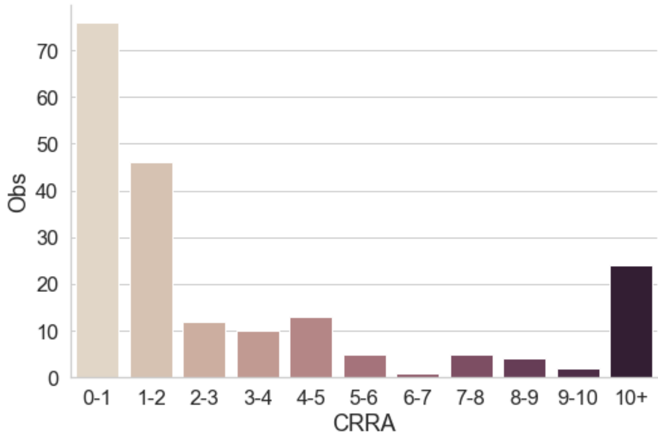


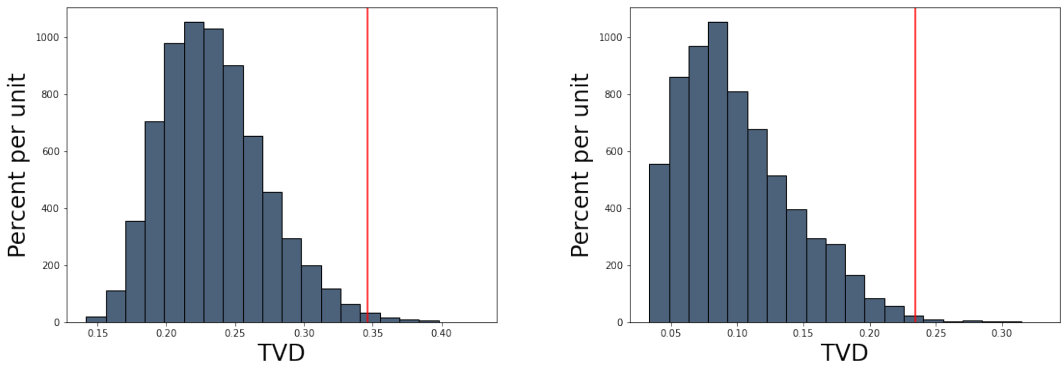
Figure 1.27: Histogram of Estimated CRRA

1.6.5 Robustness Checks

1.6.5.1 Economic Rationality

The results presented are robust to several alternative approaches. Two-sample permutation tests allow nonparametric testing of the difference in GARP violations under the two treatments. 10,000 data sets are generated by randomly shuffling the treatment assignments in the sample, and a calculation is made of the total Variation Distance (TVD) between the GARP violation distributions under these assignments. The null hypothesis is that economic rationality of choices under the Direct Procedure and Sequential Elimination come from the same distribution. If the null hypothesis is true, the TVD given by the actual data should appear with a high probability in the shuffled data sets; otherwise, it should appear with a low probability. Figure 1.28 plots the empirical distribution of the TVD in the permutations, which suggests rejection of the null hypothesis, since the observed differences in the TVD for both GARP and FOSD violations data (indicated by red lines) are statistically significant. This provides evidence for the effect of sequential elimination on economic rationality, not only in the sample but also in the population.

Figure 1.29 shows permutation tests in the low-IQ subsample and the ones in the high-IQ subsample. In particular, the TVD difference in GARP violations between the Direct Procedure and Sequential Elimination is statistically significant for low-IQ subjects ($p = 0.004$, Figure 1.29 (a)) but not for High-IQ subjects ($p = 0.1308$, Figure 1.29 (b)). Reversely, with the switch from Direct Procedure to Sequential Elimination, the TVD difference in FOSD violations is statistically significant for high-IQ subjects ($p = 0.0262$, Figure 1.29 (c)) but not for low-IQ subjects ($p = 0.2426$, Figure 1.29 (d)). In sum, the nonparametric results are consistent with our previous regression analysis.

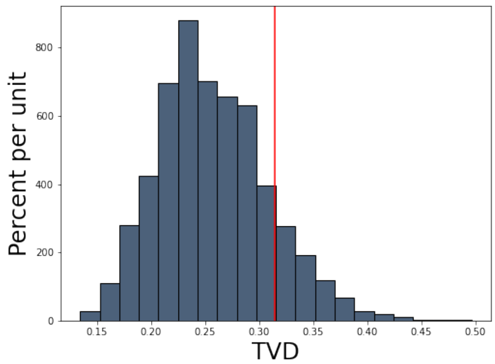


(a) GARP Violations **(b)** FOSD Violations

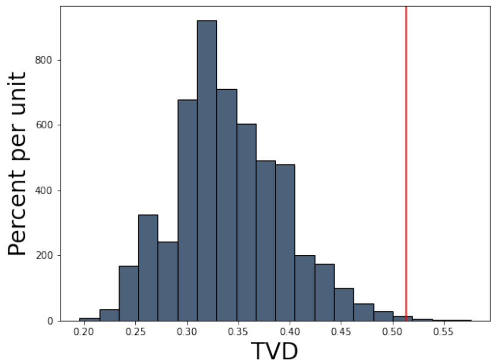
Figure 1.28: Permutation Tests of Sequential Elimination Effect on Economic Rationality

Notes: Empirical P-values are (a) 0.0058; (b) 0.0071ã

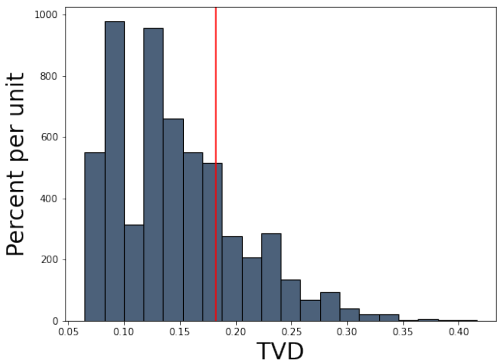
Table 1.8 shows, in addition to the Table 1.2, negative binomial regression estimates for SARP violations and the HM index, due to their count data nature. Also shown are the OLS regression estimates for the CCEI, where the OLS coefficients exactly reproduce the marginal effects. Columns (1)-(4) indicate that the effect of sequential elimination on GARP violations remains similar for SARP violations ($p = 0.15$),



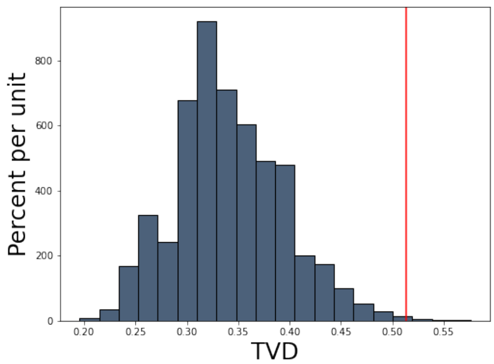
(a) GARP Violations, Low-IQ Sample



(b) GARP Violations, High-IQ Sample



(c) FOSD Violations, Low-IQ Sample



(d) GARP Violations, High-IQ Sample

Figure 1.29: Permutation Tests of Sequential Elimination Effect on Economic Rationality in Subsamples

Notes: Empirical P-values are (a) 0.004; (b) 0.1308; (c) 0.2426; (d) 0.0262.

but differs for HM index ($p = 0.63$) and CCEI ($p = 0.77$). The HM index is sensitive to the total number of decision problems and CCEI is sensitive to the GARP violation associated with the maximum wealth loss, but not to the total number of violations, which is the central interest of this paper.

The experiment also elicits the subjectâs tendencies to commit sunk cost fallacy and non-consequentialism. The sunk cost fallacy suggests that individuals influenced by sunk cost concerns (e.g., time, effort, and money) tend to make non-optimal decisions,

Table 1.8: Determinants of Economic Rationality (All Measures)

	(1) GARP Violations	(2) SARP Violations	(3) HM Index	(4) CCEI	(5) FOSD Violations
Sequential Elimination	-4.480*	-4.100*	-0.003	-0.003	-0.515**
	(3.045)	(2.871)	(0.007)	(0.011)	(0.215)
-Low-IQ Subjects	-9.409**	-8.762**	-0.014	-0.020	-0.226
	(5.246)	(4.962)	(0.011)	(0.019)	(0.233)
-High-IQ Subjects	0.799	0.833	0.008	0.014	-0.917**
	(1.302)	(1.532)	(0.008)	(0.010)	(0.434)
Age	-0.456*	-0.423*	-0.002**	-0.001**	-0.064***
	(0.253)	(0.242)	(0.001)	(0.001)	(0.024)
Female	0.885	-0.154	-0.005	0.003	0.170
	(2.138)	(2.079)	(0.007)	(0.009)	(0.177)
Education	-1.232	-0.936	0.002	-0.000	0.212
	(1.339)	(1.287)	(0.004)	(0.004)	(0.133)
High-IQ	-7.300**	-6.994***	-0.012*	-0.021**	0.145
	(2.900)	(2.711)	(0.007)	(0.010)	(0.211)
Selective Attention	-0.283	-0.266	-0.001	-0.003	-0.030
	(0.373)	(0.348)	(0.001)	(0.002)	(0.031)
Working Memory	-0.357	-0.382	-0.003	-0.001	-0.045
	(0.500)	(0.503)	(0.002)	(0.003)	(0.051)
Response Time (Minutes)	-0.491**	-0.442**	-0.001*	-0.002*	0.012
	(0.229)	(0.217)	(0.001)	(0.001)	(0.020)
Attitude towards Inconsistency	-0.840	-0.815*	-0.001	-0.002	0.021
	(0.511)	(0.478)	(0.001)	(0.002)	(0.033)
N	148	148	148	148	148

Standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

thereby violating consistency (Thaler, 1980, 1999). Adopting the Arkes and Blumer (1985)'s scenario, as described in Appendix 1.6.3, individuals who choose the higher-sunk-cost option are considered subject to sunk cost fallacy. Consequentialism refers to the case where individuals value their choice irrespective of how it is generated. Recent evidence suggests that individuals may make nonoptimal decisions (i.e., those that go against their material interest), motivated in their decision by non-consequential factors such as decision rights (Fehr et al., 2013; Bartling et al., 2014). It is possible that non-consequentialist responses have an impact on choice consistency. Subjects are therefore asked to indicate whether they prefer one of two options with identical consequences, or feel indifferent towards them. Subjects with a declared preference for one or the other is considered a non-consequentialist.

Table 1.9 reports the robustness of the results to some alternative specifications. Column (1) replicates column (1) of Table 1.2, including, in addition, the sunk cost fallacy and the non-consequentialism. The effect of sequential elimination for low-IQ individuals (i.e., IQ-Q1 subjects in column (1)) is larger and still statistically significant ($p = 0.04$). Columns (2) and (3) replicate the aforementioned negative binomial estimation where subjects are categorized by IQ based on their positions in the distribution, first by terciles and then by quartiles. The variable of interest, Sequential Elimination, reduces GARP violations among subjects with IQs in the lowest tercile ($p = 0.04$) and the lowest quartile ($p = 0.03$).

Table 1.9: Determinants of Economic Rationality (Robustness Checks)

	GARP Violations		
	(1)	(2)	(3)
	2-Quantiles	3-Quantiles	4-Quantiles
Sequential Elimination	-4.623*	-3.416*	-3.320*
	(3.079)	(2.648)	(2.554)
–1st IQ quartile	-9.747**	-9.955**	-8.871**
	(5.415)	(5.656)	(4.762)
–2nd IQ quartile	0.799	-2.234	-5.739
	(1.261)	(4.398)	(9.063)
–3rd IQ quartile		1.668	-0.257
		(1.245)	(1.864)
–4th IQ quartile			2.208
			(1.529)
Age	-0.422	-0.275	-0.337
	(0.266)	(0.251)	(0.251)
Female	1.008	-0.653	0.587
	(2.196)	(2.145)	(1.926)
Education	-1.490	-1.135	-1.373
	(1.416)	(1.136)	(1.170)
2nd IQ quartile	-7.413**	0.413	5.121
	(2.937)	(3.546)	(4.844)
3rd IQ quartile		-6.078**	-4.308
		(3.091)	(2.755)
4th IQ quartile			-5.850**
			(2.746)
Selective Attention	-0.232	-0.173	-0.196
	(0.358)	(0.286)	(0.301)
Working Memory	-0.360	-0.257	0.0461
	(0.501)	(0.449)	(0.426)
Response Time	-0.481**	-0.486**	-0.421**
	(0.223)	(0.201)	(0.191)
Attitude towards Inconsistency	-0.778	-0.775*	-0.588
	(0.484)	(0.471)	(0.441)
Sunk Cost Bias	1.509		
	(3.430)		
Non-Consequentialism	1.519		
	(2.252)		
N	148	148	148

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

1.6.5.2 Choice Revision

Table 1.10: Effects of Choice Revision on GARP Violations (Robustness Checks)

	(1)	(2)	(3)	(4)
	GARP Violations			
Choice Revision (CR)	-3.508	-3.387	-1.983	-1.852
	(2.449)	(2.595)	(2.545)	(2.583)
-Direct Procedure		-4.541		-4.142
		(3.407)		(4.692)
-Low-IQ Subjects				-4.664
				(7.004)
-High-IQ Subjects				-3.182
				(2.695)
-Sequential Elimination		-2.105		0.469
		(3.885)		(3.265)
-Low-IQ Subjects				3.486
				(3.803)
-High-IQ Subjects				-5.078
				(6.181)
-Low-IQ Subjects			-1.080	-0.978
			(4.682)	(4.239)
-High-IQ Subjects			-2.910	-4.039
			(1.921)	(3.22)
Sequential Elimination (SE)	-1.565	-0.485	-0.553	-2.017
	(2.635)	(2.200)	(2.356)	(2.724)
High-IQ	-7.336***	-6.683***	-7.042***	-7.433**
	(2.675)	(2.390)	(2.697)	(3.091)
Age	-0.731**	-0.665**	-0.689**	-0.632**
	(0.304)	(0.288)	(0.290)	(0.300)
Female	-0.599	-0.596	-1.034	-1.590
	(2.552)	(2.413)	(2.586)	(2.797)
Education	0.154	0.295	0.204	-0.034
	(1.220)	(1.143)	(1.168)	(1.312)
Selective Attention	-0.127	-0.091	-0.019	-0.062
	(0.306)	(0.260)	(0.276)	(0.288)
Working Memory	-0.497	-0.422	-0.578	-0.572
	(0.517)	(0.475)	(0.515)	(0.533)
Response Time (Minutes, Block A)	-0.535**	-0.456**	-0.551**	-0.561**
	(0.234)	(0.226)	(0.235)	(0.234)
Response Time (Minutes, Block B)	0.769	0.625	0.720	0.787
	(0.490)	(0.435)	(0.461)	(0.504)
Attitude towards Inconsistency	-0.720	-0.656	-0.696*	-0.800*
	(0.442)	(0.409)	(0.417)	(0.475)
N	151	151	151	151

Standard errors in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 1.11: Effects of Choice Revision on FOSD Violations (Robustness Checks)

	(1)	(2)	(3)	(4)
	FOSD Violations			
Choice Revision (CR)	-0.368**	-0.321	-0.423**	-0.42**
	(0.205)	(0.211)	(0.256)	(0.244)
-Direct Procedure		-0.193		-0.379
		(0.370)		(0.449)
-Low-IQ Subjects				-0.611
				0.646
-High-IQ Subjects				(0.084)
				0.466
-Sequential Elimination		-0.433***		-.475
		(0.200)		(0.227)
-Low-IQ Subjects				-0.6101
				(0.330)
-High-IQ Subjects				(-0.206)
				(0.251)
-Low-IQ Subjects			-0.830**	-0.610
			(0.490)	(0.371)
-High-IQ Subjects			-0.011	(-0.070)
			(0.190)	0.247
Sequential Elimination (SE)	-0.489***	-0.462***	-0.559***	-0.417***
	(0.203)	(0.190)	(0.240)	(0.195)
High-IQ	-0.142	-0.177	-0.258	-0.222
	(0.166)	(0.167)	(0.199)	(0.178)
Age	-0.059***	-0.055***	-0.063***	-0.058***
	(0.020)	(0.018)	(0.023)	(0.020)
Female	0.098	0.130	0.113	0.172
	(0.165)	(0.159)	(0.176)	(0.160)
Education	0.139	0.133	0.122	0.112
	(0.100)	(0.096)	(0.094)	(0.090)
Selective Attention	0.001	-0.000	0.004	0.010
	(0.025)	(0.027)	(0.028)	(0.027)
Working Memory	-0.083	-0.088	-0.069	-0.074
	(0.059)	(0.060)	(0.054)	(0.053)
Response Time (Minutes, Block A)	0.011	0.007	0.012	0.008
	(0.017)	(0.016)	(0.017)	(0.016)
Response Time (Minutes, Block B)	-0.019	-0.026	-0.033	-0.022
	(0.043)	(0.044)	(0.050)	(0.046)
Attitude towards Inconsistency	-0.013	-0.006	-0.016	-0.014
	(0.028)	(0.026)	(0.030)	(0.027)
N	151	151	151	151

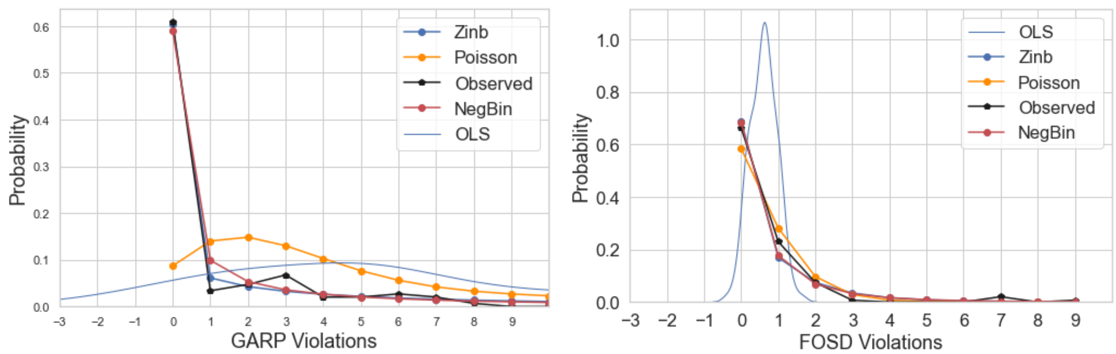
Standard errors in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

1.6.6 Details of the Experimental Results

1.6.6.1 Model Selection

Figure 1.30 presents the observed GARP and FOSD violations, together with and their values predicted by OLS, Poisson, negative binomial (*NegBin*) and zero-inflated negative binomial model (*Zinb*) models, showing that the last one provides a good fit for the observed data. The regressors in both models include sequential elimination, high-IQ, sequential elimination×high-IQ, selective attention, working memory, age, female, education, time, attitude towards inconsistency. The models are compared based on the Akaike information criterion (AIC), Bayesian information criterion (BIC), Likelihood Ratio (LR) Test, and Vuong Test (Vuong, 1989). In Table 1.12, the negative differences in AIC and BIC suggest that the NegBin can be considered markedly better. The LR test and Vuong Test reject the null hypothesis that OLS and Poisson models perform better than NegBin at the 0.1% significance level. The Vuong test is not performed for comparing NegBin and Zinb, as Wilson (2015) shows that this comparison is incorrect. Finally, Table 1.12 also shows the LR test for using NegBin versus Zinb, the results of which favor the former. Therefore, this paper uses NegBin for the empirical specifications.



(a) (b)

Figure 1.30: Observed Data and Model-predicted Values

Notes: the original plot of OLS-predicted values is nearly a horizontal line because of the continuity of OLS. The graph presents an estimated kernel density based on the OLS-predicted values.

Table 1.12: Comparisons of Models for Estimating the Effect of Sequential Elimination

Models being compared	AIC difference	BIC difference	LR Test	Vuong Test
GARP Violations				
NegBin vs Linear	-561.4985	-561.499	< 0.001	< 0.001
NegBin vs Poisson	-1474.19	-1469.19	< 0.001	< 0.001
NegBin vs Zinb	-1.0848	-34.0541	< 0.05	
FOSD Violations				
NegBin vs Linear	-205.3137	-205.3137	< 0.001	< 0.05
NegBin vs Poisson	-42.42791	-37.4307	< 0.001	< 0.001
NegBin vs Zinb	20.11763	-12.8517	< 0.001	

1.6.6.2 Economic Rationality

Table 1.13: Determinants of Economic Rationality (All Measures, Original Form)

	(1) GARP Violations	(2) SARP Violations	(3) HM Index	(4) CCEI	(5) FOSD Violations
Sequential Elimination	-1.086***	-0.963***	-0.408	-0.020	-0.413
	(0.508)	(0.486)	(0.336)	(0.019)	(0.395)
High-IQ	-1.830***	-1.629***	-0.762**	-0.038**	0.570
	(0.460)	(0.439)	(0.323)	(0.015)	(0.432)
Sequential Elimination×High-IQ	1.386**	1.225*	0.764	0.034*	-1.086*
	(0.658)	(0.641)	(0.482)	(0.020)	(0.611)
Age	-0.072*	-0.064*	-0.057**	-0.001**	-0.100***
	(0.038)	(0.034)	(0.025)	(0.001)	(0.031)
Female	0.140	-0.023	-0.173	0.003	0.265
	(0.330)	(0.313)	(0.235)	(0.009)	(0.280)
Education	-0.195	-0.141	0.060	-0.000	0.332**
	(0.191)	(0.184)	(0.119)	(0.004)	(0.165)
Selective Attention	-0.045	-0.040	-0.017	-0.003	-0.048
	(0.053)	(0.049)	(0.034)	(0.002)	(0.045)
Working Memory	-0.056	-0.057	-0.117	-0.001	-0.071
	(0.076)	(0.073)	(0.076)	(0.003)	(0.075)
Response Time (Minutes)	-0.078***	-0.066**	-0.035*	-0.002*	0.019
	(0.027)	(0.027)	(0.020)	(0.001)	(0.030)
Attitude towards Inconsistency	-0.133**	-0.123**	-0.043	-0.002	0.033
	(0.060)	(0.057)	(0.039)	(0.002)	(0.051)
Constant	6.888***	6.507***	-0.384	0.166***	1.828*
	(1.143)	(1.084)	(0.738)	(0.047)	(1.017)
N	148	148	148	148	148

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

1.6.6.3 Individual Preference for Sequential Elimination

Table 1.14: Determinants of Preference for Sequential Elimination (Original Form)

	Probability of Choosing Sequential Elimination	
	(Probit)	(Logistic)
Age	-0.0151	-0.0235
	(0.0257)	(0.0431)
Female	0.391	0.684
	(0.339)	(0.587)
Education	0.409**	0.663**
	(0.164)	(0.279)
IQ	-0.151**	-0.254*
	(0.0738)	(0.133)
Selective Attention	-0.0890	-0.145
	(0.0589)	(0.104)
Working Memory	-0.137*	-0.228*
	(0.0752)	(0.130)
Attitude towards Inconsistency	0.0110	0.0203
	(0.0701)	(0.123)
Constant	3.135**	5.093**
	(1.341)	(2.344)
N	75	75

Standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

1.6.6.4 Choice Revision

Table 1.15: Effects of Choice Revision on GARP Violations (Original Form)

	(1)	(2)	(3)	(4)
	GARP Violations			
Choice Revision (CR)	-0.560	-0.676	-0.110	-0.270
	(0.364)	(0.455)	(0.476)	(0.620)
Sequential Elimination (SE)	-0.373	-0.269	-0.091	-0.846
	(0.482)	(0.597)	(0.386)	(0.631)
High-IQ	-1.631***	-1.323***	-0.807	-1.194*
	(0.477)	(0.362)	(0.509)	(0.648)
SE×High-IQ	0.607			0.985
	(0.669)			(0.986)
Age	-0.117***	-0.113***	-0.113***	-0.101***
	(0.035)	(0.036)	(0.035)	(0.036)
Female	-0.096	-0.102	-0.170	-0.253
	(0.403)	(0.407)	(0.412)	(0.422)
Education	0.025	0.050	0.034	-0.005
	(0.195)	(0.195)	(0.192)	(0.208)
Selective Attention	-0.020	-0.015	-0.003	-0.010
	(0.049)	(0.044)	(0.045)	(0.046)
Working Memory	-0.079	-0.072	-0.095	-0.091
	(0.078)	(0.077)	(0.078)	(0.078)
Response Time (Minutes, Block A)	-0.085***	-0.078**	-0.090***	-0.089***
	(0.031)	(0.034)	(0.030)	(0.028)
Response Time (Minutes, Block B)	0.123*	0.106	0.118*	0.125*
	(0.071)	(0.069)	(0.069)	(0.071)
Attitude towards Inconsistency	-0.115*	-0.112*	-0.114**	-0.127**
	(0.059)	(0.061)	(0.058)	(0.059)
SE×CR		0.322		0.549
		(0.758)		(0.862)
High-IQ×CR			-0.883	-0.829
			(0.722)	(0.971)
High-IQ×CR×SE				-0.376
				(1.406)
Constant	7.096***	6.714***	6.472***	6.722***
	(1.159)	(1.131)	(1.099)	(1.140)
N	151	151	151	151

Standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 1.16: Effects of Choice Revision on FOSD Violations (Original Form)

	(1)	(2)	(3)	(4)
	FOSD Violations			
Choice Revision (CR)	-0.629**	-0.229	-1.112**	-0.770
	(0.320)	(0.425)	(0.470)	(0.648)
Sequential Elimination (SE)	-0.594	-0.404	-0.962***	-0.200
	(0.388)	(0.416)	(0.299)	(0.611)
High-IQ	-0.003	-0.310	-0.992**	-0.636
	(0.378)	(0.291)	(0.494)	(0.650)
SE×High-IQ	-0.838			-0.738
	(0.580)			(0.813)
Age	-0.100***	-0.094***	-0.105***	-0.100***
	(0.030)	(0.028)	(0.031)	(0.029)
Female	0.167	0.223	0.188	0.295
	(0.288)	(0.279)	(0.299)	(0.277)
Education	0.238	0.229	0.205	0.194
	(0.152)	(0.148)	(0.148)	(0.146)
Selective Attention	0.002	-0.001	0.006	0.017
	(0.043)	(0.047)	(0.047)	(0.046)
Working Memory	-0.142*	-0.152*	-0.115	-0.128
	(0.086)	(0.089)	(0.080)	(0.083)
Response Time (Minutes, Block A)	0.018	0.013	0.020	0.013
	(0.028)	(0.028)	(0.028)	(0.026)
Response Time (Minutes, Block B)	-0.032	-0.045	-0.055	-0.038
	(0.073)	(0.074)	(0.081)	(0.078)
Attitude towards Inconsistency	-0.022	-0.011	-0.028	-0.024
	(0.047)	(0.045)	(0.050)	(0.047)
SE×CR		-0.927		-0.732
		(0.610)		(0.862)
High-IQ×CR			1.086*	0.881
			(0.612)	(0.831)
High-IQ×CR×SE				0.022
				(1.230)
Constant	2.692***	2.592***	3.158***	2.528***
	(0.947)	(0.926)	(1.046)	(0.946)
N	151	151	151	151

Standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

1.6.6.5 Risk Preferences

Table 1.17: Determinants of Risk Preferences (Original Form)

	(1)	(2)
	Coefficient of Relative Risk Aversion	
IQ	-0.397*	-0.358
	(0.230)	(0.227)
-Direct Procedure		0.071
		(0.320)
-Sequential Elimination		-0.799**
		(0.397)
Sequential Elimination	2.010	2.063
	(1.619)	(1.628)
Age	-0.0790	-0.078
	(0.127)	(0.128)
Female	1.964	1.974
	(1.383)	(1.380)
Education	0.702	0.633
	(0.695)	(0.705)
Selective Attention	-0.239	-0.216
	(0.252)	(0.240)
Working Memory	-0.400	-0.449
	(0.347)	(0.364)
Response Time (Minutes)	-0.151	-0.164
	(0.196)	(0.192)
Attitude towards Inconsistency	0.164	0.143
	(0.283)	(0.286)
N	148	148

Standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

1.6.6.6 Response Times

Table 1.18 shows that subjects under Sequential Elimination spend more time making decision, on average (a); and this is particularly true for low subjects (b). To obtain a precise understanding of the relationship between response times and choice consistency, Table 1.19 perform two negative binomial regressions: one includes an interaction term between response time and Sequential Elimination (Column (1)); the other includes triple interaction between response time, Sequential Elimination, and high-IQ (Column (2)). I do not find strong evidence of response times' effects when conditioned on specific subgroups of subjects, given that only the coefficient of the triple interaction term is observed with significance. Plausibly, the analysis of response times in specific subgroups is limited by the sample size of the present experiment.

Table 1.18: Determinants of Response Times

	Response Time (Minute)
Sequential Elimination	3.788***
	(0.996)
-Low-IQ Subjects	4.041**
	(1.650)
-High-IQ Subjects	3.534***
	(0.961)
Age	-0.010
	(0.081)
Female	-0.297
	(0.910)
Education	0.275
	(0.454)
High-IQ	0.006
	(0.899)
Selective Attention	-0.256
	(0.212)
Working Memory	-0.091
	(0.228)
Attitude towards Inconsistency	0.412***
	(0.156)
N	148

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 1.19: Effects of Response Times on GARP Violations

	(1)	(2)
	GARP Violations	
Response Time (Minutes)	-0.046	-0.001
	(0.058)	(0.075)
Response Time (Minutes)×Sequential Elimination	-0.029	-0.105
	(0.067)	(0.083)
Response Time (Minutes)×High-IQ		-0.154
		(0.132)
Response Time (Minutes)×Sequential Elimination ×High-IQ		0.299*
		(0.166)
Sequential Elimination	-0.132	-0.244
	(0.636)	(0.807)
Sequential Elimination×High-IQ		-1.228
		(1.543)
High-IQ	-1.159***	
	(0.352)	
Age	-0.082**	-0.066*
	(0.037)	(0.039)
Female	0.124	0.085
	(0.346)	(0.332)
Education	-0.140	-0.229
	(0.201)	(0.192)
High-IQ		-0.682
		(1.026)
Selective Attention	-0.017	-0.050
	(0.048)	(0.053)
Working Memory	-0.054	-0.099
	(0.073)	(0.081)
Attitude towards Inconsistency	-0.120*	-0.120*
	(0.062)	(0.066)
N	148	148

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Chapter 2

VISUAL AND AUDITORY STRATEGIES IN DIGITAL MARKETS: EVIDENCE FROM FIELD EXPERIMENTS

Joint with Fadong Chen

2.1 Introduction

While mounting studies on behavioral economics have accounted for evidence in traditional markets (e.g., Bordalo et al., 2013; Taubinsky and Rees-Jones, 2018; Cosemans and Frehen, 2021), little attention has been paid to the emergence of digital markets. Significantly, more than eighty percent of the world's population use a smartphone today (Statista, 2021). The emerging mobile technology has fundamentally changed how consumers obtain information and make decisions, thereby facilitating a paradigm shift in how firms advertise to influence consumer behavior. Yet, a rigorous research-based understanding of consumer behavior in response to mobile advertising is relatively insufficient.

We provide the first paper on the effectiveness of visual and auditory strategies in mobile advertising by analyzing a novel data set of two large-scale field experiments conducted on a variety of mobile apps. Mobile advertising, a revolutionary marketing tact in industrial organization, is booming because it is an efficient way to communicate directly with modern consumers, who spend a vast amount of their time on mobile phones (Kats, 2020). Arguably, mobile advertising is state-of-the-art of marketing. Nonetheless, it is highly challenging to attract and retain attention on mobile phones, where an enormous amount of information is presented to consumers continuously. Therefore, a close examination of the evidence of behavioral strategies in this novel context may enrich our understanding of individual attention and behavior.

In terms of operation, mobile advertising firms typically buy advertising spaces within various popular mobile apps, where they provide in-app advertising services. In-app advertising spaces can be used to deliver advertisements according to two business models. In the *direct model*, firms directly display image or video advertisements in the spaces. However, one potential problem of this model is that consumers may perceive direct advertisements as noise and avoid them (Cho and as, 2004; Drèze and Hussherr, 2003).

Alternatively, more and more firms tend to operate through the *indirect model*, where in-app advertising spaces serve as links to advertising games, i.e., games containing advertisements for products. Instead of explicitly advertising products, they show banners or icons that consumers can click to enter various advertising games, such as collection, lottery, or monopoly games. The details of the advertising games included in this study are described in Section 2.2, Appendix 2.5.1, and 2.5.2. Importantly, the advertising games reward consumers for watching advertisements. They have different playing styles and are commonly simple to play. Consumers receive popups of some tokens based on their play in these games. Consumers have to watch video advertisements to earn the tokens or some multiplication of them, which can be converted to money or commercial goods. The contents of advertisements in the games are mostly irrelevant to the games. The innovative indirect model alleviates the direct model's problem as consumers are smoothly exposed to advertisements by an incentivized mechanism. Two measurable objectives characterize advertising firms' incentives in the indirect model: to maximize the number of times consumers visit advertising games via the links and the number of times consumers watch advertisements in the games.

Exploiting consumer data collected from two field experiments, we investigate whether advertising effectiveness can be affected by simple behavioral strategies in the settings of the indirect model. In Experiment 1, we examine the effect of a visual strategy on consumers' tendency to click through the link to advertising games on a weather app. More precisely, the link itself is a green trumpet on the app's user profile page. The visual strategy attaches to the trumpet a red dot containing a number. The attached number is random, as it indicates the number of items that can be collected in a proceeding advertising game that is randomly assigned to consumers. This strategy aims to increase consumers' visits to advertising games via the trumpet. The results show a significant effect of the visual strategy, which leads to almost 56% more consumers visiting advertising games. We also find that the strategy increases the total visits to advertising games by about 36%, with statistical significance approaching conventional levels. These results suggest that the visual strategy's effect may decay due to its frequent exposure.

In Experiment 2, we study the effect of an auditory strategy on consumers' tendency to watch advertisements in three advertising games (a monopoly game and two collection games). Different to the conventional silent version, the auditory strategy provides animation sound effects throughout the games. The auditory strategy is designed to lead consumers to watch more advertisements in advertising games. We find an effect of the auditory strategy, which significantly increases the number of consumers watching advertisements by 3.7%. Furthermore, the effect is persistent, as the strategy increases the number of times advertisements are viewed by 11.4%. To the best of our knowledge, Experiment 2 provides the first field evidence of auditory strategies' impact in digital markets, thus complementing the existing literature.

Our findings suggest substantial impacts of simple behavioral strategies on consumer behavior in the emerging mobile advertising market. There might be a difference in the effectiveness of visual and auditory strategies. Although we find the effects of both strategies, their natures are very different. The visual strategy directly promotes an advertised object (i.e., the trumpet), which the firm wants more consumers to click on. On the other hand, the auditory strategy does not provide sound effects when consumers see or click on advertisement popups. In other words, the auditory strategy relates to a process leading to advertised objects rather than the objects per se. The constraints of the current data set hinder us from examining the difference between the two strategies' effectiveness; this might also be important for future studies.

While we cannot precisely identify and disentangle the underlying mechanisms given the current data set, we discuss several mechanisms that could potentially account for the results. The first and perhaps the most prominent account is the notion of salience that specific properties of a stimulus can help attract attention (Bordalo et al., 2021). In the experiment, the visual and auditory strategies may enhance the advertised objects' salience, thereby attracting consumers who might otherwise overlook them. The second plausible account is that consumers might be motivated by their desire for information and feedback to explore the objects associated with the strategies, as suggested by psychology studies (e.g., Loewenstein, 1994; Anseel et al., 2007). Finally, we argue that the behavioral strategies may serve as (visual and auditory) heuristic cues that enhance consumer click-through behavior, based on the literature on heuristics (Tversky and Kahneman, 1974; Kahneman and Tversky, 1984).

Our paper contributes to the literature on digital markets. Indeed, following the innovation of the digital industry, a growing number of studies have explored digital markets (e.g., Ghose and Yang, 2009; Chan and Park, 2015; Huang et al., 2022). In contrast to those studies in online advertising, we use data on consumer behavior in response to mobile advertising. This paper is also related to the emerging literature on salience. The existing studies seem to focus on the salience driven by payoff-relevant attributes (e.g., Dertwinkel-Kalt et al., 2017; Avoyan and Schotter, 2020; Cosemans and Frehen, 2021). In contrast, our study examines the salience driven by payoff-irrelevant attributes. Moreover, existing studies focus on visual salience. While salience may also affect individual attention via auditory perception (Kahneman, 1973), the impact of auditory salience on individual behavior is relatively unexplored in the literature. Thus, our research complements the literature on salience by adding evidence of auditory salience.

The paper proceeds as follows: Section 2.2 describes the details of the experiments and presents the results. Section 2.3 provides a detailed discussion of the potential mechanisms of the results. Finally, Section 2.4 summarizes our conclusion.

2.2 Experimental Evidence

2.2.1 Experimental Background

The mobile advertising market is vast in China. According to the research report by Aurora Mobile (2021), the total number of app installations per capita among mobile netizens has risen to 63 in China, and the average daily app usage time per person is 5.3 hours.

Our data set is collected from a digital advertising firm leading in mobile advertising services in China. More precisely, the firm provides in-app advertising services to over 2,000 clients from over 20 industries, such as video, gaming, tools, finance, community, and E-commerce. The firm conducts randomized controlled experiments in the field (also known as A/B tests) to investigate and improve advertising effectiveness. In these experiments, the firm compares two versions of user interface designs and measures their performance differences.

The data set contains information on consumers' click-through behavior at the individual level. More precisely, we keep track of the number of times each consumer has clicked through specific advertised objects of interest (to be described shortly in the experimental details). This information provides two measures allowing us to examine the impact of the strategies: *unique visit* and *total visits*. Unique visit is a binary variable of 0 or 1, indicating *whether or not* a consumer has clicked on an advertised object. Total visits is a count variable (i.e., nonnegative integers), indicating the *total number of times* a consumer has clicked on the advertised object. Also, the data set includes the location information of consumers (based on the GPS of their mobile phones), which is used as a proxy for income in the regression analysis. Specifically, consumers are classified as belonging to the high-income group if they are in the Chinese first-tier and new first-tier cities.[1]

In the following, we will present the details of the two experiments. We will discuss the descriptive results and examine the treatment differences by ordinary least squares regression for each experiment.

2.2.2 Experiment 1: Visual Strategy

Experiment 1 was implemented on August 9th, 2021. The experiment aimed to test the Visual Strategy version of a trumpet icon on the user profile page of a weather app. After clicking on the trumpet, consumers enter into a randomly assigned advertising game. The upper right of Figure 2.1(a) shows the Visual Control version of the trumpet. The exact position of Figure 2.1(b) displays the Visual Strategy version of the trumpet, which in addition attaches a red dot containing a number; this number indicates the number of items that can be collected in the proceeding game. In the example of Figure 2.1, this number is 4, indicating that consumers can collect up to four items in the proceeding game.

[1]Based on Yicai Global's 2021 classification, the list of first-tier cities includes Beijing, Shanghai, Shenzhen, and Guangzhou. The list of new first-tier cities includes Chengdu, Hangzhou, Chongqing, Xi'an, Suzhou, Wuhan, Nanjing, Tianjin, Zhengzhou, Changsha, Dongguan, Foshan, Ningbo, Qingdao, and Shenyang. See https://www.yicaiglobal.com/news/yicai-big-data-project-ranks-china-cities-for-business-attractiveness.

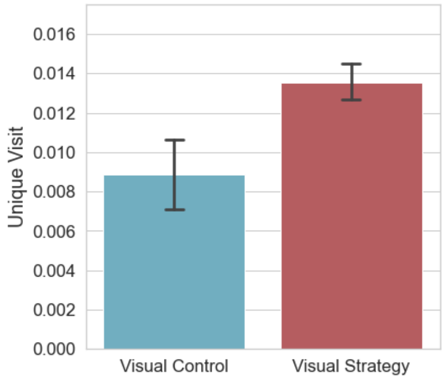
Experiment 1 was tested in a sample of 18,179 consumers from 351 cities in China. 2,821 and 15,358 consumers were randomly selected and assigned to the Visual Control and Visual Strategy groups. Before the experiment, all consumers might have used the weather app of the Visual Control version. We analyze the impact of the Visual Strategy by the measures of unique visit and total visits collected based on consumers' clicks on the trumpet.

(a) Visual Control Version **(b)** Visual Strategy Version

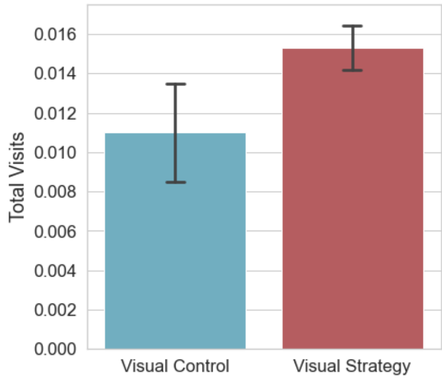
Figure 2.1: Interfaces of the Weather App's User Profile Page in Experiment 1

2.2.2.1 Results

Figure 2.2 presents the descriptive results of Experiment 1. Figure 2.2(a) depicts that the average unique visit of the Visual Control group is nearly 0.009. By contrast, the average unique visit of the visual Strategy group is higher, almost 0.014. Figure 2.2(b) illustrates that the mean total visits in the Visual Control and Visual Strategy groups are nearly 0.011 and 0.016, respectively. In other words, on average, there are more total visits in the Visual Strategy group than in the Visual Control group. The figures show similar mean differences in unique visit and total visits, indicating a higher tendency for the clicks on the trumpet in the Visual Strategy group.



(a) Unique Visit



(b) Total Visits

Figure 2.2: Click-through Behavior in Experiment 1

Notes: Error bars indicate the standard error of means.

Table 2.1 shows the estimation results of Experiment 1. Importantly, Column (1) shows that the coefficient of the Visual Strategy on unique visit is positive and significant. The coefficient indicates that this strategy increases the unique visit by 0.005, which is robust to the specifications taking into account income, as shown in Column (2). This estimate is small but economically meaningful. It represents that the Visual Strategy leads almost 56% more consumers to visit the advertising games via the trumpet compared to the Visual Control group. On the other hand, Columns (3) and (4) show that the Visual Strategy's effect on total visits is at the edge of significance by conventional standards ($p = 0.12$). According to the estimation, the Visual Strategy rises total visits by about 36%, smaller than its effect on unique visit. The results suggest a decline in the Visual Strategy's effect due to its exposure. Taken together, we find evidence that the Visual Strategy improves advertising effectiveness, but the frequency of exposure may limit this improvement.

Table 2.1: Effects of the Visual Strategy

	Unique Visit		Total Visits	
	(1)	(2)	(3)	(4)
Visual Strategy	0.005**	0.005**	0.004	0.004
	(0.002)	(0.002)	(0.003)	(0.003)
High-Income		-0.001		-0.001
		(0.002)		(0.002)
Constant	0.009***	0.009***	0.011***	0.011***
	(0.002)	(0.002)	(0.003)	(0.003)
N	18179	18179	18179	18179

Standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$.

2.2.3 Experiment 2: Auditory Strategy

Experiment 2 was implemented from March 16th to March 25th, 2021. The experiment tested an Auditory Strategy of three advertising games (including a monopoly game, a cat-shaped collection game, and a sheep-shaped collection game) on nine apps (including video, reading, weather, and health apps). Figure 2.3(a) shows the interface of the monopoly game in all groups. In this game, consumers can roll the dice three times to move around the game board. By design, consumers will move to the positions with a red pocket, which is displayed with some tokens. Once consumers arrive at one of such positions, they see a popup in which they can click on the request bar in the middle with the text "watch a video to collect the tokens", as shown in Figure 2.3(b). In the collection games, consumers can collect available tokens according to their play. In all the games, a request bar pops up during the collecting process. If consumers click on the request bars in the games, a video advisement pops up, and consumers receive the tokens or some multiplication of the tokens by watching the video. Consumers can cash out their collected tokens once it is over 50 Chinese Yuan.

(a) Initial Screen

(b) Popup of the Video Advertisement Request

Figure 2.3: Interfaces of the Monopoly Game in Experiment 2

There is no sound effect in the Auditory Control group throughout the games. Differently, the Auditory Strategy provides sound effects in all games: there are sounds of the dice rolling after consumers click on the dice in the monopoly game; there are sounds of cat mewing and sheep bleating in the cat-shaped and sheep-shaped collection games, respectively. Experiment 2 was tested in a sample of 18,179 consumers from 402 cities in China. There were 180,202 and 194,318 consumers in the Auditory Control and Auditory Strategy groups. Experiment 2 measures unique visit and total visits based on consumers' clicks on the request bar.

2.2.3.1 Results

Figure 2.4 depicts the descriptive results of Experiment 2. Figure 2.4(a) shows that nearly 38.6% of consumers click on video advertisements in the Auditory Strategy group, which is higher than that (of about 37.2%) in the Auditory Control group. Figure 2.4(b) displays that there are, on average, more total visits in the Auditory Strategy than in the Auditory Control group. The descriptive results consistently suggest that consumers are more likely to watch video advertisements in the Auditory Strategy than in the Auditory Control group; furthermore, they watch more times.

(a) Unique Visit **(b)** Total Visits

Figure 2.4: Click-through Behavior in Experiment 2

Notes: Error bars indicate the standard error of means.

Table 2.2 presents the estimation results of Experiment 2. The first two columns illustrate that the Auditory Strategy significantly raises the likelihood of a consumer's visit on advertisements by approximately 3.7% ($p < 0.01$). The last two columns show that this strategy generates almost 11.4% ($p < 0.01$) more total visits than the Auditory Control group. The Columns (3) and (4) show that the Auditory Strategy's effects is robust to specifications where income and the games' fixed effects are taken into account. The Auditory Strategy effect on total visits, in any case, is more considerable than that on unique visit. In summary, the Auditory Strategy has a positive and persistent effect on consumers' visits to the advertisements in the games.

Table 2.2: Effects of the Auditory Strategy

	Unique Visit		Total Visits	
	(1)	(2)	(3)	(4)
Auditory Strategy	0.014***	0.009***	0.117***	0.071***
	(0.002)	(0.002)	(0.012)	(0.011)
High-Income		-0.004		0.118***
		(0.003)		(0.015)
Constant	0.372***	0.510***	1.029***	2.502***
	(0.001)	(0.003)	(0.008)	(0.014)
Games' Fix Effects	No	Yes	No	Yes
N	231691	231691	231691	231691

Standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$.

2.3 Discussion

Now we put forward the theoretical interpretations of the results. The studied strategies may affect consumer click-through behavior potentially via cognitive, psychological, and behavioral mechanisms. In spite of not being able to identify the underlying mechanisms, we discuss how the observed treatment effects may operate through different mechanisms.

2.3.1 Mechanisms of the Visual Strategy

When confronted with multiple stimuli (e.g., different icons on the app or other apps in parallel), consumers may pay more attention to some of them than others because of their salience driven by specific properties (Bordalo et al., 2021). Prior research has suggested that color plays a crucial role in guiding attention towards important objects, given its prevalence in nature and culture as a powerful signal (Hutchings, 1998). Specifically, Singh (2006) finds the color effect in marketing settings, where participants interact with people or products. The Visual Strategy's effect may operate through the color red, which has been shown to attract attention in other contexts (Elliot and Maier, 2012; Kuniecki et al., 2015). Furthermore, the environment of light background and the green color of the trumpet together provide a good contrast with the color red, enhancing the strategy's salience effect (Conway et al., 2002; Jeck et al., 2019). It is also possible that the random number contained in the red dot itself may also make the trumpet salient; however, we are not able to disentangle the effects of the color red and the number, given the present data. These discussions indicate a need for thorough investigations on individual attention to colors and numbers in mobile advertising.

The Visual Strategy may also psychologically enhance consumers' click-through behavior via the notion of curiosity, defined as the desire for information and a key motivation in driving individual behavior (Loewenstein, 1994; Wojtowicz and Loewenstein, 2020). Curiosity allocates the possibly scarce attention with little or no consumption of cognitive resources. That is, curiosity can influence consumers' behavior in parallel with limited attention. The red dot in the Visual Strategy can be considered a signal indicating new information available for consumers. Consumers may click on it to acquire new information based on rational and effortful analysis, i.e., consumers may expect benefits from new information, which outweigh the marginal cost of clicking. Alternatively, the process of acquiring new information itself can be directly related to personal pleasure (Berlyne, 1960; Redgrave et al., 2008; Gottlieb et al., 2013). This suggests that consumers may be motivated by their intrinsic desire for information to click on the red-dot trumpet.

Another possible account for the Visual Strategy's effect is heuristics. Potentially, consumers may face much information simultaneously or may be multitasking when using mobile phones. In this case, they are likely mentally occupied and rely on some mental shortcuts to guide their behavior quickly (Tversky and Kahneman, 1974; Gigerenzer and Todd, 1999; Kahneman and Tversky, 1984). Such mental shortcuts may include clicking objects with a particular visual cue, specifically, the red dot in the experiment. Red itself has been proposed to be associated with positive events, e.g., sex and food, or adverse events, e.g., fire and blood. Notably, the color red is related to fortunate in

East and Southeast Asian cultures.[2] The red dot containing a number might also trigger consumers of experience in "similar" settings, e.g., email and message boxes, where they often click through red-dot icons to check new emails or messages. Given these considerations, we argue that consumers may click through the Visual Strategy version of the trumpet as an automatic, associative, and effortless response in some overloaded environments.

2.3.2 Mechanisms of the Auditory Strategy

There is general evidence that sounds can attract attention (Patterson, 1990; Escera et al., 2003; Spence et al., 2000; Huang and Elhilali, 2017). The contrast principle, one of the core theories of auditory salience, postulates that a target sound in a context is more salient if the background is silent (Moskowitz and Gerbers, 1974; Kayser et al., 2005; Mehta et al., 2021). Consider the situations where consumers are in some relatively quiet environments, e.g., offices or homes. Game sounds may be particularly salient due to their contrast to the background, thus making consumers more engaged in the games. It is possible that consumers have difficulty hearing the game sounds in some boisterous environments or prefer other environmental sounds over the game sounds. Given the observed treatment difference, these possibilities suggest that the impact of the Auditory Strategy may be particularly pronounced in some quiet environments.

People generally desire feedback, especially in high levels of uncertainty (Anseel et al., 2007; Anseel and Lievens, 2007). Sound effects provided by the strategy can be considered as feedback on consumers' behavior in advertising games. In this regard, consumers may receive a "more precise" (or less uncertain) feedback when playing games with the sound effects than without, thereby raising their arousal and incentives for more clicks. In other words, the strategy can enhance consumers' perception of receiving rewards. Also, consumers are likely to prefer the sounds of interactive animation, such as dice rolling, cat mewing, and sheep bleating that are provided by the

[2]For example, the Chinese give and receive red pockets as monetary gifts to others during holidays or special occasions.

strategy. Therefore, they may play the games as they enjoy hearing those sounds. Accordingly, Auditory Strategy may be interpreted as an auditory heuristic cue that triggers consumers' positive responses to the advertising games.

2.4 Concluding Remarks

Mobile advertising is a rapidly developing market worldwide, and it may become dominant in the future, given the growth of mobile users and digital innovations. We analyze the impacts of two simple behavioral strategies in this emerging sector based on two randomized field experiments. We find evidence in support of the positive impacts of visual and auditory strategies on advertising effectiveness on various mobile apps. More precisely, the Visual and Auditory Strategies are effective in attracting consumers to visit advertising games and advertisements, respectively. Furthermore, the effect of the Auditory Strategy is persistent, whereas that of the Visual Strategy seems to decline in the long run. We discuss cognitive, psychological, and behavioral mechanisms to account for the impacts. Further studies are needed to identify the driving mechanisms of observed treatment effects.

Our findings provide empirical evidence that simple behavioral strategies can affect individual behavior in daily life. Arguably, the studied behavioral strategies here are relatively low-cost and easy to implement. Hence, they may also play a key role in other important settings, potentially improving individual welfare. The appropriate use of behavioral strategies may enhance individual attention and response to public policies advertised on mobile phones. For example, a policymaker may consider adopting the visual strategy on the news about public issues (e.g., COVID-19) or adopting the auditory strategy when individuals are reading this news.

It will be an important subject of future experiments to compare the effectiveness of visual and auditory strategies. Another important line of research is to study the variations of the two strategies to improve their effectiveness. We hope our study can inspire more research on exploring auditory strategies and their mechanisms since relatively few studies have been conducted on this subject. Finally, it is a promising avenue for researching the interplay between the behavioral strategies and demographics, e.g., age, gender, and education.

2.5 Appendix

2.5.1 Details of the Advertising Games

2.5.1.1 Cat-shaped Collection Game

(a) Initial Screen

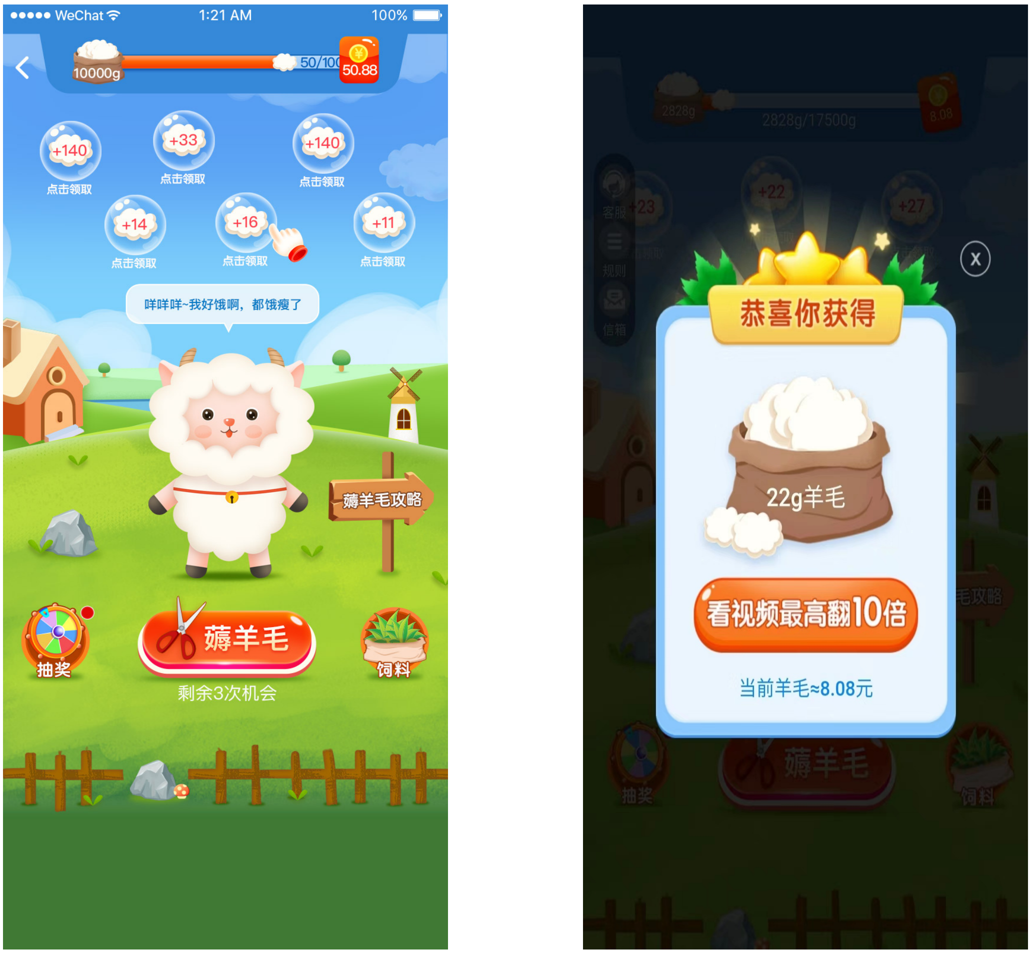
(b) Popup of the Video Advertisement Request

Figure 2.5: Interfaces of the Cat-shaped Collection Game

When entering this collection game, consumers see some cat-shaped boxes with different levels, as shown in Figure 2.5(a). The boxes collect tokens automatically according to their levels: boxes with a higher level reward more tokens. Consumers can also buy more boxes with their tokens. Consumers can combine two boxes of the same level to obtain a box with an ungraded level. Then a request page pops up, as shown in Figure 2.5(b), displaying that consumers can either collect the displayed tokens directly (e.g., 100 tokens in this example), or watch a video advisement to collect a multiplication of (e.g., a triple amount in this example) the displayed tokens.

2.5.1.2 Sheep-shaped Collection Game

In this game, consumers see a sheep in the middle of the mobile screen. There are also some pieces of wool associated with different amount of tokens above the sheep, as displayed in Figure 2.6(a). Consumers can click on a piece of wool to collect its associated tokens, after which a request page pops up, as shown in Figure 2.6(b). Consumers can either confirm to collect the displayed tokens directly, or watch a video advisement to collect a multiplication of the displayed tokens.



(a) Initial Screen

(b) Popup of the Video Advertisement Request

Figure 2.6: Interfaces of the Sheep-shaped Collection Game

Chapter 3

PERCEPTUAL DESCRIPTIONS OF DECISIONS AND THEIR ECONOMIC IMPLICATIONS

Joint with Fadong Chen

3.1 Introduction

Neoclassical economics and social sciences stem from the premise that individuals maximize a well-behaved utility function (Kahneman, 2003). However, research on behavioral economics suggests that individual choices might not be consistent with utility maximization because of cognitive limitations (Simon, 1955, 1956). A growing body of literature emphasizes such limitations in terms of perception, suggesting that individuals may not perfectly perceive all available options (Woodford, 2020; Khaw et al., 2021; Frydman and Jin, 2022). Most existing studies, including the cited ones, analyze economic choice behavior conventionally via choice experiments where decision problems are described visually to subjects. However, the impact of different perceptual descriptions on the economic consequences of individual choice behavior remains unclear.

We study the impact of auditory descriptions on economic decisions compared to visual descriptions. While visual descriptions may be most common, auditory descriptions also play a key role in a broad range of settings. For example, consumers may make purchase decisions primarily based on sales calls or radio advertisements; or managers may sometimes need to reach verbal agreements based mainly on discussions in business meetings. Hence, a close examination of the two perceptual descriptions may enrich our understanding of individual choice behavior and generate important implications for welfare policies. To this end, we evaluate individual choice behavior according to rationality measures well proposed and widely used in the literature (Choi et al., 2007, 2014; Kim et al., 2018).[1] These rationality measures give an indication of the frequency and the severity of individual deviation from utility maximization.

The cognitive sciences have long acknowledged a crucial distinction in the individual processing mechanisms of visual and auditory information, mainly in perceptual judgments (Kahneman, 1973; Kubovy and Van Valkenburg, 2001; Shinn-Cunningham, 2008). For example, individual auditory cognitive capacity may be inferior to visual cognitive capacity (Cohen et al., 2009; Kaiser, 2015; Plakke and Romanski, 2016). There is also evidence of the positive association between cognitive capacity and economic rationality (Burks et al., 2009; Cappelen et al., 2020). Given this evidence, we hypothesize that the economic rationality revealed by the two descriptions might be substantially different. For the same information content, individuals may not be as efficient with processing information with auditory descriptions as with visual descriptions, resulting in a lower level of economic rationality in the former case.

We conduct an experimental test of the above hypothesis by adapting the experimental setting of Kim et al. (2018). In our experiment, subjects are randomly assigned to make decisions under either the Visual Description or the Auditory Description treat-

[1] Apesteguia and Ballester (2015) and Halevy et al. (2018) provide detailed discussions of rationality measures.

ments, where they are asked to make choices for twenty decision problems with visual descriptions or the auditory descriptions, respectively. Each decision problem represents eleven portfolio options from a two-dimensional budget line; each option (x_1, x_2) rewards x_1 or x_2 amounts of experimental tokens with equal probability. The Visual Descriptions and Auditory Descriptions convey the exact content of an option (i.e., "x_1 or x_2") by visually and auditorily describing this information, respectively. The subject can perceive only one option at a time by clicking on it and as many times as they want.

We compare the economic rationality measures revealed in the two treatments to test the hypothesis. Our main results are based on two main measures of economic rationality. As established by the revealed preference theory, choices are consistent with utility maximization if and only if they satisfy the Generalized Axiom of Revealed Preference (GARP) (Afriat, 1967; Varian, 1982, 1983). Hence, we compute the number of GARP violations to indicate the frequency of individual choices that violate economic rationality. To infer the severity of the deviations from economic rationality, we also use Afriat's Critical Cost Efficiency Index (CCEI), which finds the minimal wealth change to rationalize the choice data (Afriat, 1972). The number of GARP violations is a non-negative integer, and CCEI ranges continuously from 0 to 1. More GARP violations or a higher CCEI indicate a lower level of economic rationality. The computational rationales of the rationality measures are reported in the Appendix 3.5.4.

To gain better insight into the differences between the two perceptual descriptions, we account for demographic factors (including age, gender, education) and cognitive ability, which are suggested to influence economic rationality (Burks et al., 2009; Choi et al., 2014; Dean and Martin, 2016; Kim et al., 2018). To investigate the possible mechanism of the results, we analyze the differences in response times and the numbers of perceived options between the two treatments. Finally, we examine the treatment effects on risk preferences revealed by the Money Metric Index (MMI) method (Halevy et al., 2018).

We present three main results of the experiment. First and most importantly, individual choice behavior substantially deviates from rationality under the Auditory Description treatment. Specifically, the Auditory Description subjects commit GARP violations 104% more than the Visual Description subjects. The welfare loss associated with the Auditory Description is almost 92%, as indicated by CEEI.[2] Second, while we find that subjects spend about 22% more time making decisions under the Auditory Description treatment than under the Visual Description treatment, whereas there is no conclusive evidence that they perceived more options under the Auditory Description treatment. Finally, we find that women reveal a higher level of relative risk aversions under the Visual Description treatment, as aligned with existing studies (e.g., Eckel and Grossman, 2008; Croson and Gneezy, 2009). However, this gender gap becomes insignificant under the Auditory Description treatment.

Our paper contributes to the growing literature on perception. This study probably is among the first to empirically analyze and investigate the effect of different perceptual descriptions on economic choice behavior, thus adding evidence to the importance of perception in economics. This paper also provides a simple experimental choice paradigm, which is adaptable to examining perceptual descriptions in various choice contexts. This paper also contributes to the strand of literature on economic rationality. The existing literature mainly examines the relationship between economic rationality and individual characteristics (e.g., Burks et al., 2009; Choi et al., 2014; Echenique et al., 2021; Kim et al., 2018). Complementing prior research, this paper provides novel evidence that how decision problems are described has an impact on economic rationality. To some degree, perceptual descriptions may lead to different levels of complexity for subjects in the experiment. Hence, this paper also relates to the literature on the influence of complexity on decision-making (e.g., Caplin and Dean, 2015; Carvalho and Silverman, 2019).

The paper proceeds as follows: Section 3.2 describes the experimental design. Section 3.3 presents the results. Section 3.4 concludes.

[2] The significance of this result is robust to other rationality measures, including FOSD violations, HM index, and MMI, as reported in Appendix 3.5.5.

3.2 Experimental Design

3.2.1 Experimental Treatments

In both treatments, decision problems are described to reward experimental tokens. Subjects are informed that one of the decision problems will be randomly selected for their payment with the conversion rate of five tokens to one Chinese Yuan. In the Visual Description Treatment, subjects can click on each option to see its visual information, displayed as "x_1 or x_2" (the word "or" is printed in Mandarin Chinese). In the Auditory Description Treatment, subjects can click on each option to hear its auditory information. The voice data is generated by Python *pyttsx3* library, which synthesizes text into audio using native speech drivers from Windows. The auditory information is, literally, "x_1 or x_2", in the Mandarin Chinese in a female voice. Given the evidence that lower speech rates improve information processing (Picheny et al., 1985, 1986), we set the playing speed of an option's auditory information to be 120 words per minute, which is slightly slower than the recommended conversational speech rate for Mandarin Chinese (Li, 2010).

Individuals may perceive options with visual and auditory descriptions according to different processes. An individual may, for example, tend to see multiple options simultaneously but hear them sequentially. Hence, the observed difference in choice behavior may be partially attributed to the sequentiality of the perception process. To minimize the impact of the sequentiality, we fix the speed rates of displaying visual information and playing auditory information of options. Specifically, by clicking on an option, subjects can see (hear, respectively) only the option in the Visual (Auditory, respectively) Description treatment. Depending on the content, the auditory information for an option is played for 3.5 to 4 seconds, and the visual information is displayed for 4 seconds. Subjects can perceive each option's visual (auditory, respectively) information unlimited times in the Visual (Auditory, respectively) Description treatment. In addition, while perceiving an option's information in either treatment, subjects are not allowed to stop this process and reveal other options. Further details of the treatments are reported in the Appendix 3.5.1.

Our main analysis is based on the between-subjects treatment differences in choice behavior. For robustness analysis, the experiment also includes a within-subjects design. Specifically, after making decisions under their assigned treatments (e.g., the Visual Description treatment), subjects are asked to make decisions under the other treatment for the same decision problem (e.g., the Auditory Description treatment).

3.2.2 Measuring Economic Rationality

We count the number of GARP violations for each subject to measure level of economic rationality. GARP is a necessary and sufficient condition for a choice dataset to be rationalized by a well-behaved utility function (Afriat, 1967, 1972). A higher number of GARP violations indicate a lower level of rationality. Appendix 3.5.2 presents an example of GARP violations. We also measure economic rationality by the CCEI, which indicates the minimum wealth that needs to be wasted in order to rationalize the dataset. Thus, CCEI provides an indication of the severity of the violations of rationality in the dataset, i.e., a higher CCEI suggests a more severe deviation from rationality.

For robustness analysis, we report additional measures of economic rationality, including the number of first-order stochastic dominance (FOSD) violations (Choi et al., 2014), the HoutmanâMaks (HM) index (Houtman and Maks, 1985), and the Money Metric Index (Halevy et al., 2018; Kurtz-David et al., 2019). A violation of FOSD is defined as choosing an option over another that provides better outcomes without more risk. The HM index (Houtman and Maks, 1985) finds the minimum number of choices to be removed such that the remaining data is consistent. MMI finds the minimal percentage of adjustments in expenditure required to reconcile an individualâs choices with the best-fitting parametric utility function. All economic rationality measures in the paper are computed by Halevy et al. (2018)'s code packages.

3.2.3 Measuring Cognitive Ability

Cognitive ability is mainly expressed as IQ scores using the matrix reasoning and three-dimensional rotation questions from the ICAR test. The two types of questions are independent of language skills. They are commonly used as the primary measure of fluid intelligence, which relates to problem-solving and reasoning abilities. We also measure selective attention by the Stroop test (Stroop, 1935) and working memory capacity by the Sternberg test (Sternberg, 1966), which involve twenty and ten trials, respectively.

3.2.4 Experimental Procedure

A total of 117 subjects (47.9% females, mean age 22.1 years) were recruited to participate in the experiment in 24 sessions of maximum 10 subjects from July 07 to July 16, 2021. 57 (57.9% female, mean age 22.2 years) were randomly allocated to the Visual Description treatment and 60 (38.3% female, mean age 22 years) to the Auditory Description treatment. All subjects are native in Mandarin Chinese and passed the pretests of correctly identifying visual and auditory information relevant to the experiment.

The experiment was conducted through Qualtrics at the Neuromanagement Lab of Zhejiang University. The experiment had received the approval of Zhejiang University's Internal Review Board. All subjects agreed with the information consent before starting the experiment and were free to leave the experiment at any moment without giving a reason. There was a physical distance of a minimum of 2 meters between each computer in the laboratory. There was no interaction between subjects by design during each experimental session, and subjects were also asked to keep quiet. Subjects received their earnings in cash after the experiment. On average, subjects spent 94 minutes in the experiment and earned 71.9 Chinese Yuan.

3.3 Experimental Results

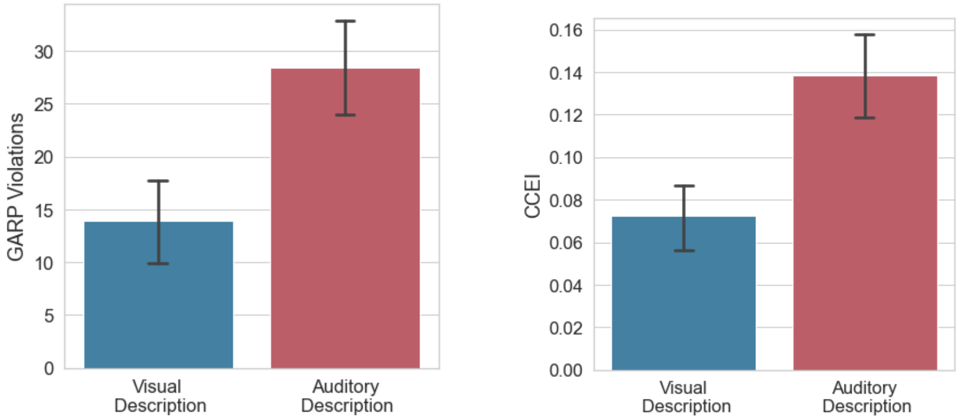
3.3.1 Economic Rationality

Figure 3.1 and Figure 3.2 present the key results of our study, including the mean GARP violations and CCEI, their standard errors, and empirical cumulative distributions. We find that subjects commit, on average, 13.91 GARP violations in the Visual Description treatment (Figure 3.1(a)), and their mean CCEI is about 0.072 (Figure 3.1(b)). This level of economic rationality differs from that found in the related literature with the closest design. For example, Kim et al. (2018) conduct the experiment on a sample of Malawian secondary school female students in which they find a CCEI of 0.19 in their baseline control group. The difference in economic rationality may be attributed to the gaps in education (Choi et al., 2014) and economic development (Cappelen et al., 2020) between their study and ours.

Figure 3.1(a) and (b) also show that the mean GARP violations and CCEI in the Auditory Description treatment are 28.45 and 0.138, respectively. With the switch from the Visual Description treatment to the Auditory Description treatment, subjects' GARP violations increase by about 104% and CCEI by almost 92%, on average. Furthermore, Figure 3.2 displays that the cumulative distributions of GARP violations and CCEI in the Auditory Description treatment (first-order) stochastically dominate that in the Visual Description treatments strongly (except on the extreme right tails of the distributions in Figure 3.2(a). In other words, it is more likely to observe a lower level of economic rationality in the Auditory Description treatment than in the Visual Description treatment.

To identify the treatment effect, we conduct a negative binomial regression analysis for GARP violations and a linear regression analysis for CCEI.[3] Table 3.1 presents the

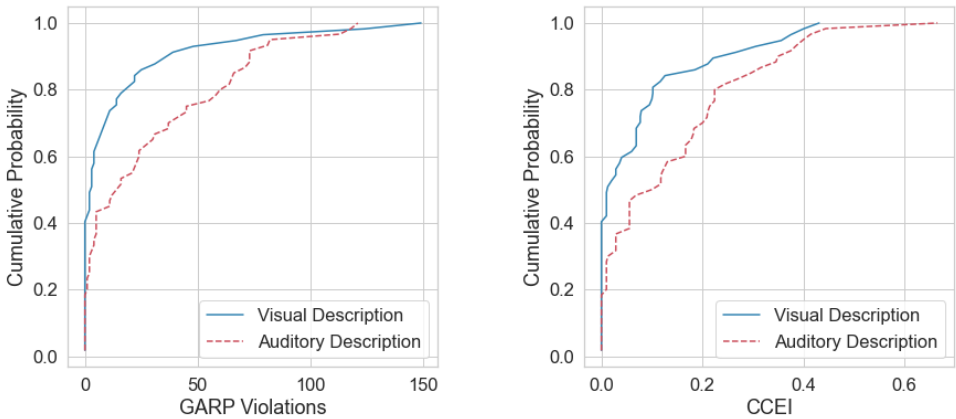
[3]GARP violations are count data, which is suggested to be analyzed by the nonlinear regressions (Cameron and Trivedi, 2013). CCEI is continuous data, which is analyzed by linear regressions by convention. We provide more details in Appendix 3.5.4.



(a) GARP Violations **(b)** CCEI

Figure 3.1: Means of Economic Rationality Measures by Treatment

Notes: Error bars indicate the standard error of means.



(a) GARP Violations **(b)** CCEI

Figure 3.2: Cumulative Distributions of Economic Rationality Measures by Treatment

results in the form of average marginal effects. All full tables and regressions in the original form are reported in Appendix 3.5.5. In line with the descriptive evidence, the GARP violations and CCEI between the two treatments differ significantly ($p < 0.01$), robust across all models. Specifically, the Auditory Description treatment increases approximately 22.522 GARP violations (almost 162%, Column (2)) and 0.093 (about

129%, Column (4)) CCEI compared with the Visual Description treatment taking into account all controls.

Apart from the treatment effect, only the effect of response times is significant on GARP violations ($p < 0.05$, Column (2)) and CCEI ($p < 0.01$, Column (4)). Longer response times may involve more (deliberate) processing of choice tasks, thus improving economic rationality, as implied by the speed-accuracy tradeoff hypothesis (Wickelgren, 1977). We do not find effects of demographics and cognitive ability in the experiment, although the literature has suggested them (Burks et al., 2009; Choi et al., 2014; Echenique et al., 2021). The insignificance of these factors may be due to the present design, where choice complexity can rise as the subject are asked to perceive options sequentially. The results lead to the question of the robustness of relationships between economic rationality and demographics or cognitive ability in the face of choice complexity, which desires further investigations.

In addition, Table 3.6 in Appendix 3.5.5 shows that the main result is robust to other measures of rationality, including FOSD violations, HM index, and MMI taking into account controls. Table 3.10 and 3.11 present the within-subjects treatment analysis and show results consistent with the between-subjects treatment analysis. Taken together, all the results indicate a substantial impairment of economic rationality caused by auditory descriptions in terms of both frequency and severity.

3.3.2 Response Times and Perception

As discussed previously, one possible mechanism of the lower level of economic rationality revealed in the Auditory Description treatment is that subjects spend less time in it than in the Visual Description treatment. It is also possible that subjects perceived fewer options in the Auditory Description treatment. We examine the differences in response times and the numbers of perceived options in the two treatments to verify these possibilities. We count the total number of unique options that each subject has clicked on to indicate the number of perceived options. We conduct a linear regression

Table 3.1: Impacts of Auditory Descriptions on Economic Rationality

	(1)	(2)	(3)	(4)
	GARP Violations		CCEI	
Auditory Description	14.538**	22.522***	0.066***	0.093***
	(5.705)	(6.263)	(0.024)	(0.027)
Response Time (Minutes)		-1.185**		-0.006***
		(0.475)		(0.002)
Other Control variables	No	Yes	No	Yes
N	117	117	117	117

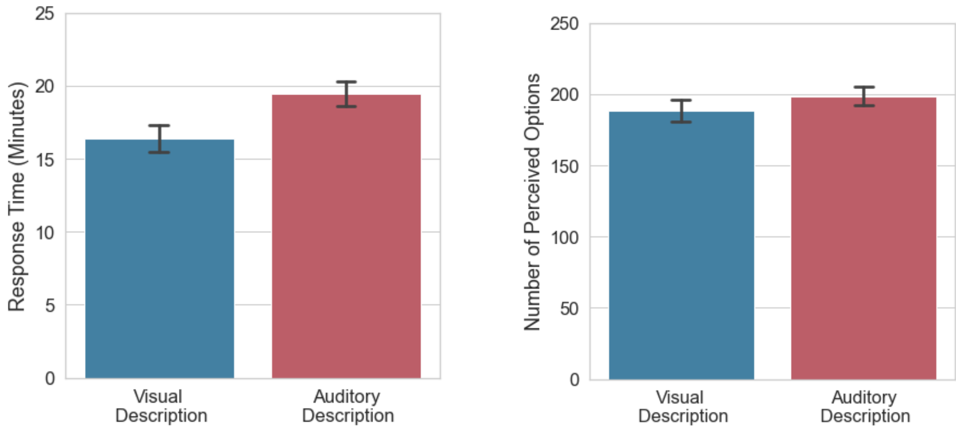
Standard errors in parentheses.

** $p < 0.05$, *** $p < 0.01$.

Other control variables include Age, Female, Education, IQ, Selective Attention, and Working Memory.

analysis for response times and a negative binomial regression analysis for the numbers of perceived options. Figure 3.3(a) shows that subjects spend, on average, more time making decisions in the Auditory Description treatment than in the Visual Description treatment. Meanwhile, the gap between the numbers of perceived options in both treatments seems not large, as shown in Figure 3.3(b).

Table 3.2 shows the results of the regression models in the form of average marginal effects. The Auditory Description treatment corresponds to a longer response time of over 3.1 minutes, compared to the Visual Description treatment ($p < 0.05$, Column (1)); and this becomes much longer with controls taken into account ($p < 0.05$, Column (2)). As a baseline, subjects spend, on average, 16.37 minutes in the Visual Description treatment. This indicates that subjects spend markedly more time in the Auditory Description treatment, with the increment being almost 22% of the baseline group. However, we do not find that the numbers of perceived options differ significantly between the two treatments (Column (3) and 4). These findings together rule out the potential mechanism that the treatment effect operates through the response time channel. Also, they imply that subjects may spend more time processing each option in the Auditory Description treatment than in the Visual Description treatment. The present findings of a lower level of economic rationality and longer response times in the Auditory Description treatment are aligned with the evidence of inferior auditory working memory.



(a) Response Time **(b)** Number of Perceived Options

Figure 3.3: Means of Response Times and Numbers of Perceived Options by Treatment

Notes: Error bars indicate the standard error of means.

Table 3.2: Impacts of Auditory Descriptions on Response Times and Perception

	(1)	(2)	(3)	(4)
	Response Time (Minutes)		Number of Perceived Options	
Auditory Description	3.115**	3.555***	10.459	10.379
	(1.351)	(1.336)	(10.563)	(10.452)
Control variables	No	Yes	No	Yes
N	117	117	117	117

Standard errors in parentheses.

** $p < 0.05$, *** $p < 0.01$.

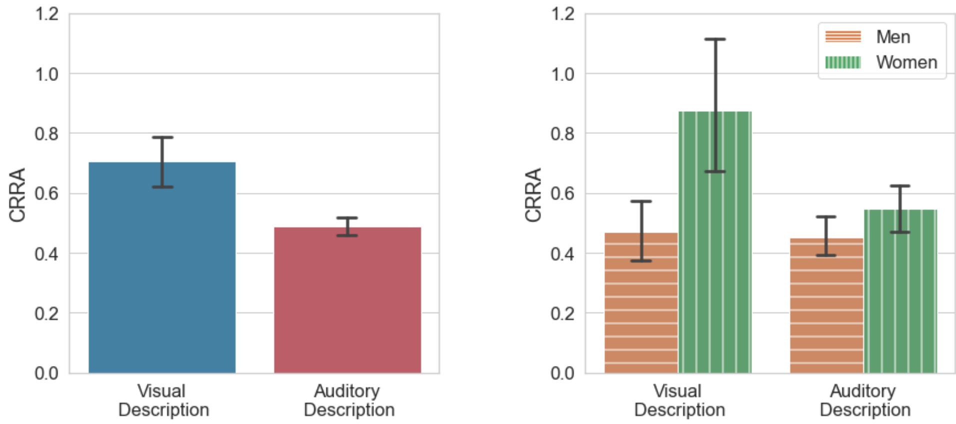
Control varibles include Age, Female, Education, IQ, Selective Attention, and Working Memory.

3.3.3 Risk Preferences

Would the different perceptual descriptions cause other behavioral consequences? We continue to examine the impact of descriptions on risk preferences, one fundamental determinant of individual economic choice behavior (Falk et al., 2018). We consider the coefficient of relative risk aversion (CRRA) form expected utility model to measure risk preferences. Each subject's choices can be characterized by a CRRA parameter, which is recovered using the MMI (Halevy et al., 2018). A higher level of CRRA indicates a higher level of relative risk aversion. Further details of risk preferences recovery are included in Appendix 3.5.3.

Figure 3.4(a) shows that subjects in the Auditory Description treatment reveal a higher level of CRRA than in the Visual Description treatment, on average. Specifically, women reveal a higher level of relative risk aversion than men in the Visual Description treatment, consistent with the literature on risk preferences (Eckel and Grossman, 2008; Croson and Gneezy, 2009), as shown in Figure 3.4(b). Interestingly, the same figure also shows that the average level of women revealed CRRA becomes lower in the Auditory Description treatment as compared to the Visual Description treatment. In contrast, men's choice behavior reveals similar levels of CRRA in both treatments.

Table 3.3 presents the linear regression results of treatment effects on the CRRA. We find that the Auditory Description Treatment corresponds to a lower level of CRRA ($p < 0.01$, Column (1)). The treatment effect on risk preferences remains significant in the presence of all controls ($p < 0.01$, Column (2)), displaying a slightly smaller magnitude. Although the relationship between cognitive ability and risk aversion is suggested in the literature (Dohmen et al., 2010, 2018), it is not found in the present experiment. This is perhaps due to the complexity of the choice task. Indeed, Benjamin et al. (2013) suggest choice mistakes may drive the revealed risk preferences to be different. We confirm that female is associated with a higher level of risk aversion ($p < 0.01$, Column (2)). In Models 3 and 4, we control the potential interaction between the treatment and female dummies. Aligned with the descriptive evidence, while the Auditory Description treatment does not seem to affect males' revealed CRRA significantly, we find a significant negative impact on women's revealed CRRA ($p < 0.10$, Column (3)) in the absence of controls. The significance of this effect is approaching conventional levels ($p = 0.105$) in Column (4). The evidence suggests that women may drive the Auditory Description treatment's overall impact on risk preferences.



(a) By Treatment **(b)** By Treatment× Female

Figure 3.4: Means of Estimated CRRA by Treatment and by Gender

Notes: Error bars indicate the standard error of means.

Table 3.3: Determinants of Risk Preferences

	(1)	(2)	(3)	(4)
	Coefficient of Constant Relative Risk Aversion			
Auditory Description	-0.217**	-0.180**	-0.020	-0.053
	(0.091)	(0.090)	(0.076)	(0.082)
Female		0.218***	0.402***	0.355**
		(0.075)	(0.148)	(0.139)
Auditory Description×Female			-0.308*	-0.257
			(0.162)	(0.157)
Other Control Variables	No	Yes	No	Yes
N	117	117	117	117

Standard errors in parentheses.

** $p < 0.05$, *** $p < 0.01$.

Other control variables include Age, Education, IQ, Selective Attention, and Working Memory.

3.4 Conclusion

Perceptions of visual and auditory information are both genuinely relevant in a wealth of choice contexts. Motivated by this empirical relevance, this paper studies the economic outcomes of individual decision-making with visual and auditory descriptions. Apart from presenting decision problems visually to subjects, which is the convention in the literature, we describe the problems auditorily to subjects. This experiment allows us to contrast the levels of economic rationality under different perceptual descriptions, thus complementing the existing literature.

Using a randomized controlled experiment, we first discover that providing auditory descriptions, as opposed to visual descriptions, may impair economic rationality substantially, both in terms of frequency and severity. While we find no treatment differences in the number of perceived options, subjects spend more time making decisions with auditory descriptions than with visual descriptions. Our results suggest that the decision-making processes under these two types of descriptions may differ to some extent, which requires a further investigation.

This paper has meaningful policy implications. Most importantly, policymakers may consider promoting visual descriptions to improve individual welfare. There may exist contexts where visual descriptions are not available. For example, in some undeveloped areas, households may need to make crucial financial decisions mainly based on auditory descriptions of options due to a poor level of literacy. Previous studies have suggested that individuals have a low level of rationality due to low levels of economic development (Cappelen et al., 2020) or low education (Kim et al., 2018). Despite our experiment being conducted on students from one of the top universities in China, we still find substantial welfare losses due to auditory descriptions. In other words, auditory descriptions might cause more considerable welfare losses in low literacy areas than in this study. In addition, policymakers may need to take into account perceptual descriptions when interpreting individual choices, especially when a policy requires the identification of individual preferences. Finally, auditory descriptions lead to less risk-averse choices than visual descriptions, particularly among females; this could be relevant for a policy concerning risk-taking behavior.

While we do not claim that the impairment in economic rationality is prevalent across all settings with auditory descriptions of options, our experiment presents the first evidence showing this issue may deserve some concern. Our study and, desirably, more research on richer variations of descriptions should be considered together to draw firm conclusions.

3.5 Appendix

3.5.1 Details of the Experimental Treatments

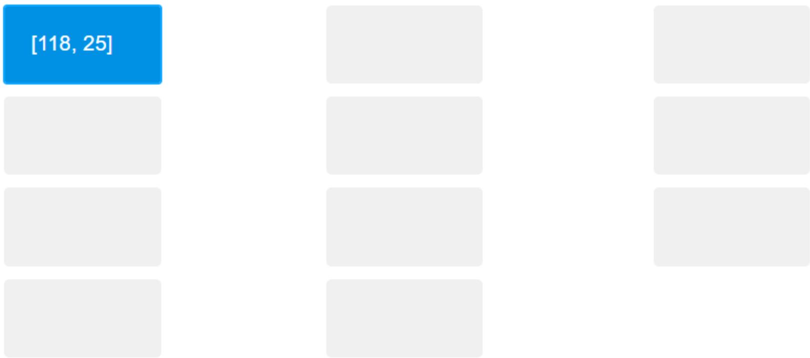


Figure 3.5: Screenshot of the Visual Description Treatment

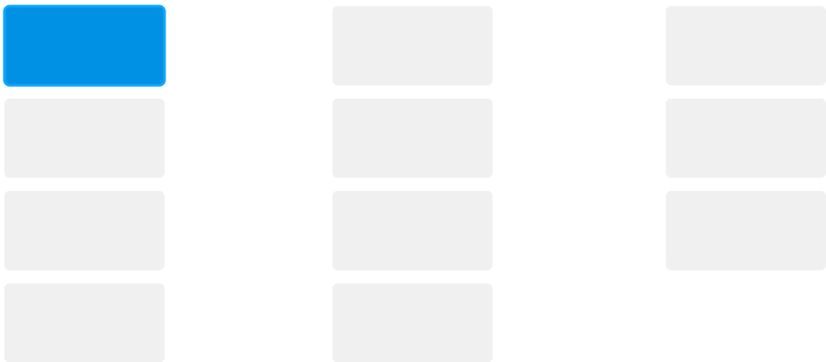


Figure 3.6: Screenshot of the Auditory Description Treatment

3.5.2 Statistical Analysis and Regression Models

We employ two types of regression models to estimate the treatment effects. For the dependent variables of count data, including GARP violations, FOSD violations, HM index, and the number of explored options, we conduct negative binomial regressions, as suggested by Cameron and Trivedi (2013). The negative binomial distribution

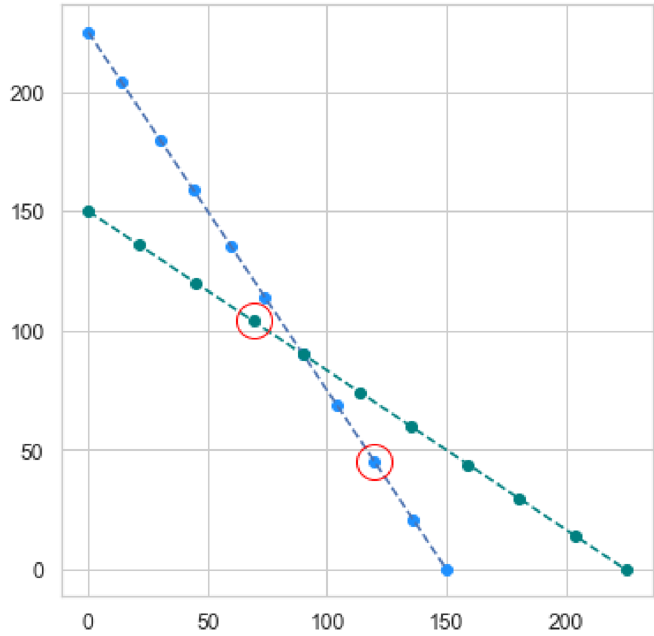


Figure 3.7: A Simple Violation of GARP

probability mass function is given by:

$$Pr(Y = y; \alpha, \delta) = \frac{\Gamma(y + 1/\alpha))}{\Gamma(1/\alpha)\Gamma(y + 1)}(\frac{1}{1 + \delta\alpha})^{1/\alpha}(1 - \frac{1}{1 + \delta\alpha})^{y} \tag{3.1}$$

The negative binomial regressions result from finding the finding the maximum likelihood estimators $\beta_0, \beta_1, \beta_2$ by introducing coefficients via $\alpha = \theta exp(\beta_0 + \beta_1 Auditory + \beta_2 Controls)$ and $\delta = exp(\beta_0 + \beta_1 Auditory + \beta_2 Controls)$. *Auditory* is a independent dummy variable that takes value 1 if the subject is assigned to the Auditory Description Treatment and 0 otherwise. β_0 is a constant term, β_1 is the coefficient associated with *Auditory*. β_2 is a vector of coefficient associated with a vector of the corresponding variable. To compute the treatment effects or the effects of controls, the coefficient estimates can be converted to the form of average marginal effects (AMEs), which is given by:

$$AME_j = \sum_i exp(\hat{\beta}_0 + \hat{\beta}_1 Auditory + \hat{\beta}_2 Controls) \times \hat{\beta}_j \tag{3.2}$$

where the estimated coefficients are expressed with hats, AME_j refers to the average marginal effect of variable j. For example, the AME of *Auditory* is 22.52 on GARP violations, which implies that being assigned to the Auditory Description Treatment increases the number of GARP violations by almost 23, *ceteris paribus*.

For the dependent variables of continuous data, including CCEI, MMI, response times, and CRRA, we conducted linear regressions of the following form:

$$Y = \beta_0 + \beta_1 Auditory + \beta_2 Controls + \epsilon \tag{3.3}$$

The coefficient estimates of linear regression can be used directly to interpret the effect of the variables. For example, the estimated coefficient of *Auditory* on CCEI is 0.093, which implies that being assigned to the Auditory Description Treatment increases CCEI by about 0.09, *ceteris paribus*.

3.5.3 Estimating Risk Preferences

To estimate risk preferences, we use the CRRA functional form of the expected utility model. Formally,

$$U(x_1, x_2; p) = pu(x_1) + (1-p)u(x_2) \tag{3.4}$$

$$u(x_i) = \begin{cases} \frac{x_i^{1-\rho}}{1-\rho} & , \rho \geq 0 \\ ln(x_i) & , \rho = 1 \end{cases} \text{, for } i = 1, 2. \tag{3.5}$$

where p (which is 0.5 in the experimental setup) is that probability of rewarding x_1 is and $1 - p$ (0.5 as well) is that probability of rewarding x_2. ρ is the CRRA, and $\rho = 0$ implies that the subject is risk-neutral, a higher CRRA indicates a higher level of relative risk aversion. Each subjectâs ρ is recovered using the MMI by Halevy et al. (2018)'s code packages.

3.5.4 Other Economic Rationality Measures

3.5.4.1 First-order stochastic dominance (FOSD)

We compute FOSD violations by the following criterion: For each decision problem, subjects commit a FOSD violation if they choose an option (x_1, x_2) when there exists another option (y_1, y_2) in the same problem such that $y_2 > x_1$ and $y_1 > x_2$.

3.5.4.2 Houtman-Maks index (HM Index)

HM index (Houtman and Maks, 1985) is computed by finding the largest subset of the dataset D that satisfies GARP.

3.5.4.3 Money Metric Index (MMI)

As formulated by Halevy et al. (2018), given the prices p^i and a utility function u, the money metric $m(x^i, p^i, u)$ for observation i is the minimal expenditure needed to include a bundle y in the dataset such that $u(y) \geq u(x^i)$:

$$m(x^i, p^i, u) = \min_{u(y \geq u(x^i))} p^i \cdot y \tag{3.6}$$

The money metric measure for observation i is then normalized by the original expenditure to compute the adjustment, $v_i(D, u) = 1 - \frac{m(x^i, p^i, u)}{x^i \cdot x^i}$. Halevy et al. (2018) propose to recover the utility function parameters by finding the parameter that minimizes the normalized average sum of squares aggregator of all v_i.

$$f(v) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(1 - v_i)} \tag{3.7}$$

The MMI of the dataset D is then given by the $f(v)$ with the best fitting utility function u_i^*

3.5.5 Details of the Experimental Results

Table 3.4: Impacts of Auditory Descriptions on Economic Rationality (Average Marginal Effects, Full Table)

	(1)	(2)	(3)	(4)
	GARP Violations		CCEI	
Auditory Description	14.538**	22.522***	0.066***	0.093***
	(5.705)	(6.263)	(0.024)	(0.027)
Age		-1.143		0.005
		(1.710)		(0.006)
Female		0.152		0.020
		(7.085)		(0.023)
Education		4.784		-0.007
		(4.638)		(0.014)
IQ		-0.968		-0.006
		(1.477)		(0.006)
Selective Attention		-0.133		0.001
		(1.128)		(0.003)
Working Memory		0.888		-0.005
		(1.962)		(0.006)
Response Time (Minutes)		-1.185**		-0.006***
		(0.475)		(0.002)
Constant			0.072***	0.107
			(0.015)	(0.134)
N	117	117	117	117

Standard errors in parentheses.
** $p < 0.05$, *** $p < 0.01$.

Table 3.5: Impacts of Auditory Descriptions on GARP Violations (Original Form)

	(1)	(2)
	GARP Violations	
Auditory Description	0.715**	1.100***
	(0.311)	(0.276)
Age		-0.052
		(0.073)
Female		0.007
		(0.321)
Education		0.217
		(0.194)
IQ		-0.044
		(0.067)
Selective Attention		-0.006
		(0.051)
Working Memory		0.040
		(0.088)
Response Time (Minutes)		-0.054***
		(0.019)
Constant	2.633***	3.878**
	(0.273)	(1.531)
N	117	117

Standard errors in parentheses.
** $p < 0.05$, *** $p < 0.01$.

Table 3.6: Impacts of Auditory Descriptions on Economic Rationality (Robustness Checks, Average Marginal Effects)

	(1)	(2)	(3)	(4)	(5)	(6)
	FOSD Violations		HM Index		MMI	
Auditory Description	0.285	0.613***	0.031**	0.043***	0.161**	0.217***
	(0.272)	(0.228)	(0.014)	(0.014)	(0.062)	(0.062)
Age		-0.017		-0.003		-0.014
		(0.050)		(0.003)		(0.015)
Female		0.099		-0.001		0.053
		(0.225)		(0.014)		(0.061)
Education		0.039		0.008		0.045
		(0.144)		(0.008)		(0.035)
IQ		-0.002		-0.004		-0.005
		(0.056)		(0.003)		(0.014)
Selective Attention		-0.032		-0.002		-0.001
		(0.028)		(0.001)		(0.008)
Working Memory		-0.069		0.004		-0.011
		(0.064)		(0.004)		(0.016)
Response Time (Minutes)		-0.096***		-0.004***		-0.018***
		(0.020)		(0.001)		(0.004)
N	117	117	117	117	117	117

Standard errors in parentheses.
** $p < 0.05$, *** $p < 0.01$.

Table 3.7: Impacts of Auditory Descriptions on on Economic Rationality (Robustness Checks, Original Form)

	(1)	(2)	(3)	(4)
	FOSD Violations		HM Index	
Auditory Description Treatment	0.259	0.551***	0.394**	0.539***
	(0.256)	(0.213)	(0.191)	(0.181)
Age		-0.015		-0.032
		(0.045)		(0.036)
Female		0.090		-0.011
		(0.203)		(0.171)
Education		0.035		0.096
		(0.130)		(0.102)
IQ		-0.002		-0.044
		(0.050)		(0.040)
Selective Attention		-0.029		-0.022
		(0.025)		(0.019)
Working Memory		-0.062		0.056
		(0.058)		(0.048)
Response Time (Minutes)		-0.086***		-0.045***
		(0.017)		(0.014)
Constant	-0.036	2.120**	-2.748***	-1.302
	(0.213)	(1.039)	(0.158)	(0.870)
N	117	117	117	117

Standard errors in parentheses.

** $p < 0.05$, *** $p < 0.01$.

Table 3.8: Impacts of Auditory Descriptions on Response Times and Perception (Average Marginal Effects, Full Table)

	(1)	(2)	(3)	(4)
	Response Time (Minutes)		Number of Explored Options	
Auditory Description Treatment	3.115**	3.555***	10.459	10.379
	(1.351)	(1.336)	(10.563)	(10.452)
Age		-0.370		-7.016**
		(0.312)		(3.428)
Female		3.594**		17.788
		(1.420)		(11.350)
Education		-0.632		-0.311
		(0.724)		(6.258)
IQ		0.617**		6.496**
		(0.280)		(2.714)
Selective Attention		0.043		1.063
		(0.196)		(1.920)
Working Memory		-0.282		-0.291
		(0.338)		(2.725)
Constant	16.368***	21.322***		
	(0.978)	(7.742)		
N	117	117	117	117

Standard errors in parentheses.
** $p < 0.05$, *** $p < 0.01$.

Table 3.9: Impacts of Auditory Descriptions on Response Times and Perception (Original Form)

	(1)	(2)
	Number of Explored Options	
Auditory Description Treatment	0.054	0.061
	(0.055)	(0.059)
Age		-0.036**
		(0.018)
Female		0.092
		(0.059)
Education		-0.002
		(0.032)
IQ		0.034**
		(0.014)
Selective Attention		0.005
		(0.010)
Working Memory		-0.002
		(0.014)
Constant	5.237***	5.683***
	(0.042)	(0.359)
N	117.000	117.000

Standard errors in parentheses.

** $p < 0.05$, *** $p < 0.01$.

Table 3.10: Within-Subjects Treatment Differences in Economic Rationality (Average Marginal Effects)

	(1) GARP Violations	(2) FOSD Violations	(3) HM Index
Auditory Description	15.583**	0.323**	0.025***
	(6.104)	(0.159)	(0.009)
Age	-0.020	-0.030	-0.002
	(1.535)	(0.037)	(0.002)
Female	7.681	0.205	0.012
	(6.622)	(0.162)	(0.009)
Education	0.269	0.064	0.006
	(3.577)	(0.093)	(0.005)
IQ	0.213	-0.034	-0.001
	(1.149)	(0.038)	(0.002)
Selective Attention	0.305	-0.040*	-0.002**
	(0.932)	(0.021)	(0.001)
Working Memory	0.595	-0.026	-0.001
	(1.521)	(0.051)	(0.003)
Response Time (Minutes)	-1.290***	-0.073***	-0.003***
	(0.443)	(0.013)	(0.001)
N	234	234	234

Standard errors in parentheses.

** $p < 0.05$, *** $p < 0.01$.

Table 3.11: Within-Subjects Treatment Differences in Economic Rationality (Original Form)

	(1) GARP	(2) FOSD	(3) HM	(4) CCEI	(5) MMI
Auditory Description	0.762***	0.275**	0.342***	0.056***	0.145***
	(0.206)	(0.138)	(0.120)	(0.018)	(0.045)
Age	-0.001	-0.025	-0.025	0.005	-0.007
	(0.059)	(0.031)	(0.029)	(0.005)	(0.010)
Female	0.360	0.174	0.162	0.019	0.082*
	(0.246)	(0.138)	(0.120)	(0.017)	(0.044)
Education	0.013	0.054	0.083	-0.009	0.027
	(0.147)	(0.079)	(0.072)	(0.010)	(0.027)
IQ	0.010	-0.029	-0.012	-0.002	0.003
	(0.051)	(0.032)	(0.029)	(0.004)	(0.011)
Selective Attention	0.014	-0.034*	-0.030**	-0.002	-0.004
	(0.034)	(0.018)	(0.014)	(0.003)	(0.006)
Working Memory	0.028	-0.022	-0.010	0.001	-0.011
	(0.058)	(0.043)	(0.037)	(0.005)	(0.013)
Response Time (Minutes)	-0.061***	-0.062***	-0.045***	-0.006***	-0.015***
	(0.017)	(0.010)	(0.010)	(0.002)	(0.003)
Constant	2.918**	2.112***	-1.275*	0.132	0.873***
	(1.201)	(0.741)	(0.691)	(0.109)	(0.240)
N	234	234	234	234	234

Standard errors in parentheses.
** $p < 0.05$, *** $p < 0.01$.

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