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TOWARD AN UNDERSTANDING OF INSINCERE BIDDING IN A VICKREY AUCTION EXPERIMENT

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Toward an Understanding of Insincere Bidding in a Vickrey Auction Experiment*

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Abstract

This study explores two key factors influencing subjects' deviation from sincere bidding in Vickrey auction experiments. The first factor examines subjects' understanding of strategy-proofness (SP), while the second focuses on "human interaction" which includes social preferences (spite and altruism), responses to strategic uncertainty, and tacit collusion. To analyze the effect of understanding SP, we quiz subjects before an experimental Vickrey auction and examine whether their bidding behavior changes if one of the quizzes includes hints about SP. We design the quiz carefully, incorporating implicit hints about SP and ensuring the avoidance of explicit demands or advice to mitigate experimenter demand effects. However, completing the quiz enables the subjects to understand SP themselves. To analyze the effects of human interaction, we examine whether subjects' bidding behavior changes if they compete against robots instead of human rivals in the auctions. We design 2×2 treatments by varying the type of quiz (with or without hints about SP) and the nature of the rivals (humans or robots). We found that the quiz with hints about SP increases sincere bidding. The nature of rivals also influences the bidding behavior; nonetheless, its impact is not as robust as that of SP hints. Thus, the main factor causing insincere bidding in Vickrey auction experiments is not human interaction but a lack of understanding of SP.

Keywords: Market design; Strategy-proofness; Vickrey auction; Hints; Human interaction; Human vs robot rivals

JEL Classification: D44, D82, D61

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1 Introduction

The Vickrey auction (Vickrey, 1961) is strategy-proof (SP). It is a dominant strategy for bidders to bid sincerely—to bid according to their true valuation. However, many experimental studies have reported that most subjects deviate from sincere bidding in Vickrey auctions with single units (Garratt et al., 2012; Kagel & Levin, 1993; Shogren et al., 2006) and multiple units (Kagel & Levin 2009; Manelli et al., 2006; Masuda et al., 2022).

In experiments, many researchers have proposed hypotheses to explain insincere bidding, such as the joy of winning (Cooper & Fang, 2008), spiteful behaviors (Andreoni et al., 2007; Nishimura et al., 2011), underestimation of possible losses (Georganas et al., 2017), and cognitive limit of reasoning (Li, 2017). These studies suggest that several factors may cause insincere bidding in Vickrey auctions.

Subjects' cognitive reasoning limitations may make it difficult for them to understand the concept of SP in Vickrey auction rules. Conversely, most subjects find it easy to understand that sincere bidding represents the dominant strategy in English auctions. Li (2007) demonstrated that this difference leads to divergent performances in Vickrey and English auctions despite both auction rules being SP. In matching models, Hassidim et al. (2017) proposed a potential explanation for preference misrepresentation—subjects in the experiments may have failed to understand the SP nature of the deferred acceptance mechanism, a widely recognized SP mechanism.

Several researchers guide subjects to address the difficulty of understanding SP. They examine whether this guidance contributes to an increase in truth-telling rates across various SP mechanisms, such as pivotal mechanism (Kawagoe & Mori, 2001), top trading cycle matching algorithms (Guillen & Hing, 2014; Guillen & Hakimov, 2018), school matching mechanisms (Ding & Schotter, 2019), and multi-unit Vickrey auctions (Masuda et al., 2022). However, it remains unclear whether subjects express their genuine preferences because they understand SP or if they simply follow the guidance as a result of experimenter demand effects (Zizzo, 2010).

To promote subjects' understanding of SP without inducing demand effects, we administer quizzes containing hints about SP. These quizzes refrain from offering explicit

advice; however, completing them enables subjects to understand the concept of SP independently. In essence, by solving the quizzes, subjects experience an "Aha!" moment, realizing that the Vickrey auction is SP. Thus, the effect of these quizzes on subjects' bidding behavior can be attributed to the factor of understanding SP.

Specifically, we designed three distinct types of quizzes: **Quiz 1**, **Quiz 2 with hints about strategy-proofness** (hereafter, *Quiz 2 w/ hints*), and **Quiz 2 without hints about strategy-proofness** (hereafter, *Quiz 2 w/o hints*). All subjects receive these quizzes before the auction begins. Quiz 1 assesses whether subjects comprehend the auction rules and simultaneously enhances their comprehension of the auction rules. It is administered to all subjects after receiving initial instructions. Quiz 2 w/ hints assesses whether subjects understand the concept of SP and simultaneously enhances their understanding of SP. This is administered to subjects in two out of the four treatments immediately following Quiz 1. Quiz 2 w/o hints closely replicates Quiz 2 w/ hints but omits SP hints. It focuses solely on the computations of payoffs in the Vickrey auction. Its purpose is to adjust the subjects' earnings and comprehension levels of auction rules without the influence of SP hints before the auction. It is administered to subjects in the other two treatments immediately following Quiz 1. Our analytical focus centers on understanding SP, which involves comparing the effects of Quiz 2 w/ hints and Quiz 2 w/o hints on subjects' bidding behaviors.

As mentioned earlier, insincere bidding in Vickrey auctions can be influenced by multiple factors. In addition to examining the impact of understanding SP, we focus on another significant factor, which we term "human interaction." This factor includes various elements, such as social preferences (spite and altruism), responses to strategic uncertainty regarding other bidders' behavior, and tacit collusion. All these aspects stem from interactions among human subjects.

These human interaction factors do not affect bidding behavior when each subject competes solely against robot rivals, whose bids are automatically generated using a known distribution. In this controlled environment, the effects of understanding SP on subjects' bidding behavior emerge in a purer form. Thus, to analyze the factor of understanding SP within two of the four treatments, we conduct an auction experiment

in which each human subject competes against robot rivals. Simultaneously, we analyze the effects of the human interaction factor by contrasting the bidding behavior of subjects in the two treatments, where each subject competes against robot rivals, with those in the other two treatments, where only human subjects compete.

Several researchers have recently investigated the use of experimental designs in which human subjects play against robot rivals in auction experiments (Chen & Takeuchi 2010; Kagel & Levin, 2001, 2009).[5] They analyze subjects' learning of the robot bidders' strategies and their responses to them. However, we attempt to minimize these effects so that the effects of understanding SP and human interaction appear in purer forms. Thus, we inform subjects that the bids of the robot bidders are automatically generated using a known distribution. We intentionally avoid mentioning the robot bidders' strategies or even their valuations to prevent the subjects from consciously thinking about the robot bidders' strategies.

In summary, our study focuses on two factors that influence sincere bid rates in Vickrey auctions: understanding SP and human interaction. To analyze the effects of these two factors, we designed 2×2 treatments varying whether subjects took Quiz 2 w/ hints or Quiz 2 w/o hints and whether they competed against human or robot rivals.

In our experiment, we auction two homogeneous object units. There are two reasons for choosing a multi-unit Vickrey auction. First, the multi-unit Vickrey auction is a more complicated design than single-unit Vickrey auctions (or second-price auctions). Therefore, understanding the concept of SP proves to be more difficult for subjects in a multi-unit Vickrey auction than for those in a single-unit Vickrey auction. Indeed, extremely low sincere bidding rates of approximately 20% were observed in multi-unit Vickrey auction experiments, such as Kagel and Levin (2009) and Masuda et al. (2022). Thus, in multi-unit Vickrey auction experiments, the effects of understanding SP and human interactions are more salient and easier to observe. In pursuit of a broader spectrum of understanding levels regarding SP, we opt for a multi-unit Vickrey auction rather than a single-unit auction. Second, multi-unit auctions are widely used in reality, such as in spectrum and treasury bill auctions, although Vickrey-type auctions are not

[5] In addition to auction experiments, the interactions between human subjects and robots have been investigated in public goods game experiments (Yamakawa et al., 2016).

commonly used.

In our experimental results, most subjects obtain maximum or near maximum scores in Quiz 1. This implies that most subjects have a thorough comprehension of the Vickrey auction rules. Therefore, it is improbable that insincere bidding can be attributed to insufficient comprehension of the auction rules. Even after eliminating human interactions in treatments where subjects compete against robot rivals, insincere bidding persists. This suggests that the human interaction factor can only partially explain the occurrence of insincere bids in Vickrey auctions. We find that hints about SP (Quiz 2 w/ hints) increase sincere bids in the Vickrey auction. This is observed irrespective of whether the subjects compete against human or robot rivals. Subjects who score higher on Quiz 2 w/ hints tend to make sincere bids more frequently. Thus, subjects who understand SP bid sincerely more frequently. These experimental data imply that the major factor causing insincere bidding in Vickrey auctions is the subject's inability to comprehend SP. Although present, the effect of human interactions appears to be smaller. Additionally, our auction outcomes are efficient, with efficiency rates of approximately 98% across all treatments. Nevertheless, bidders' payoffs and seller's revenues exhibit mixed results.

The remainder of this paper is organized as follows. Section 2 describes the experimental design and presents several proposed hypotheses. Subsequently, Section 3 presents our experimental results, and Section 4 discusses efficiency, the bidder's payoff, and the seller's revenue. Finally, Section 5 concludes the paper.

2 Experimental Design

The purpose of this experiment is to investigate two factors that influence the sincere bid rates in a multi-unit Vickrey auction: (i) the understanding of SP and (ii) human interaction. Our experimental design follows that of Masuda et al. (2022). For the theoretical background of the multi-unit Vickrey auction, please refer to Masuda et al. (2022).

2.1 Theoretical considerations

There are three bidders, $\{1, 2, 3\}$, and two indivisible, identical objects to be auctioned. Each bidder is allowed to bid for two units. Bidder i's *valuation* of objects is $v_i = (v_i^1, v_i^2)$, where $v_i^1 \geq v_i^2 \geq 0$ and v_i^j denote the valuations that bidder i assigns to the j-th unit. Given any v_i, bidder i's utility of obtaining k units of objects and paying m_i units of money is as follows:[6]

$$U(k, m_i; v_i) \equiv \begin{cases} v_i^1 + v_i^2 - m_i & \text{if } k = 2 \\ v_i^1 - m_i & \text{if } k = 1 \\ -m_i & \text{if } k = 0. \end{cases}$$

A list $v = (v_1, v_2, v_3)$ is a *valuation profile*. The *bid* submitted by bidder i is denoted as $b_i = (b_i^1, b_i^2)$, where $b_i^1 \geq b_i^2 \geq 0$ and b_i^j denote the bidder's bid i for the j-th unit. Let $b = (b_1, b_2, b_3)$ be the *bid profile*.

An *assignment function* is a function $d = (d_1, d_2, d_3)$ that specifies that for each bid profile b, the number $d_i(b) \in \{0, 1, 2\}$ of the objects bidder i is obtained under the resource constraint: $d_1(b) + d_2(b) + d_3(b) = 2$. A *payment function* is a function $m = (m_1, m_2, m_3)$ that specifies, for each bid profile b, the amount $m_i(b)$ of money bidder i pays. A *rule* is a pair of assignment and payment functions (d, m).

We are interested in rules in which sincere bidding (i.e., bidding true valuations) is a weakly dominant strategy for everyone. Formally,

Strategy-proofness: For each bidder i, each bidder i's valuation v_i, each bidder i's bid b_i, and all other bids b_{-i},

$$U(d_i(v_i, b_{-i}), m_i(v_i, b_{-i}); v_i) \geq U(d_i(b_i, b_{-i}), m_i(b_i, b_{-i})); v_i).$$

Vickrey auction rules are central to the auction theory literature.

Vickrey auction: Each bidder i simultaneously submits their bid $b_i = (b_i^1, b_i^2)$. After

[6] In standard auctions, such as the Vickrey auction, $m_i = 0$ if $k = 0$.

the seller collects a bid profile, the seller ranks the bids $\{b_i^k : i = 1, 2, 3 \ \& \ k = 1, 2\}$ from highest to lowest and allocates the two units to the two highest bids. Ties are broken by equal probabilities. If a bidder wins one (or two) unit, then they have to pay the highest bid (the sum of the highest and second-highest bids) among the losing bids. If a bidder wins nothing, they pay nothing.

The most important feature of the Vickrey auction is that it is SP. However, several experimental studies report that bidders tend to overbid in Vickrey auctions.

2.2 Procedure

In each treatment, three bidders compete for two units of identical objects. For each bidder, two integer valuations are drawn from a uniform distribution with intervals of 10 to 1,000 in increments of 10. The larger (smaller) integer is then assigned a valuation for the first (second) unit. All values are presented in Japanese yen (JPY).

We designed four treatments, varying the type of Quiz 2 (with/without SP hints) and the nature of the rivals (human/ robot). Employing a between-subject design, the four treatments are as follows:

- Treatment HHnohint: only human subjects compete, and each subject completes Quiz 2 without SP hints
- Treatment HHhint: only human subjects compete, and each subject completes Quiz 2 with SP hints
- Treatment HRnohint: each subject competes with two robot rivals and completes Quiz 2 without SP hints
- Treatment HRhint: each subject competes with two robot rivals and completes Quiz 2 with SP hints

Table 1 summarizes the basic data for the four treatments.

Table 1: Summary of treatments

Treatments	HHnohint	HHhint	HRnohint	HRhint
Type of Quiz 2	w/o hints	w/ hints	w/o hints	w/ hints
Nature of rivals	human	human	robot	robot
No. of sessions	2	2	2	2
Duration (min)	150	150	150	150
No. of rounds	20	20	20	20
No. of subjects	48	45	43	48
Avg. payment (JPY)[7]	4,780	4,941	5,020	5,026
Avg. score of Quiz 1	9.604	9.800	9.488	9.521
Avg. score of Quiz 2 w/ hints	/	9.200	/	9.146
Avg. score of Quiz 2 w/o hints	9.500	/	9.628	/

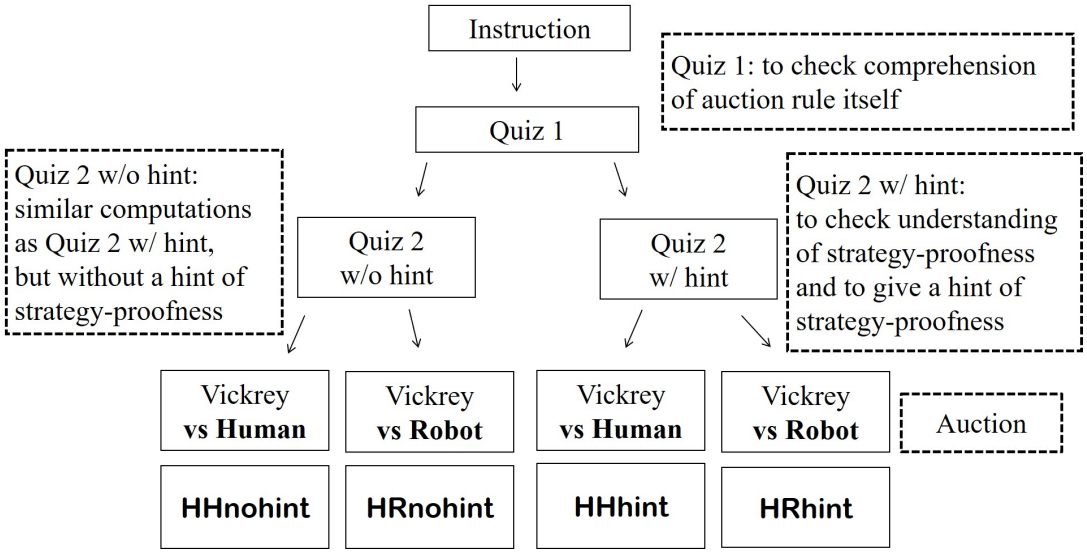
The experiments were conducted at Osaka University in eight sessions between February and March 2022. We recruited 184 students at Osaka University registered in the ORSEE (Greiner, 2015) database of the Institute of Social and Economic Research. Each subject took part in a single session. Subjects provided their consent online by clicking a button before registering for the experiment. Each session lasted approximately 150 min and was conducted by the same experimenter. Our experiment was computerized using the experimental software z-Tree (Fischbacher, 2007). Figure 1 illustrates the experimental flow.

Subjects were randomly assigned to seats. Each subject received printed handouts containing the instructions and then listened to audio instructions. Subsequently, subjects were given 3 minutes to read the instructions. Throughout the entire experiment, subjects were not allowed to ask questions. However, they were allowed to use a calculator during the experiment.

First, subjects engaged in Quiz 1, the details of which are explained in Subsection 2.3.1. Each subject received a Quiz 1 sheet and promptly began answering the questions. Subjects received 100 JPY for each correct answer, with a total of ten questions and the maximum potential payoff of 1,000 JPY. The time limit for Quiz 1 was set at 10 minutes. Upon completing Quiz 1, subjects received the answer key and listened to an

[7] We compare payment across treatments using an OLS regression model, regressing payment on four treatment dummies while incorporating robust standard errors. Subsequently, we compare the estimated dummy coefficients using an F test, with the results presented through Bonferroni-adjusted p values. There is no statistically significant difference in payments across treatments ($p = 0.604$).

Figure 1: Flow of the experiment



audio explanation. Subsequently, subjects were then given three minutes to review the answer key for Quiz 1.

Second, the subjects engaged in Quiz 2. Each subject received Quiz 2, the details of which are provided in Subsections 2.3.2 and 2.3.3. In HHnohint and HRnohint, subjects completed Quiz 2 w/o hints. In HHhint and HRhint, subjects completed Quiz 2 w/ hints. For Quiz 2 w/o hints and Quiz 2 w/ hints, they received 100 JPY for each correct answer, with a total of ten questions and a maximum potential payoff of 1,000 JPY. Subjects promptly began answering the Quiz 2 questions. The time limit for Quiz 2 was set at 20 minutes. Upon completing Quiz 2, subjects in HHnohint and HRnohint received the answer key for Quiz 2 w/o hints, and those in HHhint and HRhint received the answer key for Quiz 2 w/ hints. They listened to the audio explanations and were given five minutes to review the answer keys.

Third, the subjects participated in a Vickrey auction experiment. In HHnohint and HHhint, the subjects competed against human rivals. In HRnohint and HRhint, each human subject competed against robot rivals. The subjects proceeded to two practice periods and 20 successive payment periods under a random matching protocol. At the beginning of each period, each subject was randomly matched with two other subjects into groups of three in HHnohint and HHhint and matched with two robot rivals into groups of three in HRnohint and HRhint. In the bidding stage, each subject received

two integer valuations for two units of identical objects. Subjects were then instructed to enter two bids, ranging from 0 to 2,000, as integers in increments of 10. A crucial requirement was that the first-unit bid must be weakly greater than the second-unit bid. In HRnohint and HRhint, subjects were informed that the bids of their robot rivals are generated by a uniform distribution over $\{10, 20, \ldots, 1,000\}$, and the first-unit bid of the robot rivals is weakly greater than the second-unit bid.

After 20 successive payment periods, the subjects completed a questionnaire and were immediately paid in cash. Each subject received a private payment equal to the sum of their earnings over the 20 periods, along with earnings from Quiz 1 and Quiz 2. The average payment amounted to 4,780 JPY in HHnohint, 4,941 JPY in HHhint, 5,020 JPY in HRnohint, and 5,026 JPY in HRhint.

2.3 Design of Quizzes

Before the auction experiment, we provided three types of quizzes to subjects: **Quiz 1** for all the subjects, ***Quiz 2 w/ hints*** for subjects in HHhint and HRhint, and ***Quiz 2 w/o hints*** for subjects in HHnohint and HRnohint. Quiz 1 assesses and enhances subject comprehension of the Vickrey auction rules. Quiz 2 w/ hints assesses and enhances the subjects' understanding of SP in Vickrey auctions. Quiz 2 w/o hints adjusts levels of earnings and auction rule comprehension for the subjects in HHnohint and HRnohint before the auction, similar to those of HHhint and HRhint.

2.3.1 Quiz 1

Quiz 1 is administered to the subjects of all treatments and assesses their comprehension of Vickrey auction rules while enhancing their comprehension. Quiz 1 includes 10 questions, and the maximum score is 10 points. The subjects receive 100 JPY for each correct answer.

Figure 2 shows sample questions used in Quiz 1. As illustrated in the figure, the quiz gives numerical examples of the bid profiles and valuations, and the questions ask about the winning bids, payments, and payoffs of the examples. Three out of 10 questions are about winning bids, four are about payments, and the remaining three are about

payoffs.

The payoffs for two questions are positive, and the payoff for one question is negative. Thus, if a subject correctly answers these questions, they can realize that their payoff can be negative because of an overbid. However, to avoid giving hints regarding SP, we designed the quiz such that bids are equal to valuations in no numerical example.

The time limit for Quiz 1 is 10 minutes. After the subjects complete Quiz 1, they are provided with a handout containing the correct answers, and they listen to the explanation of the correct answers using reading software. Subsequently, subjects are given 3 minutes to review the handout before moving to Quiz 2.

Figure 2: Quiz 1 sample questions

Assume that the bids from the three bidders and bidder A's evaluation are as given in the table below. Please answer Questions 1–4 based on the table.

	First unit	Second unit
Bidder A's bid	800	500
Bidder B's bid	1000	700
Bidder C's bid	600	500
Bidder A's evaluation	900	700

[Question 1] (Two) Winning bids Answer:_____ _____

[Question 2] Bidder A's payment Answer:_____

[Question 3] Bidder A's earning (Their evaluation on the items they win – Payment)

Answer:_____

[Question 4] Bidder C's payment Answer:_____

2.3.2 Quiz 2 w/ hint (Quiz 2 w/ hint of strategy-proofness)

Quiz 2 w/ hints is exclusively administered to subjects inHHhint and HRhint. It aims to assess the subjects' understanding of the concept of SP in Vickrey auctions while enhancing their understanding of it. Quiz 2 w/ hints comprises 10 questions, and the maximum score is 10 points. Subjects receive 100 JPY for each correct answer.

Figure 3 shows sample questions used in Quiz 2 w/ hints. As indicated at the

beginning of the quiz, each subject plays the role of Bidder B, with valuations of 400 and 700 for the first and second units in the auction, respectively. Quiz 2 w/ hints provides six bidding choices (Choices a - f) for the first and second units, and Choice c coincides with Bidder B's valuations $(400, 700)$. Each of the 10 questions in the quiz requires subjects to select the correct answers from the provided six choices—the questions are multiple-choice in nature. Five of the ten questions ask about the choices that make Bidder B's earnings positive, zero, or negative for given bid profiles of other bidders (A and C). Five of the ten questions ask about the choices that maximize Bidder B's payoff. Note that the bidding choices that maximize Bidder B's payoff for bid profiles of the other bidders are typically not unique. Nevertheless, as Vickrey auctions are SP, Choice C (Bidder B's valuations) is always one of the payoff maximizers. Moreover, Question 10 specifically addresses choices that maximize the payoff for three different bid profiles of other bidders, and Choice C is the unique answer to this question. Thus, if subjects correctly answer these questions, they may observe that bidding valuations maximize one's payoff regardless of the other bidders' bids, demonstrating the concept of SP. Accordingly, the quiz provides subjects with hints regarding SP. Nonetheless, we deliberately refrain from stipulating or advising subjects to bid according to the prescribed valuations to mitigate, or at least minimize, potential demand effects (Zizzo, 2009).

Calculation sheets are provided to the subjects to compute payoffs efficiently. The time limit for answering Quiz 2 w/ hints is 20 minutes. After subjects finish the quiz, they are provided with a handout of the correct answers, and they listen to an explanation of the correct answers using reading software. The subjects are then given 5 minutes to review the handout before the auction begins.

2.3.3 Quiz 2 w/o hint (Quiz 2 w/o hint of strategy-proofness)

Quiz 2 w/o hints is administered to subjects in HHnohint and HRnohint, aiming to adjust their earnings levels and comprehension levels of the auction rules so that these aspects align with subjects in HHhint and HRhint, except their understanding of SP before the auction. While the primary purpose of Quiz 2 w/ hints is to provide hints regarding SP,

Figure 3: Quiz 2 w/ hint

Assume that you are bidder B, and your valuations of the first and second units are 700 and 400, respectively. Maintain these assumptions for Questions 1–10 below. For each question, select the correct answers from the choices provided in the table below, where the the first and second figures in each choice are the bids of the first and second units, respectively. If several choices are correct, select all of them.

Choice a: (900, 820)	Choice b: (780, 500)	Choice c: (700, 400)
Choice d: (400, 390)	Choice e: (310, 200)	Choice f: (660, 200)

The calculation sheets for these questions are attached on pages 4–6. Use them if necessary. (However, the calculation sheets will not be marked.)

In Questions 1 and 2, assume that you expect the other two bidders (A and C) to bid as shown in the table below. The calculation sheet for the two questions is shown on page 4.

Bidder	Bid for 1st unit	Bid for 2nd unit
A	380	300
C	300	250

[Question 1] Select the choices that make your earnings (the sum of valuations of the units you win - your payments) zero. If no such choice exists, answer "none."

Answer:_____

[Question 2] Select the choices that maximize your earnings (the sum of valuations of the units you win – your payments). (Note that if the earnings from all choices are nonpositive, the maximized earnings may be zero.) Answer:_____

In Questions 3–5, assume that you expect the other two bidders (A and C) to bid as shown in the table below. The calculation sheet for the three questions is shown on page 5.

Bidder	Bid for 1st unit	Bid for 2nd unit
A	650	300
C	750	450

⋮

[Question 5] Select the choices that maximize your earnings (the sum of valuations of the units you win – your payments). (Note that if the earnings from all choices are nonpositive, the maximized earnings may be zero.)

Answer:_____

[Question 6] Select the choices that are the correct answers of both Questions 2 and 5—the choices that maximize your earnings for both of the two expectations about the bids of the two other bidders. If no such choice exists, answer "none."

Answer:_____

Figure 4: Quiz 2 w/o hint

Assume that you are Bidder B in Questions 1–10. For each question, select the correct answers from the choices given in the table below, where the first and second figures in each choice are the bids of the first and second units, respectively. If several choices are correct, select all of them.

Choice a: (900, 820)	Choice b: (780, 500)	Choice c: (700, 400)
Choice d: (400, 390)	Choice e: (310, 200)	Choice f: (660, 200)

The calculation sheets for these questions are attached on pages 4–6. Use them if necessary. (However, the calculation sheets are not marked.)

In Questions 1–3, assume that your valuations of the first and second units are 500 and 300, respectively, and you expect the other two bidders (A and C) to bid as shown in the table below. The calculation sheet for the three questions is shown on page 4.

Bidder	Bid for 1st unit	Bid for 2nd unit
A	380	300
C	300	250

[Question 1] Select the choices that make your earnings (the sum of valuations of the units you win - your payments) zero. If no such choice exists, answer "none."

Answer:_____

[Question 2] Select the choices that make your earnings (the sum of valuations of the units you win - your payments) negative. If no such choice exists, answer "none."

Answer:_____

[Question 3] Select the choices that make your earnings (the sum of valuations of the units you win - your payments) positive. If no such choice exists, answer "none."

Answer:_____

In Questions 4–6, assume that your valuations of the first and second units are 710 and 290, respectively, and you expect the other two bidders (A and C) to bid as shown in the table below. The calculation sheet for the three questions is shown on page 5.

Bidder	Bid for 1st unit	Bid for 2nd unit
A	650	300
C	750	450

[Question 4] Select the choices that make your earnings (the sum of valuations of the units you win - your payments) zero. If no such choice exists, answer "none."

Answer:_____

[Question 5] Select the choices that make your earnings (the sum of valuations of the units you win - your payments) negative. If no such choice exists, answer "none."

Answer:_____

it inevitably induces other effects.

First, the correct answer to each of the 10 questions in Quiz 2 w/ hints earns subjects in HHhint and HRhint 100 JPY, providing them with a substantial amount from the quiz. Thus, unless subjects in HHnohint and HRnohint are compensated with amounts similar to those in HHhint and HRhint, the subjects in HHnohint and HRnohint might behave differently, regardless of their understanding of SP.

However, if we simply provide subjects in HHnohint and HRnohint amounts similar to those in HHhint and HRhint, this may induce the "house money effect" (Corgnet et al., 2015). To avoid such an effect, it is necessary to offer subjects the opportunity to earn similar amounts to those available from Quiz 2 w/hints through similar effort rather than simply providing them with similar amounts.

Second, Quiz 2 w/ hints does not specifically enhance the understanding of SP; instead, it further improves the comprehension of the auction rules. Therefore, to accurately analyze the effects of understanding SP, it becomes crucial to adjust the comprehension levels of subjects inHHnohint and HRnohint, making them similar to those in HHhint and HRhint.

To summarize, the purposes of Quiz 2 w/o hints are as follows: (i) to give subjects in HHnohint and HRnohint the opportunity to earn amounts similar to those from Quiz 2 w/ hints through similar efforts and (ii) to align their earnings and comprehension levels of the auction rules with those of subjects in HHhint and HRhint before the auction. However, Quiz 2 w/o hints should not provide hints regarding SP. Thus, we designed Quiz 2 w/o hints as follows.

Figure 4 shows sample questions used in Quiz 2 w/o hints. Similar to Quiz 2 w/ hints, Quiz 2 w/o hints includes 10 questions, the maximum score is 10 points, and each subject receives 100 JPY for each correct answer. Each subject plays the role of Bidder B. The quiz provides six bidding choices (Choices a – f) for the first and second units at the beginning, and each question in the quiz asks the subjects to select the correct answer from the six choices. Calculation sheets are also provided to subjects to compute payoffs efficiently.

Nevertheless, the six choices in Quiz 2 w/o hints do not include Bidder B's valuations,

and all the questions in the quiz ask only about bidding choices making positive, zero, or negative payoffs; nonetheless, no question asks about choices that maximize Bidder B's payoffs. These questions do not provide hints regarding SP, similar to Quiz 2 w/hints. However, they enhance the subjects' further comprehension of the auction rules. This is because three questions ask about bidding choices that result in negative payoffs. By answering these questions, the subjects can realize that their payoff can be negative because of overbidding. Notably, Quiz 2 w/o hints varies Bidder B's valuations such that its difficulty level is similar to that of Quiz 2 w/ hints. Otherwise, Quiz 2 w/o hints would be simpler than Quiz 2 w/ hints.

As reported in Subsection 3.2, Quiz 2 w/o hints is devised with its average scores similar to that of Quiz 2 w/ hints. This implies that, as intended, subjects' comprehension levels of the auction rules in HHnohint and HRnohint are similar to those in HHhint and HRhint, and the subjects of HHnohint and HRnohint can earn amounts similar to those of HHhint and HRhint.

2.4 Hypotheses

Although the literature has firmly established the SP nature of the Vickrey auction, various experimental results have shown that many subjects overbid or underbid relative to their valuations. We hypothesize that this discrepancy may be due to the complexity of understanding the concept of SP as opposed to merely comprehending the Vickrey auction rules. To examine this, we first ensure that most of the subjects comprehend the Vickrey auction rules by administering a quiz on the rules (Quiz 1) to all subjects. Subsequently, we administer two different types of a second quiz: one includes hints about SP (Quiz 2 w/ hints) and is given to subjects in HHhint and HRhint, whereas the other lacks these hints (Quiz 2 w/o hint) and is given to subjects in HHnohint and HRnohint. We predict that Quiz 2 w/ hints may make subjects more aware of the benefits of sincere bidding. To statistically evaluate the effect of the hints about SP, we propose the following null hypothesis:

Hypothesis 1 (*Effect of Hints on Strategy-Proofness*): The rate of sincere bidding among subjects who take Quiz 2 w/ hints in HHhint is statistically similar to that

among those who take Quiz 2 w/o hints in HHnohint.

Some experimental results suggest that other factors, such as strategic interaction and social preferences, may also play a significant role in insincere bidding. These factors are closely related to interactions among human subjects. When each subject competes against robot rivals in an auction, the human interaction factor is eliminated. Nevertheless, we predict that hints regarding SP in Quiz 2 make the subjects more aware of the advantages of sincere bidding, even when their rivals are robots. To statistically evaluate the effect of hints about SP, we propose the following null hypothesis:

Hypothesis 2 (*Effect of Hints on Strategy-Proofness with robot rivals*): The rate of sincere bidding among subjects who take Quiz 2 w/ hints in HRhint is statistically similar to that among those who take Quiz 2 w/o hints in HRnohint.

To investigate the impact of factors related to human interaction, we compare the rate of sincere bidding in treatments in which each subject competes against robot rivals with the rate in treatments in which only human subjects compete. To examine the effect of human interactions on sincere bidding, we propose the following null hypotheses:

Hypothesis 3a (*Effect of human interaction with Quiz w/o hints*) The sincere bidding rate is similar regardless of whether subjects compete against human subjects in HHnohint or solely against robot rivals in HRnohint.

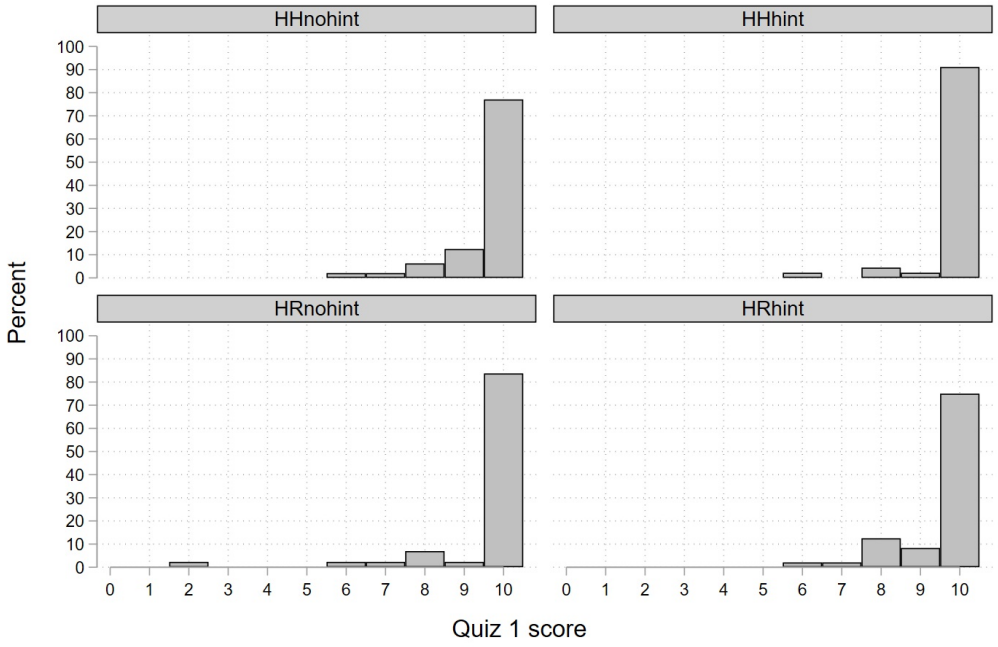
Hypothesis 3b (*Effect of human interaction with Quiz w/ hint*) The sincere bidding rate is similar regardless of whether subjects compete against human subjects in HHhint or solely against robot rivals in HRhint.

3 Experimental results

3.1 Level of comprehension of the Vickrey auction rules.

Figure 5 illustrates Quiz 1 score distributions across the four treatments. As shown, a significant majority of subjects in each treatment achieved perfect scores (77% for HHnohint, 91% for HHhint, 84% for HRnohint, and 75% for HRhint). Other subjects in

Figure 5: Distribution of Quiz 1 scores



each treatment group attained nearly perfect scores (8 or 9 points). To compare Quiz 1 scores across treatments, we employ an OLS regression model, regressing Quiz 1 scores on four treatment dummies. Robust standard errors are utilized, and the estimated dummy coefficients are compared using an F test, with results assessed through Bonferroni-adjusted p values. There is no statistical difference in the Quiz 1 scores across the treatments ($p = 0.328$).[8] Most subjects in all treatments have a good comprehension of the Vickrey auction rules. Moreover, their comprehension levels do not differ across treatments.

After Quiz 1, the correct answers are distributed to each subject and explained using voice software. As this step further enhances the comprehension, most subjects exhibit a thorough understanding of the Vickrey auction rules prior to the auction. This is confirmed by the post-experiment survey (See Online Appendix F): 79.167% of HHnohint subjects, 91.111% of HHhint subjects, 74.419% of HRnohint subjects, and 75% of HRhint subjects indicated that they understood the Vickrey auction rules thoroughly before the auction commenced.

[8] We also compare Quiz 1 scores across treatments using a one-way analysis of variance (ANOVA). There is no statistical difference in Quiz 1 scores across the treatments ($p = 0.481$).

3.2 Level of understanding of the strategy-proofness

Figure 6: Distribution of Quiz 2 scores

Figure 6 displays the distributions of the scores of Quiz 2 w/ hints for HHhint and HRhint, as well as those of Quiz 2 w/o hints for HHnohint and HRnohint. The figure highlights that most subjects in HHhint and HRhint (69% in HHhint and 77% in HRhint) attained perfect scores (10 points) in Quiz 2 w/ hints. Additionally, most of the other subjects in these treatments scored near the maximum (8 or 9 points). Thus, most subjects in HHhint and HRhint received hints, which facilitated their understanding of SP. After Quiz 2 w/ hints, we distributed the correct answers to each subject in HHhint and HRhint and explained them using voice software. As this step further enhances the understanding of SP, most subjects in HHhint and HRhint received hints to understand SP prior to the auction.

As shown in the figure, most subjects in HHnohint and HRnohint (85% in HHnohint and 93% in HRnohint) attained perfect scores (10 points) in Quiz 2 w/o hints. Additionally, most of the other subjects in these treatments scored near the maximum (7, 8, or 9 points). As outlined in Subsection 2.3.3, Quiz 2 w/o hints focuses solely on questions that ask whether the payoffs are positive, negative, or zero. Although this quiz does

not explicitly provide hints about SP, its emphasis on a thorough comprehension of the Vickrey auction rules could indirectly make subjects recognize the concept of SP.

In comparing Quiz 2 scores across treatments, we employed an OLS regression model, regressing Quiz 2 scores on four treatment dummies while incorporating robust standard errors. Subsequently, we compared the estimated dummy coefficients using an F test, with results presented through Bonferroni-adjusted p-values. There are no statistically significant differences in Quiz 2 scores across treatments ($p = 0.454$).[9] This implies that Quiz 2 w/o hints adjusts the subjects' earnings levels and comprehension levels of the auction rules before the auction in HHnohint and HRnohint similar to those in HHhint and HRhint.

In summary, most subjects in HHhint and HRhint had a good understanding of SP in Vickrey auctions by obtaining perfect scores in Quiz 2 w/ hints. Additionally, the earnings levels and comprehension levels of the auction rules before the auction in all treatments are well controlled.

3.3 Bidding behavior

We classify a subject's bids as follows: given subject i's valuation, v_i^1 (v_i^2) for the first (second) unit, their bid b_i^1 (b_i^2) for the first (second) unit is *sincere* if $b_i^1 = v_i^1$ ($b_i^2 = v_i^2$), *over* if $b_i^1 > v_i^1$ ($b_i^2 > v_i^2$), and *under* if $b_i^1 < v_i^1$ ($b_i^2 < v_i^2$). For example, assume that the valuations $v_i = (v_i^1, v_i^2)$, $i = 1, 2, 3$, of the three subjects are $v_1 = (800, 200)$, $v_2 = (600, 400)$, $v_3 = (910, 500)$ and that their bids $b_i = (b_i^1, b_i^2)$, $i = 1, 2, 3$, are $b_1 = (850, 240)$, $b_2 = (600, 450)$, and $b_3 = (900, 500)$. Subsequently, the sincere bids are as follows: bidder 2's bids for the first unit ($b_2^1 = 600 = v_2^1$) and the second unit of bidder 3 ($b_3^2 = 500 = v_3^2$). Overbids are bidder 1's bids for the first and second units ($b_1^1 = 850 > v_1^1 = 800$ and $b_1^2 = 240 > v_1^2 = 200$) and the second unit of bidder 2 ($b_2^2 = 450 > v_2^2 = 400$). In this example, an underbid is unique and is the first unit of bidder 3 ($b_3^1 = 900 < v_3^1 = 910$). The *sincere bidding rate* is the number of sincere bids divided by the total number of bids. Thus, the sincere bid rates of the subjects

[9] We also compare Quiz 2 scores across the four treatments by using one-way ANOVA. There are no statistically significant differences in Quiz 2 scores across treatments ($p = 0.444$). However, the ratio of the subjects with perfect scores is higher in HHnohint and HRnohint (0.890) than in HHhint and HRhint (0.731) with a 1% significance level by using two-sample t-tests.

$i = 1, 2, 3$ are 0, 0.5, and 0.5, respectively, and the overall average sincere bid rate is $2/6 = 1/3 = 33.33\%$. We primarily use the overall average sincere bid rate for the statistical analysis.

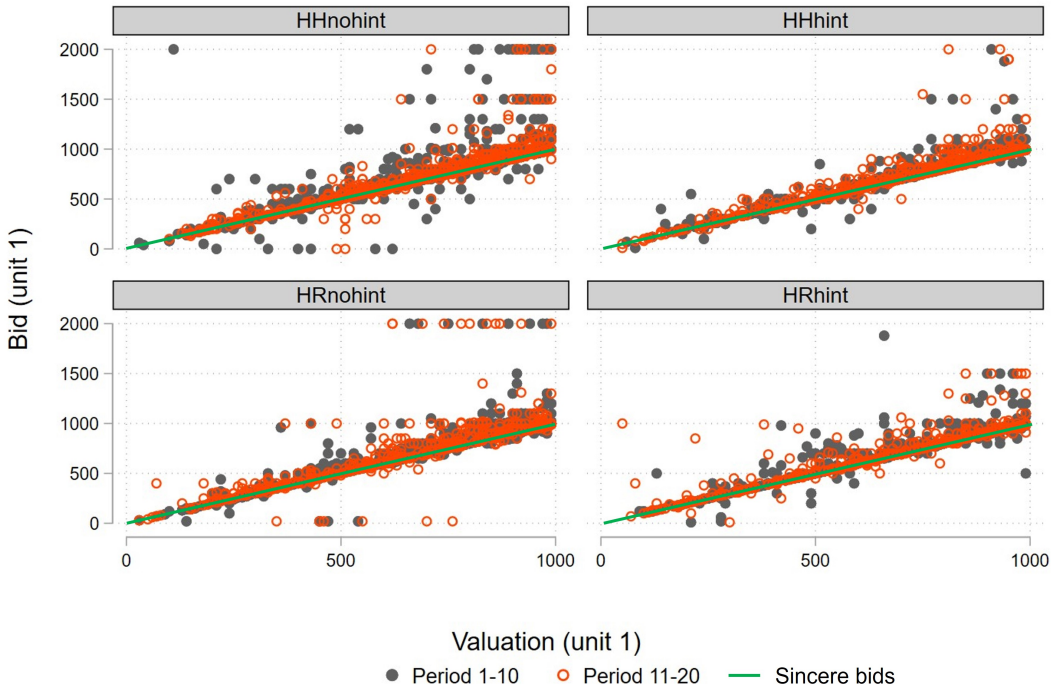
Figure 7 plots the valuations and the corresponding bids for each treatment. Panels (a) and (b) show the data for Units 1 and 2, respectively. Note that sincere bids lie along the 45° green line. The eight graphs in the figure reveal a concentration of valuations and bids on the 45° line, representing sincere bids. The data points located above and below this line indicate overbids and underbids, respectively. Panel (a) shows that some bids for Unit 1 reached a maximum of 2,000. Furthermore, the frequencies of these maximum bids are higher in HHnohint and HRnohint than in HHhint and HRhint. Conversely, Panel (b) shows that some bids for Unit 2 are at a minimum value of 0, and these minimum bids are also more common in HHnohint and HRnohint than in HHhint and HRhint.

Figure 8 shows the frequencies of sincere bids, overbids, and underbids for each treatment.[10] Panels (a)–(c) display results of the first and second units. HHnohint is the benchmark environment in which no hints about SP are provided, and the subjects bid against human rivals. Panel (a) shows that in this treatment, the total overbidding rate is approximately 53%, and the total sincere and underbidding rates are lower, 25% and 21%, respectively. This observation is consistent with findings in experiments on the multi-unit Vickrey auction by Manelli et al. (2006), Engelmann and Grimm (2009), and Kagel and Levin (2009). Panel (b) illustrates a more pronounced overbidding tendency for the first unit, whereas Panel (c) indicates that this tendency is weaker for the second unit. HRnohint, which excludes the human interaction present in HHnohint, exhibits a tendency similar to HHnohint. This implies that even without the impact of human interaction, such as strategic interaction and social preference, many subjects overbid, and few bid sincerely. As summarized in Subsection 3.2, most subjects have a good understanding of Vickrey auction rules. Thus, most subjects in HHnohint and HRnohint overbid, although they have a good understanding of Vickrey auction rules.

[10] We asked subjects how they bid in the auction through a post-experimental survey. We confirmed that there is a positive correlation between their reported bidding behavior in the survey and their actual bidding behavior in the experiments. This suggests that subjects honestly reported their bidding strategies in the survey. For detailed results from the post-experimental survey, please refer to Online Appendix A.

Figure 7: Scatter plots between bids and valuation in Periods 1–10 and 11–20 by treatment and units

(a) Unit 1



(b) Unit 2

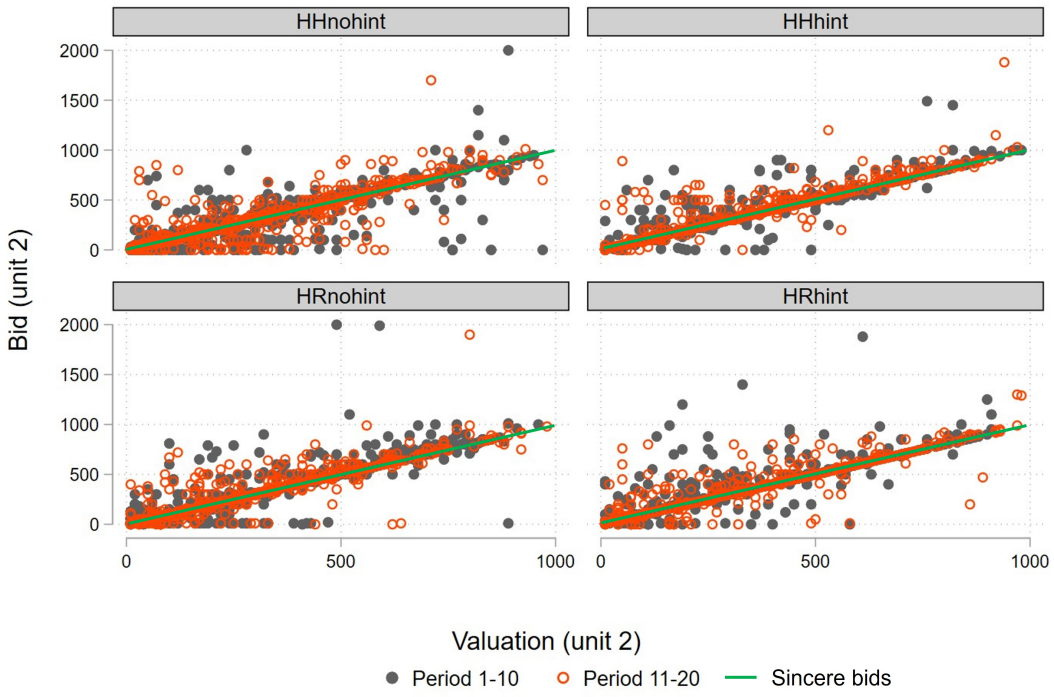
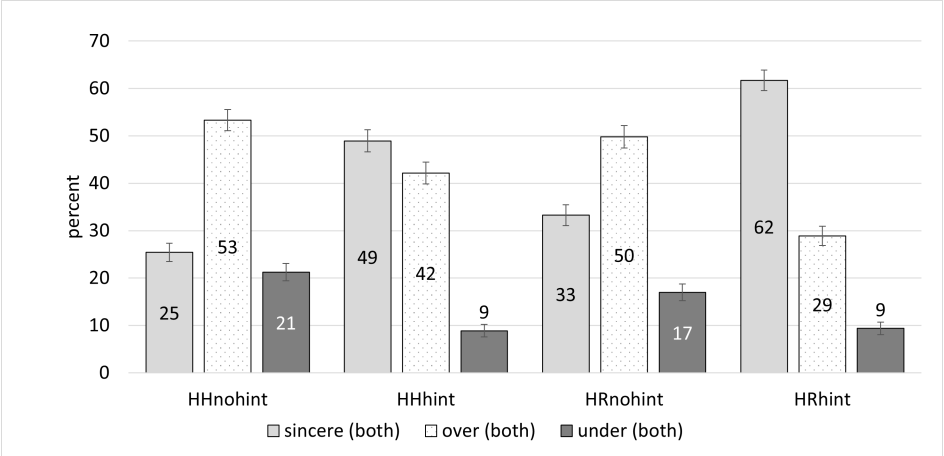
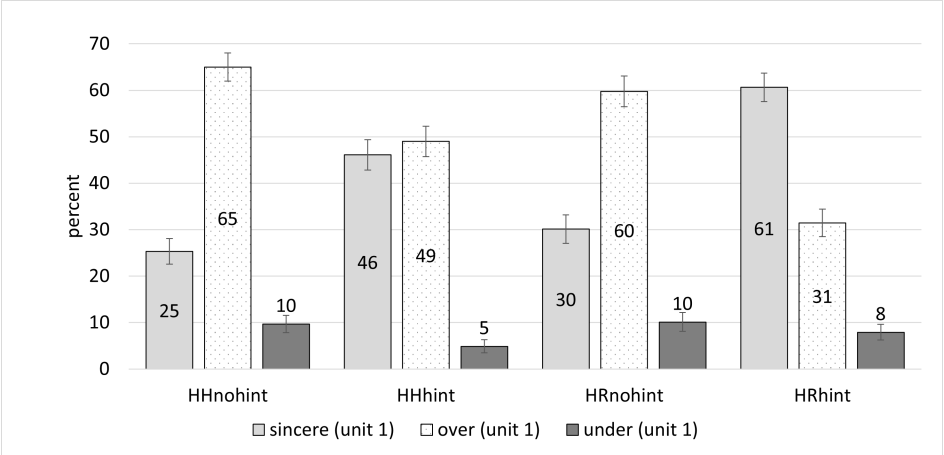


Figure 8: Bid category by treatments and units

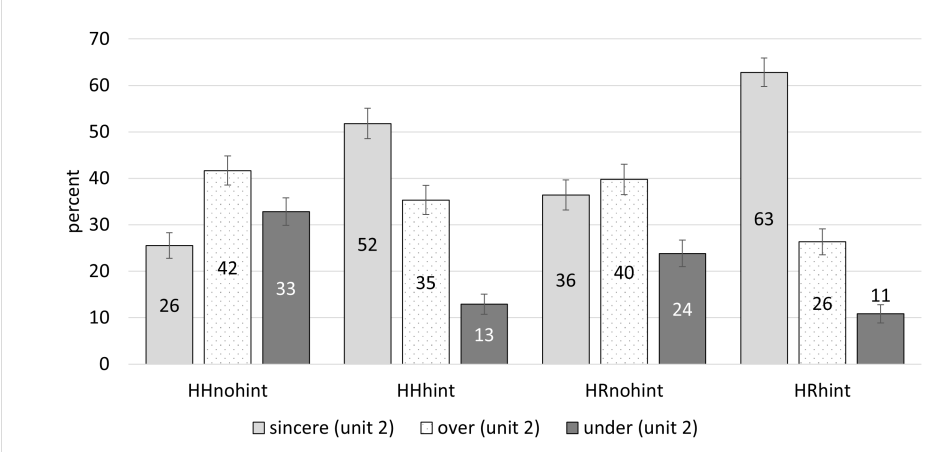
(a) Both units



(b) Unit 1



(c) Unit 2



Notes: The error bars correspond to the 95% confidence interval.

In summary, in the absence of hints about SP, subjects tend to overbid in the Vickrey auction, even when most of them have a good comprehension of Vickrey auction rules, and factors such as strategic interaction and social preference are removed. Thus, overbidding in Vickrey auctions cannot be solely attributed to insufficient comprehension of auction rules or human interaction.

However, the bidding tendencies of HHhint and HRhint differ. This implies that the hints about SP influenced the subjects' bidding behavior. In Subsection 3.4, we statistically examine this effect.

3.4 Effect of hint on strategy-proofness

Table 2 summarizes the sincere bidding rates for (i) all subjects, (ii) subjects with perfect scores in Quiz 2, and (iii) subjects with imperfect scores in Quiz 2 in each treatment. First, to assess whether SP hints have a significant impact on the sincere bid rate, we conducted statistical tests, specifically two-sample t-tests. The summarized findings are as follows:

Result 1 (*Effect of hints about SP*)
(i) Hints about SP significantly increase sincere bids in Vickrey auctions when considering data from both units. The mean increase is 23.528% from HHnohint to HHhint (95% confidence interval, 20.518% to 26.537%).
(ii) The effectiveness of hints persists in HHnohint and HHhint, even when focusing solely on subjects with perfect scores or those with imperfect scores.

Support. To establish (i), Hypothesis 1 is rejected at $p < 0.001$. To establish (ii), we analyze data separately for subjects with perfect and imperfect scores in Quiz 2. For (ii), Hypothesis 1 is rejected at $p < 0.001$ for subjects with perfect and imperfect scores.

Result 2 (*Effect of hints about SP with robot rivals*)
(i) In environments with no human interaction (HRnohint and HRhint), hints about SP are effective when considering data from both units. The mean increase is 28.463% from HRnohint to HRhint (95% confidence interval, 25.344% to 31.582%).

(ii) Hints are effective when focusing only on the data of subjects with perfect scores. However, the hints become ineffective and even decrease sincere bids when focusing only on data of subjects with imperfect scores.

Support. We first establish (i). Thus, Hypothesis 2 is rejected at $p < 0.001$. Regarding (ii), Hypothesis 2 is rejected at $p < 0.001$ regarding subjects with perfect scores. Nevertheless, it is rejected at $p < 0.05$ in a direction that is different from what we expected regarding subjects with imperfect scores.

The results indicate that subjects provided with SP hints via Quiz 2 w/ hints have significantly higher rates of sincere bidding. This suggests that understanding SP is an important factor in sincere bidding. We postulate that the subjects achieving perfect scores in Quiz 2 w/ hints possess a better understanding of SP, resulting in higher rates of sincere bids compared to those with imperfect scores. This postulation was statistically tested. In HHhint, subjects with perfect scores in Quiz 2 w/ hints submit sincere bids more frequently than those with imperfect scores across all data points for both units. The mean increase is 10.392% (95% confidence interval, 5.420% to 15.363%). Similarly, in HRhint, even in the absence of human interaction, perfect scores have a significant impact on the rate of sincere bids. Using all data from both units, the mean increase is 58.544% (95% confidence interval, 54.078% to 63.011%). These results further support our hypothesis that understanding SP is an important factor in sincere bidding.

3.5 Effect of human interaction

Based on the data presented in Table 2, we analyze the effects of human interaction. We summarize our findings on human interaction as follows:

Result 3 (*Effect of Human interaction*)
(i) Removing human interaction increases the sincere bid rate in Vickrey auctions when no hints about SP are provided. This is based on the dataset for both units. The mean increase from HHnohint to HRnohint is 7.839% (95% confidence interval, 4.892% to 10.786%).
(ii) When hints about SP are provided, removing human interaction leads to an increase

Table 2: Sincere bidding rates by treatment, Quiz 2 scores, and unit

Treatments	(1) HHnohint		(2) HHhint	(3) HRnohint		(4) HRhint	(3) − (1)	(4) − (2)
(a)Both units								
All	0.254	<***	0.489	0.333	<***	0.617	0.078***	0.128***
(S.E.)	(0.010)		(0.012)	(0.011)		(0.011)		
obs.	1920		1800	1720		1920		
Perfect score	0.249	<***	0.522	0.339	<***	0.751	0.089***	0.230***
(S.E.)	(0.011)		(0.014)	(0.012)		(0.011)		
obs.	1640		1240	1600		1480		
	∧		∨***	∨**		∨***		
Imperfect score	0.282	<***	0.418	0.250	>**	0.166	−0.032	−0.252***
(S.E.)	(0.027)		(0.021)	(0.040)		(0.018)		
obs.	280		560	120		440		
(b)Unit 1								
All	0.253	<***	0.461	0.301	<***	0.606	0.048**	0.145***
(S.E.)	(0.014)		(0.017)	(0.016)		(0.016)		
obs.	960		900	860		960		
Perfect score	0.248	<***	0.508	0.295	<***	0.736	0.047**	0.228***
(S.E.)	(0.015)		(0.020)	(0.016)		(0.016)		
obs.	820		620	800		740		
	∧		∨***	∧		∨***		
Imperfect score	0.286	<	0.357	0.383	>***	0.168	0.098	−0.189***
(S.E)	(0.038)		(0.029)	(0.063)		(0.025)		
obs.	140		280	60		220		
(c)Unit 2								
All	0.255	<***	0.518	0.364	<***	0.628	0.109***	0.110***
(S.E.)	(0.014)		(0.017)	(0.016)		(0.016)		
obs.	960		900	860		960		
Perfect score	0.251	<***	0.535	0.383	<***	0.766	0.131***	0.231***
(S.E)	(0.015)		(0.020)	(0.017)		(0.016)		
obs.	820		620	800		740		
	∧		∨	∨***		∨***		
Imperfect score	0.279	<***	0.479	0.117	<	0.164	−0.162**	−0.315***
(S.E)	(0.038)		(0.030)	(0.042)		(0.025)		
obs.	140		280	60		220		

Notes: a) In HHnohint, subjects compete against human rivals and take Quiz 2 w/o hints. In HHhint, subjects compete against human rivals and take Quiz 2 w/ hints. In HRnohint, subjects compete against robot rivals and take Quiz 2 w/o hints. In HRhint, subjects compete against robot rivals and take Quiz 2 w/ hints. b) We compare the sincere bidding rates between treatments using two sample t-tests. c) * ** and *** denote significance at the 10%, 5%, and 1% levels, respectively. d) Numbers in parentheses are standard errors. e) The unit of observations is the decision-making in each period. The total number of observations is the number of subjects × number of periods × number of units in each treatment.

in the sincere bid rate in Vickrey auctions, again based on the dataset for both units. The mean increase from HHhint to HRhint is 12.774% (95% confidence interval, 9.604% to 15.945%).

(iii) Eliminating human interaction results in an increased rate of sincere bids in Vickrey auctions. However, this increase is only observed in the data from subjects who achieved perfect scores in either Quiz 2 w/o hints or Quiz 2 w/ hints. No such increase is observed when analyzing the data from subjects who scored imperfectly in either quiz.

Support. We first establish (i) and (ii): Hypotheses 3a and 3b are rejected at $p < 0.001$. Regarding (iii), Hypotheses 3a and 3b are rejected at $p < 0.001$ for the data of subjects with perfect scores. For the subjects with imperfect quiz scores, Hypothesis 3a is supported. Hypothesis 3b is rejected at $p < 0.001$ in a direction that is different from our expectations.

The results in this subsection imply that human interaction is also a non-negligible factor in sincere bidding. In particular, human interactions and understanding SP affect the rate of sincere bidding. Thus, our findings suggest that various factors, including human interactions and differing levels of understanding SP, cause insincere bidding in Vickrey auctions.

3.6 Learning Effect

Table 3 summarizes the sincere bidding rates for (i) the first round, (ii) the first ten rounds, and (iii) the last ten rounds of each treatment. We statistically test whether SP hints increase the sincere bid rate during the first period by conducting two sample t-tests.

Result 4 (*First period*)

(i) Hints about SP increase the sincere bids in the Vickrey auctions in the first period. The mean increase is 25.000% from HHnohint to HHhint (95% confidence interval, 11.419% to 38.581%).

(ii) In environments with no human interaction (i.e., in HRnohint and HRhint), hints about SP are effective in the first period. The mean increase is 31.347% from HRnohint to HRhint (95% confidence interval, 17.417% to 45.277%).

(iii) Hints are effective when focusing only on the data of the subjects with perfect scores. However, they are ineffective when focusing only on subjects with imperfect scores.

The results indicate that subjects provided with SP hints via Quiz 2 w/ hints have significantly higher rates of sincere bidding in the first period. This suggests that an understanding of SP is an important factor in sincere bidding, even if the bidders do not have much experience with auctions.

We use two-sample t-tests to statistically test whether learning leads to increased sincere bid rates by comparing the rates between the first and last 10 periods.

Result 5 (*Learning effect*)

(i) There is no significant difference in sincere bidding rates between the first and last 10 periods in all treatments ($p = 0.463$ for HHnohint; $p = 0.962$ for HHhint; $p = 0.357$ for HRnohint; $p = 0.241$ for HRhint).

(ii) Focusing only on the data of the subjects with perfect scores, there is no significant difference in sincere bidding rates between the first and last 10 periods in HHnohint ($p = 0.530$), HHhint ($p = 0.776$) and HRnohint ($p = 0.342$). There is a 10% significant difference in HRhint.

(iii) Focusing only on the data of the subjects with imperfect scores, there is no significant difference in sincere bidding rates between the first and last 10 periods in all treatments ($p = 0.692$ for HHnohint; $p = 0.608$ for HHhint; $p = 1.000$ for HRnohint; $p = 0.701$ for HRhint).

The results indicate that the subjects do not increase their sincere bidding over time. This suggests that while an understanding of SP is an important factor in sincere bidding, learning does not effectively increase sincere bidding rates.

3.7 Regression analysis of sincere bidding

We conducted a logistic regression analysis to examine the treatment effect on sincere bidding. The analysis uses a sincere bidding dummy variable as the dependent variable, which takes the value of 1 if the subject bids sincerely in a given period and 0 otherwise. The independent variables include an SP hint dummy (SP hint), which is set to 1 for

Table 3: Sincere bidding rates of both units by treatment, Quiz 2 scores and periods

Treatments	(1) HHnohint		(2) HHhint		(3) HRnohint		(4) HRhint	(3) − (1)	(4) − (2)
(a) Period 1									
All	0.250	<***	0.500	<***	0.291	<***	0.604	0.041	0.104
(S.E.)	(0.044)		(0.053)		(0.049)		(0.050)		
obs.	96		90		86		96		
Perfect score	0.244	<***	0.532	<***	0.288	<***	0.716	0.044	0.184**
(S.E.)	(0.048)		(0.064)		(0.051)		(0.053)		
obs.	82		62		80		74		
	∧		∨		∨		∨***		
Imperfect score	0.286	<	0.429		0.333	>	0.227	−0.048	−0.201
(S.E.)	(0.125)		(0.095)		(0.211)		(0.091)		
obs.	14		28		6		22		
(b) Former 10 periods									
All	0.247	<***	0.489	<***	0.322	<***	0.604	0.075***	0.115***
(S.E.)	(0.014)		(0.017)		(0.016)		(0.016)		
obs.	960		900		860		960		
Perfect score	0.243	<***	0.526	<***	0.328	<***	0.732	0.085***	0.207***
(S.E.)	(0.015)		(0.020)		(0.017)		(0.016)		
obs.	820		620		800		740		
	∧		∨***		∨		∨***		
Imperfect score	0.271	<***	0.407		0.250	>	0.173	−0.021	−0.234***
(S.E.)	(0.038)		(0.029)		(0.056)		(0.026)		
obs.	140		280		60		220		
(c) Latter 10 periods									
All	0.261	<***	0.490	<***	0.343	<***	0.630	0.082***	0.140***
(S.E.)	(0.014)		(0.017)		(0.016)		(0.016)		
obs.	960		900		860		960		
Perfect score	0.256	<***	0.518	<***	0.350	<***	0.770	0.094***	0.253***
(S.E.)	(0.015)		(0.020)		(0.017)		(0.015)		
obs.	820		620		800		740		
	∧		∨**		∨		∨***		
Imperfect score	0.293	<	0.429		0.250	>	0.159	−0.043	−0.269***
(S.E)	(0.039)		(0.030)		(0.056)		(0.025)		
obs.	140		280		60		220		

Notes: a) In HHnohint, subjects compete against human rivals and take Quiz 2 w/o hints. In HHhint, subjects compete against human rivals and take Quiz 2 w/ hints. In HRnohint, subjects compete against robot rivals and take Quiz 2 w/o hints. In HRhint, subjects compete against robot rivals and take Quiz 2 w/ hints. b) We compare the sincere bidding rates between treatments using two-sample t-tests. c) * ** and *** denote significance at the 10%, 5%, and 1% levels, respectively. d) Numbers in parentheses are standard errors. e) The unit of observations is the decision-making in each period. The total number of observations is the number of subjects × number of periods × number of units in each treatment.

treatments where Quiz 2 w/ hints is administered to the subjects, and a robot dummy, which is set to 1 for treatments involving robot rivals. We also included a control variable, a perfect score dummy, which takes the value of 1 if subjects achieved a perfect score on Quiz 2, and Period, which ranges from 1 to 20. We clustered the robust standard errors at the individual level. The results of Unit 1, Unit 2, and both units are summarized in Table 4.

The logistic regression results demonstrate that the SP hint dummy has a statistically significant positive impact on sincere bidding—administering Quiz 2 w/ hints enhances sincere bidding. The perfect score dummy also has a significant positive impact on sincere bidding. These results confirm the conclusion drawn in Subsection 3.4 that understanding SP is an important factor in sincere bidding. However, the robot dummy is not statistically significant, indicating that the human interaction factor does not significantly affect sincere bidding. This contradicts the conclusion in Subsection 3.5. In our logistic regression analysis, the human interaction factor is not as robust as the understanding of SP. Additionally, the period variable is not statistically significant, indicating that learning does not significantly affect sincere bidding. This is consistent with the results presented in Subsection 3.6.

Next, we performed a regression analysis to examine the impact of the subjects' performance in Quiz 2, with and without hints, on sincere bidding. We conducted an OLS linear regression, considering average sincere bids for Units 1 and 2, as well as both units collectively, with robust standard errors. The dependent variable is the average rate of sincere bids, which ranges from 0 to 1. The independent variables included the Quiz 2 scores, which range from 0 to 10, and a dummy variable for treatments with robot rivals, referred to as the robot dummy. The results are summarized in Table 5, organized by Quiz 2 type and units.

The results indicate that higher scores in Quiz 2 w/ hints are associated with more frequent sincere bidding in Units 1 and 2, as well as when both units are combined. However, the scores in Quiz 2 w/o hints do not seem to influence the rate of sincere bids. Based on these findings, we suggest that our design of Quiz 2 w/ hints effectively enhances sincere bidding and serves as a reliable method for measuring the level of

Table 4: Regression analysis of treatment dummy on sincere bidding

	Both			Unit 1			Unit 2		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
SP hint	1.034***	1.230***	1.230***	0.926**	1.110***	1.110***	1.142***	1.351***	1.351***
	(0.347)	(0.375)	(0.375)	(0.371)	(0.399)	(0.399)	(0.356)	(0.389)	(0.389)
Robot	0.380	0.320	0.321	0.240	0.181	0.181	0.513	0.454	0.454
	(0.374)	(0.381)	(0.382)	(0.408)	(0.419)	(0.419)	(0.390)	(0.395)	(0.395)
SP hint × Robot	0.140	0.138	0.138	0.347	0.351	0.351	−0.060	−0.067	−0.067
	(0.513)	(0.517)	(0.517)	(0.552)	(0.557)	(0.558)	(0.531)	(0.536)	(0.536)
Perfect score		1.040***	1.040***		1.012**	1.012**		1.071***	1.071***
		(0.370)	(0.370)		(0.402)	(0.402)		(0.378)	(0.378)
Period			0.006			0.008			0.005
			(0.004)			(0.006)			(0.005)
Constant	−1.077***	−1.998***	−2.063***	−1.082***	−1.978***	−2.060***	−1.071***	−2.021***	−2.069***
	(0.262)	(0.457)	(0.457)	(0.270)	(0.479)	(0.482)	(0.270)	(0.472)	(0.471)
Obs.	7,360	7,360	7,360	3,680	3,680	3,680	3,680	3,680	3,680
Cluster	184	184	184	184	184	184	184	184	184
Wald Chi2	20.71	26.58	29.86	18.85	22.74	24.68	20.15	25.82	28.50
Prob > Chi2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes: a) We conducted logit regression on the sincere bidding dummy, considering the SP hint dummy and robot dummy, conditional on the Quiz 2 perfect score dummy, with robust standard errors clustered at the individual level. b) Sincere bidding dummy equals 1 if subjects submitted a sincere bid in a period and 0 otherwise. SP hint dummy equals 1 if subjects take Quiz 2 w/ hints and 0 if they take Quiz 2 w/o hints. Robot dummy equals 1 if subjects compete against robot rivals and 0 if they compete against human rivals. Perfect score equals 1 if subjects get a perfect score in Quiz 2 and 0 otherwise. Period ranges from 1 to 20. c) * ** and *** denote significance at the 10%, 5%, and 1% levels, respectively. d) Numbers in parentheses are standard errors. e) The total number of observations is the number of subjects × number of periods × number of units in each treatment.

Table 5: Regression analysis of Quiz 2 scores on average sincere bids

	w/ hints (HHhint & HRhint)			w/o hints (HHnohint & HRnohint)		
	Both	Unit 1	Unit 2	Both	Unit 1	Unit 2
	(1)	(2)	(3)	(4)	(5)	(6)
Quiz 2 score	0.078***	0.081***	0.076***	0.005	−0.006	0.016
	(0.016)	(0.016)	(0.017)	(0.016)	(0.024)	(0.017)
Robot	0.132	0.150*	0.114	0.078	0.049	0.107
	(0.082)	(0.087)	(0.084)	(0.078)	(0.084)	(0.084)
Constant	−0.230	−0.281*	−0.178	0.205	0.309	0.101
	(0.160)	(0.154)	(0.171)	(0.157)	(0.228)	(0.172)
Obs.	93	93	93	91	91	91
R-squared	0.140	0.137	0.122	0.012	0.004	0.023

Notes: a) We conducted OLS linear regression on the average sincere bids for units 1 and 2, as well as both units collectively, regressed on Quiz 2 scores with robust standard errors. b) Average sincere bids indicate the mean of sincere bidding over 20 periods for each subject, ranging from 0 to 1. Quiz 2 scores range from 0 to 10. Quiz 2 w/ hints scores are used in Model (1-3), and Quiz 2 w/o hints are used in Model (4-6). Robot dummy is 1 if subjects compete against robot rivals and 0 if subjects compete against human rivals. c) * ** and *** denote significance at the 10%, 5%, and 1% levels, respectively. d) Numbers in parentheses are standard errors. e) The total number of observations is the number of subjects in HHhint & HRhint or in HHnohint & HRnohint.

understanding of SP in Vickrey auctions.

The OLS results indicate that higher scores in Quiz 2 w/ hints are associated with more frequent sincere bidding in Units 1 and 2 as well as when both units are combined. Nevertheless, the scores in Quiz 2 w/o hints do not appear to influence the rate of sincere bids. As confirmed in Subsection 3.2, there is no statistical difference in the earnings levels and comprehension levels of the auction rules between Quiz 2 w/ hints and Quiz 2 w/o hints. Thus, these results confirm the conclusion that understanding SP is an important factor in sincere bidding. However, the robot dummy is not statistically significant, except for in Unit 1 of HHhint & HRhint (10%). Similar to the logistic regression analysis, our OLS analysis suggests that the human interaction factor is not as robust as the understanding of SP. Notably, our OLS analysis further indicates that our design of Quiz 2 w/ hints effectively enhances sincere bidding and serves as a reliable method for measuring the level of understanding of SP in Vickrey auctions.

3.8 Ratios of sincere and insincere bidders

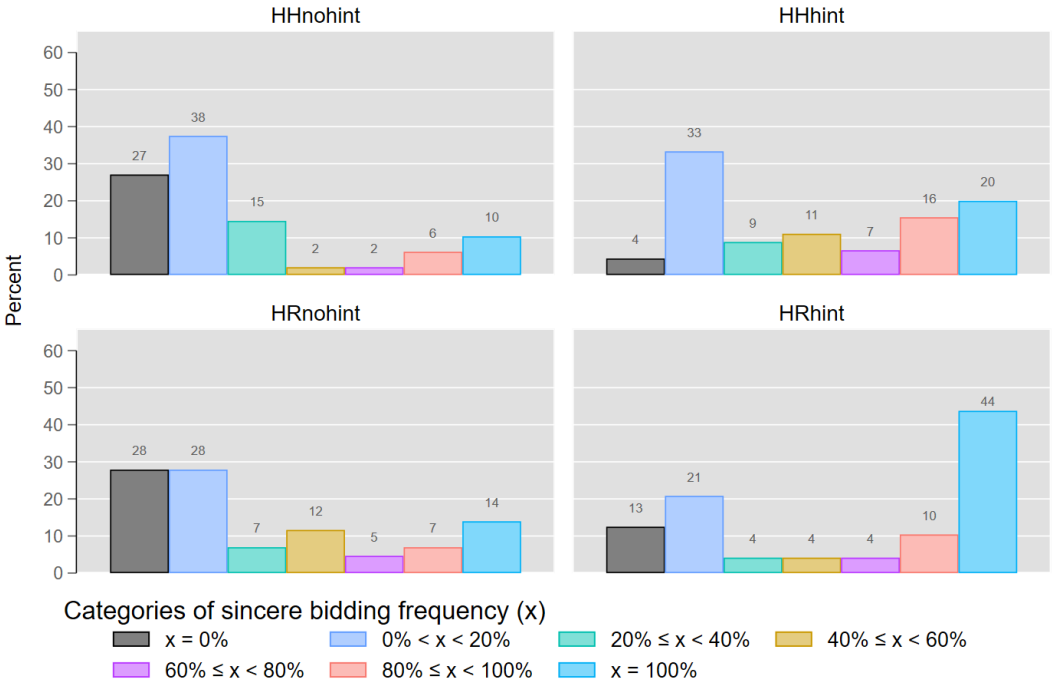
We categorize subjects into the following groups based on their sincere bidding frequencies x specifically: "$x = 0\%$"; "$0\% < x < 20\%$"; "$20\% \leq x < 40\%$"; "$40\% \leq x < 60\%$"; "$60\% \leq x < 80\%$"; "$80\% \leq x < 100\%$"; "$x = 100\%$." Each subject submits 40 bids (i.e., 20 periods $\times$ 2 units per period). For instance, a subject who bids sincerely 20 times is categorized as "$40\% \leq x < 60\%$." Similarly, a subject who bids sincerely 25 times is categorized as "$60\% \leq x < 80\%$." Figure 9 shows the ratios of the subjects who bid sincerely at various frequencies. Figure 9a shows the results for the overall dataset, whereas Figure 9b presents the outcomes for the data of subjects with perfect and imperfect scores in Quiz 2.

Figure 9 illustrates two distribution concentrations. One is the group of subjects whose sincere bidding frequencies are greater than or equal to 80%, and the other is the group of subjects whose sincere bidding frequencies are less than 20%. We call bidders in the first group "sincere bidders" and those in the second group "insincere bidders."[11] Subsequently, we employ a two-sample t-test to compare the ratios of sincere

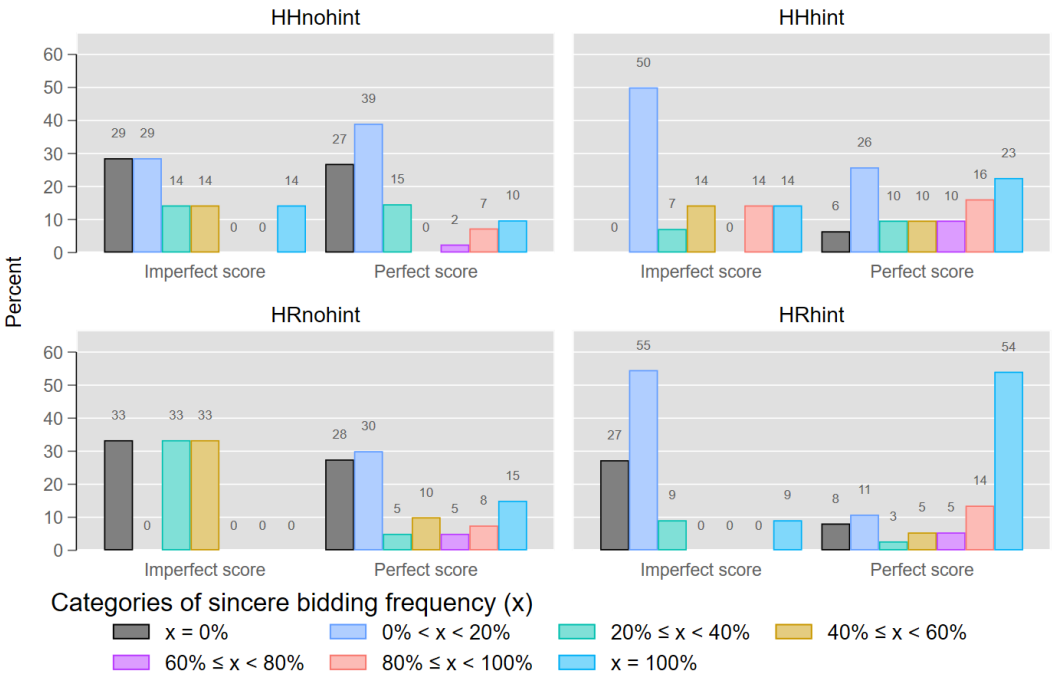
[11] We calculate the correlation between bidder types and Quiz 2 w/ hints scores using the Spearman correlation method. We find a significant positive correlation between "sincere bidders" and Quiz

Figure 9: The ratios of sincere and insincere bidders

(a) Overall



(b) Imperfect score vs Perfect score



and insincere bidders across the treatments.

3.8.1 Sincere bidders

First, we analyze the impact of SP hints on the ratios of sincere bidders. Overall, our findings reveal that the ratios of sincere bidders increases from 17% in HHnohint to 36% in HHhint at the 5% significance level. The ratio increases from 21% in HRnohint to 54% in HRhint at the 1% significance level. For subjects with perfect scores, the ratio increases from 17% in HHnohint to 39% in HHhint at the 5% significance level and from 23% in HRnohint to 68% in HRhint at the 1% significance level. Conversely, for subjects with imperfect scores in Quiz 2, the ratios of sincere bidders remains similar between HHnohint (14%) and HHhint (29%) with no significant difference ($p = 0.494$). Similarly, there is no significant difference between HRnohint (0%) and HRhint (9%) with respect to the ratios of sincere bidders ($p = 0.621$).

Second, we analyze the impact of human interaction on the ratios of sincere bidders. For subjects given Quiz 2 w/o hints, we observe no statistically significant difference in the ratios of sincere bidders between HHnohint and HRnohint in the overall dataset (17% in HHnohint vs 21% in HRnohint, $p = 0.607$), perfect score dataset (17% in HHnohint vs 23% in HRnohint, $p = 0.546$), and imperfect score dataset (14% in HHnohint vs 0% in HRnohint, $p = 0.545$). Nevertheless, when subjects are given Quiz 2 w/ hints, we find a statistically significant increase in the ratios of sincere bidders, from 36% in HHhint to 54% in HRhint, at the 10% significance level. This increase is also pronounced among subjects with perfect scores in Quiz 2, with the ratio increasing significantly from 39% in HHhint to 68% in HRhint at the 5% significance level. Contrarily, no such increase is observed among subjects with imperfect scores in Quiz 2, with the ratio being 29% in HHhint and 9% in HRhint ($p = 0.244$).

In summary, the SP hints exert a positive influence, particularly on subjects with perfect scores, compelling them to bid sincerely frequently. A substantial ratio of these subjects comprises sincere bidders when competing against robot rivals. Conversely, the effects of human interaction are mixed. We observe no significant impact on the ratios

2 w/ hints scores ($\rho = 0.305$, $p < 0.01$) and a negative correlation between "insincere bidders" and Quiz 2 w/ hints scores ($\rho = -0.361$, $p < 0.01$).

of sincere bidders when subjects are given Quiz 2 w/o hints but significant impacts when subjects receive Quiz 2 w/ hints.

3.8.2 Insincere bidders

First, we analyze the impact of SP hints on the ratios of insincere bidders. Overall, our findings reveal that the ratios of insincere bidders decrease from 65% in HHnohint to 38% in HHhint at the 1% significance level. The ratios decrease from 56% in HRnohint to 33% in HRhint at the 5% significance level. For subjects with perfect scores, the ratios decrease from 66% in HHnohint to 32% in HHhint at the 1% significance level and from 58% in HRnohint to 19% in HRhint at the 1% significance level. Conversely, for subjects with imperfect scores in Quiz 2, the ratios of insincere bidders remain similar between HHnohint (57%) and HHhint (50%) with no significant difference ($p = 0.772$) and also between HRnohint (33%) and HRhint (82%) with no significant difference ($p = 0.115$).

Second, we analyze the impact of human interaction on the ratios of insincere bidders. For subjects given Quiz 2 w/o hints, we observe no statistically significant difference in the ratios of insincere bidders between HHnohint and HRnohint in the overall dataset (65% in HHnohint vs 56% in HRnohint, $p = 0.399$), perfect score dataset (66% in HHnohint vs 58% in HRnohint, $p = 0.446$), and imperfect score dataset (57% in HHnohint vs 33% in HRnohint, $p = 0.545$). When subjects are given Quiz 2 w/ hints, we find no statistically significant difference in the ratios of insincere bidders between HHhint and HRhint in the overall dataset (38% in HHhint vs 33% in HRhint, $p = 0.659$), perfect score dataset (32% in HHhint vs 19% in HRhint, $p = 0.211$), and imperfect score dataset (50% in HHhint vs 82% in HRhint, $p = 0.108$).

In summary, the SP hint has a positive impact on reducing the ratio of insincere bidders. However, the factor of human interaction does not influence the ratios of insincere bidders, regardless of whether subjects are given Quiz 2 w/ hints or Quiz 2 w/o hints.

3.8.3 Converting insincere bidders to sincere bidders

The above results imply that SP hint converts a substantial ratio of insincere bidders into sincere bidders. This conversion explains the increase of the sincere bidding rates caused by SP hint, which is reported in Subsection 3.4. Conversely, the above results imply that human interaction does not make such clear conversion. This differs from the results in Subsection 3.5 that human interaction has non-negligible effects on sincere bidding rates but is consistent with results in Subsection 3.7 that the impact of human interaction is not as robust as SP hints.

4 Efficiency, bidders' payoffs, and seller's revenue

4.1 Efficiency measure

We follow Kagel and Levin (2009)'s efficiency measure. For the details of the efficiency measures, please refer to Masuda et al. (2022). In each period, if bidders i and j are, respectively, the winners with the first and second highest bids, then the *efficiency* is given by

$$r = \begin{cases} (v_i^1 + v_j^1) \diagup (v[1] + v[2]) \text{ if } i \neq j \\ (v_i^1 + v_i^2) \diagup (v[1] + v[2]) \text{ if } i = j \end{cases},$$

where $v[1]$ and $v[2]$ denote the two highest valuations among $\{v_1^1, v_1^2, v_2^1, v_2^2, v_3^1, v_3^2\}$.[12]

We apply the above efficiency formula to calculate the efficiencies of HHnohint and HHhint, where the experiments involve only human bidders, which we refer to as *observed efficiency*. In the auctions of HRnohint and HRhint, two of the three bidders are robot bidders, whose bids are automatically generated from a specified probability distribution. It does not make sense to compute efficiency by using the bid data of robot bidders. Thus, to calculate the efficiency of HRnohint and HRhint only for the bid data of human subjects, we conduct simulations as explained in Subsection 4.2. We refer to the simulation results as *simulated efficiency*.

We divide the dataset into two parts: one containing subjects with perfect scores in

[12] It might be the case that $i = j$ when one bidder's two bids are the first and second highest. Ties are broken with equal probability.

Quiz 2 and the other containing subjects with imperfect scores in Quiz 2. Subsequently, we calculate the simulated efficiencies of each part of the data. Thus, we analyze the efficiency when only subjects with perfect scores are matched with each other, as well as when only subjects with imperfect scores are matched.

4.2 Simulation method

In each treatment, let G be the largest integer, such that $3 * G$ is less than or equal to the number of subjects in the treatment group. For example, if the number of subjects in the treatment is 43, as in HRnohint, then $G = 14$ and $3 * G = 42$. For each treatment and each period t of the experiment, we calculate the *simulated* efficiency, *simulated* bidders' payoffs, and *simulated* seller's revenue using the following steps:

Step 1: We randomly draw $3 * G$ subjects from the human subjects in the treatment group and match them into G groups, each of which comprises three subjects. The groups are named $1, \cdots, G$.

Step 2: In each group $g \in \{1, \cdots, G\}$, we have three subjects with valuations of the two units observed in period t, that is, $(v^1_{1gt}, v^2_{1gt}, v^1_{2gt}, v^2_{2gt}, v^1_{3gt}, v^2_{3gt})$. Let $v_{gt}[1]$ and $v_{gt}[2]$ be the first- and second-highest valuations among $\{v^1_{1gt}, v^2_{1gt}, v^1_{2gt}, v^2_{2gt}, v^1_{3gt}, v^2_{3gt}\}$.

Step 3: In each group $g \in \{1, \cdots, G\}$, we also have the submitted bids of the three subjects observed in period t. In other terms, $(b^1_{1gt}, b^2_{1gt}, b^1_{2gt}, b^2_{2gt}, b^1_{3gt}, b^2_{3gt})$. Let bidders i and j be the winners, with the first and second highest bids among $\{b^1_{1gt}, b^2_{1gt}, b^1_{2gt}, b^2_{2gt}, b^1_{3gt}, b^2_{3gt}\}$. Ties are broken with equal probability.

Step 4: In each group $g \in \{1, \cdots, G\}$, we calculate efficiency r_{gt} in period t as follows:

$$r_{gt} = \begin{cases} (v^1_{igt} + v^1_{jgt}) \diagup (v_{gt}[1] + v_{gt}[2]) \text{ if } i \neq j \\ (v^1_{igt} + v^2_{igt}) \diagup (v_{gt}[1] + v_{gt}[2]) \text{ if } i = j \end{cases},$$

We also calculate the bidders' payoffs and seller's revenue from period t.

Step 5: We compute the efficiency averaged across all groups and periods as follows: $r = \frac{1}{G \times 20} \sum_{t=1}^{20} \sum_{g=1}^{G} r_{gt}$. We also compute the mean of the bidders' payoffs and seller's revenue for all groups and periods.

Step 6: We repeat Steps 1–5 1,000 times—we perform bootstrap sampling 1,000 times.

Subsequently, we obtain the efficiency, the bidders' payoffs, and the seller's revenue for each bootstrap sample $B = 1, 2, 3, ..., 1,000$, where B is the bootstrap sampling index.

Step 7: We calculate simulated efficiency, which is the the mean efficiency of all bootstrap sampling by $\frac{1}{1,000}\sum_{B=1}^{1,000} r_B$, and its bootstrapped standard error by taking the mean of standard errors of each bootstrap sample. We then similarly calculate the simulated bidders' payoffs, the simulated seller's revenue, and their bootstrapped standard errors.

4.3 Efficiency: observed and simulated

Table 6 summarizes the results for the observed and simulated efficiencies. Overall, the observed efficiency is higher for HHhint (0.992), where subjects are given Quiz 2 w/ hints compared to HHnohint (0.984). The simulated efficiencies of HHnohint (0.982) and HHhint (0.991) exhibit similar trends. The simulated efficiencies in HRnohint (0.983) and HRhint (0.982) are closer, although the difference is statistically significant at the 1% level.

For the dataset of subjects with perfect scores in Quiz 2, the simulated efficiencies are higher when Quiz 2 w/ hints is taken than when Quiz 2 w/o hints is taken—higher in HHhint (0.991) than in HHnohint (0.984) and higher in HRhint (0.993) than in HRnohint (0.983). This implies that SP hints consistently increase the efficiency of subjects with perfect scores in Quiz 2.

Conversely, for subjects with imperfect scores in Quiz 2, while the simulated efficiency in HHhint (0.988) is higher than that in HHnohint (0.970), it is lower in HRhint (0.951) than in HRnohint (0.990). In particular, simulated efficiency in HRhint is notably low, which accounts for the overall low simulated efficiency of all subjects in HRhint.

4.4 Bidder's payoff and seller's revenue: observed and simulated

Table 7 summarizes the results for observed bidders' payoffs and sellers' revenues and simulated bidders' payoffs and sellers' revenue. Overall, the observed bidders' payoffs are higher in HHhint (152.044) than in HHnohint (143.490), although the difference is not statistically significant.

For the simulation results, the impact of SP hints on the simulated bidders' payoffs

Table 6: Efficiency by treatment and Quiz 2 scores: observed and simulated

Treatments	(1) HHnohint		(2) HHhint	(3) HRnohint		(4) HRhint	(3) − (1)	(4) − (2)
Observed efficiency								
All	0.984	$<^{**}$	0.992					
	(0.003)		(0.002)					
obs.	320		300					
Simulated efficiency								
All	0.982	$<^{***}$	0.991	0.983	$>^{***}$	0.982	0.001^{***}	-0.008^{***}
	(0.002)		(0.001)	(0.002)		(0.002)		
obs.	320,000		300,000	280,000		320,000		
Perfect Score	0.984	$<^{***}$	0.991	0.983	$<^{***}$	0.993	-0.002^{***}	0.002^{***}
	(0.002)		(0.001)	(0.002)		(0.001)		
obs.	260,000		200,000	260,000		240,000		
Imperfect Score	0.970	$<^{***}$	0.988	0.990	$>^{***}$	0.951	0.019^{***}	-0.037^{***}
	(0.002)		(0.001)	(0.001)		(0.003)		
obs.	40,000		80,000	20,000		60,000		

Notes: a) We compare the observed and simulated efficiencies between treatments using two-sample t-tests. b) * ** and *** denote significance at the 10%, 5%, and 1% levels, respectively. c) Numbers in parentheses are standard errors for efficiency and bootstrapped standard errors for simulated efficiency. d) For efficiency, the total number of observations is the number of groups × 20 periods in each treatment. For simulated efficiency, the number of observations is the number of simulated groups in each treatment × 20 periods × 1,000 bootstraps.

are mixed. When their rivals are humans, subjects who take Quiz 2 w/ hints receive lower payoffs in HHhint (145.385) than those who take Quiz 2 w/o hints in HHnohint (147.785). However, this trend is reversed when the rivals are robots in HRnohint (139.638) and HRhint (148.560).

When we divide the subjects based on their Quiz 2 scores, different patterns are found. Subjects with perfect scores in Quiz 2 w/ hints earn higher payoffs (143.745 in HHhint; 162.900 in HRhint) than those with perfect scores in Quiz 2 w/o hints (142.690 in HHnohint; 139.536 in HRnohint), irrespective of whether they face human or robot rivals. Conversely, subjects with imperfect scores experience reversed outcomes and receive low payoffs (100.679) in HRhint.

Overall, the observed seller's revenue is higher in HHhint (1117.333) than in HHnohint (1098.531), although the difference is not statistically significant. For the simulation results, the impacts of SP hints on the simulated seller's revenue are mixed, and the patterns are reversed for bidders' payoffs. In other words, SP hints increase simulated seller's revenue when bidders face human rivals (1085.880 in HHnohint vs 1129.619 in

Table 7: Bidder's payoffs and seller's revenues by treatment and Quiz 2 Score: observed and simulated

Treatments	(1) HHnohint		(2) HHhint	(3) HRnohint		(4) HRhint	(3) − (1)	(4) − (2)
Observed bidder's payoff								
All	143.490	<	152.044					
	(6.032)		(5.467)					
obs.	320		300					
Simulated bidder's payoff								
All	147.785	>***	145.385	139.638	<***	148.560	−8.148***	3.175***
	(3.392)		(3.074)	(3.326)		(3.302)		
obs.	320,000		300,000	280,000		320,000		
Perfect score	142.690	<***	143.745	139.536	<***	162.900	−3.154***	19.155***
	(3.353)		(2.970)	(3.360)		(3.021)		
obs.	260,000		200,000	260,000		240,000		
Imperfect score	169.884	>***	147.427	132.833	>***	100.679	−37.051***	−46.748***
	(3.551)		(3.342)	(3.006)		(3.888)		
obs.	40,000		80,000	20,000		60,000		
Observed seller's revenue								
All	1098.531	<	1117.333					
	(21.298)		20.620					
obs.	320		300					
Simulated seller's revenue								
All	1085.880	<***	1129.619	1127.693	>***	1092.384	41.813***	−37.234***
	(12.029)		(11.253)	(12.239)		(11.281)		
obs.	320,000		300,000	280,000		320,000		
Perfect score	1099.216	<***	1144.788	1131.434	>***	1070.032	32.217***	−74.756***
	(12.042)		(10.982)	(12.277)		(10.977)		
obs.	260,000		200,000	260,000		240,000		
Imperfect score	1021.469	<***	1098.884	1079.000	<***	1168.208	57.531***	70.325***
	(12.320)		(11.764)	(13.826)		(11.959)		
obs.	40,000		80,000	20,000		60,000		

Notes: a) We compare the bidder's payoff, simulated bidder's payoff, seller's revenue, and simulated seller's revenue between treatments using two-sample t-tests. b) * ** and *** denote significance at the 10%, 5%, and 1% levels, respectively. c) Numbers in parentheses are standard errors for efficiency and bootstrapped standard errors for simulated efficiency. d) For bidder's payoff and seller's revenue, the total number of observations is the number of groups × 20 periods in each treatment. For simulated bidder's payoff and simulated seller's revenue, the number of observations is the number of simulated groups in each treatment × 20 periods × 1,000 bootstraps.

HHhint) but decrease when bidders face robot rivals (1127.693 in HRnohint vs 1092.384 in HRhint). When focusing on subjects with perfect scores, we observe the same pattern as the overall simulated seller's revenue. Conversely, when focusing on subjects with imperfect scores, SP hints lead to increased simulated seller's revenue, regardless of whether the rivals are human or robot bidders.

5 Conclusion

In our experiment, we focused on two key factors that influence sincere bidding in homogeneous multi-unit Vickrey auctions: the subjects' understanding of SP and human interaction, which includes social preferences (spite and altruism), responses to strategic uncertainty, and tacit collusion. To analyze the effect of understanding SP, we compared the bidding behavior of subjects who took a quiz with SP hints and those who took a quiz without SP hints. To analyze the effect of human interaction, we compared the bidding behavior of subjects competing against robot rivals and those competing against human rivals. Our study demonstrates that a better understanding of SP is a crucial and strong driver of sincere bids. Conversely, although human interaction had a non-negligible impact, it did not have as much influence as the understanding of SP. This led us to conclude that the main factor causing insincere bidding was not human interaction but a lack of understanding of the concept of SP.

We raise several questions for future research. First, is the difficulty in understanding SP confined to Vickrey auctions, or is it a broader issue applicable to other types of auctions? As discussed in Section 1, several researchers have offered insights based on their experiments in which they aid subjects in recognizing SP. Recently, Gonczarowski et al. (2023) proposed menu descriptions of mechanisms to enable subjects to understand SP more easily. Second, what are the most effective ways to educate subjects about SP to encourage more sincere bidding?

In summary, our study contributes new insights to existing research on Vickrey auctions by focusing on the factors that lead to insincere bidding. Our findings highlight the importance of understanding SP as a key determinant of sincere bidding. This lays the groundwork for future research to delve deeper into the causes of insincere bidding

and paves the way for targeted educational and design solutions that encourage more sincere bidding practices in auctions.

References

Andreoni, J., Y.-K. Che, and J. Kim (2007): "Asymmetric information about rivals' types in standard auctions: An experiment," *Games and Economic Behavior*, 59, 240–259.

Chen, Y., and K. Takeuchi (2010): "Multi-object auctions with package bidding: An experimental comparison of Vickrey and iBEA," *Games and Economic Behavior*, 68, 557–579.

Cooper, D. J., and H. Fang (2008): "Understanding overbidding in second price auctions: An experimental study," *The Economic Journal*, 118, 1572–1595.

Corgnet, B., R. Hernán-González, P. Kujal, and D. Porter (2015): "The effect of earned versus house money on price bubble formation in experimental asset markets," *Review of finance*, 19, 1455–1488.

Ding, T., and A. Schotter (2019): "Learning and mechanism design: An experimental test of school matching mechanisms with intergenerational advice," *The Economic Journal*, 129, 2779–2804.

Garratt, R. J., M. Walker, and J. Wooders (2012): "Behavior in second-price auctions by highly experienced eBay buyers and sellers," *Experimental Economics*, 15, 44–57.

Georganas, S., D. Levin, and P. McGee (2017): "Optimistic irrationality and overbidding in private value auctions," *Experimental Economics*, 20, 772–792.

Gonczarowski, Y. A., O. Heffetz, and C. Thomas (2023): "Strategyproofness-exposing mechanism descriptions,"Technical report, National Bureau of Economic Research.

Guillen, P., and R. Hakimov (2018): "The effectiveness of top-down advice in strategy-proof mechanisms: A field experiment," *European Economic Review*, 101, 505–511.

Guillen, P., and A. Hing (2014): "Lying through their teeth: Third party advice and truth telling in a strategy proof mechanism," *European Economic Review*, 70, 178–185.

Hassidim, A., D. Marciano, A. Romm, and R. I. Shorrer (2017): "The mechanism is truthful, why aren't you?" *American Economic Review*, 107, 220–224.

Kagel, J. H., and D. Levin (1993): "Independent private value auctions: Bidder behaviour in first-, second-and third-price auctions with varying numbers of bidders," *The Economic Journal*, 103, 868–879.

——— (2001): "Behavior in multi-unit demand auctions: experiments with uniform price and dynamic Vickrey auctions," *Econometrica*, 69, 413–454.

——— (2009): "Implementing efficient multi-object auction institutions: An experimental study of the performance of boundedly rational agents," *Games and Economic Behavior*, 66, 221–237.

Kawagoe, T., and T. Mori (2001): "Can the pivotal mechanism induce truth-telling? An experimental study," *Public Choice*, 108, 331–354.

Li, S. (2017): "Obviously strategy-proof mechanisms," *American Economic Review*, 107, 3257–3287.

Manelli, A. M., M. Sefton, and B. S. Wilner (2006): "Multi-unit auctions: A comparison of static and dynamic mechanisms," *Journal of Economic Behavior & Organization*, 61, 304–323.

Masuda, T., R. Mikami, T. Sakai, S. Serizawa, and T. Wakayama (2022): "The net effect of advice on strategy-proof mechanisms: an experiment for the Vickrey auction," *Experimental Economics*, 25, 902–941.

Nishimura, N., T. N. Cason, T. Saijo, and Y. Ikeda (2011): "Spite and reciprocity in auctions," *Games*, 2, 365–411.

Shogren, J. F., G. M. Parkhurst, and C. McIntosh (2006): "Second-price auction tournament," *Economics Letters*, 92, 99–107.

Vickrey, W. (1961): "Counterspeculation, auctions, and competitive sealed tenders," *The Journal of finance*, 16, 8–37.

Yamakawa, T., Y. Okano, and T. Saijo (2016): "Detecting motives for cooperation in public goods experiments," *Experimental Economics*, 19, 500–512.

Zizzo, D. J. (2010): "Experimenter demand effects in economic experiments," *Experimental Economics*, 13, 75–98.

Online Appendix to "Toward an Understanding of Insincere Bidding in a Vickrey Auction Experiment"

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Contents

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A How did subjects bid in the auction, and why?

Based on Questions 5 and 6 of our post-experimental survey, we examine subjects' bidding policies in the auction and the motivations for their policies. Question 5 is about the subjects' bidding policies. It asks, "How did you bid in the auction?" subjects chose one of four answers:

(a) Bid the amount of valuation

(b) Bid higher than valuation

(c) Bid lower than valuation

(d) Other

Table A1: Survey of bidding policies (Question 5)

Treatments	HHnohint	HHhint	HRnohint	HRhint
Proportion of selection of choice (a)	27%	40%	35%	60%
Average sincere bid rates among subjects who select choice (a)	0.642	0.864	0.81	0.947
Proportion of selection of choice (b)	46%	51%	44%	27%
Average overbid rates among subjects who select choice (b)	0.814	0.682	0.754	0.808
Proportion of selection of choice (c)	4%	0%	5%	6%
Average underbid rates among subjects who select choice (c)	0.4		0.938	0.758
Proportion of selection of choice (d)	23%	9%	16%	6%
obs.	48	45	43	48

Notes: The number of observations is that of subjects in each treatment.

Table A1 summarizes the proportion of subjects selecting each answer in survey question 5 and their average sincere bid rates, overbid rates, and underbid rates. We report the correlation between "Choice (a) Bid the amount of valuation" and the average sincere bid rates using pairwise correlation analyses, specifically the Spearman correlation method. We find a significant correlation between "Choice (a)" and the average sincere bid rates obtained in the experiments ($\rho = 0.793$, $p < 0.01$). Additionally, using the Spearman correlation method, we find significant correlations between "Choice (b)" and the average overbid rates ($\rho = 0.735$, $p < 0.01$), as well as between "Choice (c)" and the average underbid rates ($\rho = 0.302$, $p < 0.01$). Therefore, we conclude that most subjects are likely to report their bidding policies honestly.

Question 6 concerns the motivations of subjects' bidding policies. It asks subjects why they bid as they did in Question 5, and subjects choose one of four answers:

(a) To maximize your earnings in the auction

(b) To maximize your winning probability rather than to maximize your earnings in the auction

(c) To make the earnings of other bidders smaller

(d) To make the earnings of other bidders larger

(e) Other

Choice (a) corresponds to the motivation assumed by standard auction theory. Choice (b) corresponds to the joy of winning (Cooper & Fang, 2008). Choices (c) and (d), respectively, correspond to social preferences of spite and altruism.

Table A2 summarizes the proportion of subjects selecting each choice in Question 6. The proportion of subjects selecting (a) was approximately half for each treatment. Moreover, the proportion of subjects who chose option (b) was approximately one-third for each treatment. These violations of the fundamental assumptions of auction theory may have caused insincere bidding. However, only a few subjects reported social preferences for spite and altruism. Thus, such social preferences may have had a limited impact on inducing insincere bidding.

Table A2: Survey of motivations of bidding policies (Question 6)

Treatments	HHnohint	HHhint	HRnohint	HRhint
Proportion of selection of choice (a)	48%	64%	58%	65%
Proportion of selection of choice (b)	33%	31%	28%	25%
Proportion of selection of choice (c)	2%	2%	5%	0%
Proportion of selection of choice (d)	0%	0%	0%	2%
Proportion of selection of choice (e)	17%	2%	9%	8%
obs.	48	45	43	48

We found that 21% of the subjects in HHnohint, 38% in HHhint, 28% in HRnohint, and 52% in HRhint chose (a) for Questions 5 and 6. These subjects understood that a sincere bidding strategy could maximize their earnings. The introduction of SP hints (Quiz 2 w/ hints about SP) led to an increase in the proportion of such subjects. This aligns with the results presented in Section 3. We also found that 29% of subjects in HHnohint, 29% in HHhint, 26% in HRnohint, and 19% in HRhint chose (b) for Questions

5 and 6. The objective of these subjects was to win the auction instead of maximizing payoffs, and indeed, they did so. Thus, these data reveal that the joy of winning (Cooper & Fang, 2008) is also an important factor in insincere bidding. SP hints (Quiz 2 w/ hints about SP) did not decrease the proportion of such subjects.

Notably, 13% of the subjects in HHnohint, 20% in HHhint, 16% in HRnohint, and 6% in HRhint chose (b) for Question 5 and (a) for Question 6. These subjects assumed that overbidding could maximize their earnings—they failed to understand SP. The average scores for Quiz 2 of these subjects were 10 in HHnohint, 8.2 in HHhint, 10 in HRnohint, and 8 in HRhint. The proportions of these subjects who got perfect scores in Quiz 2 are 100% in HHnohint, 56% in HHhint, 100% in HRnohint, and 33% in HRhint. These data suggest that subjects who misunderstood SP and believed that overbidding could maximize their earnings tended to score low in Quiz 2 w/ hints. Additionally, only a few subjects achieved a perfect score.

B Advice effect

Masuda et al. (2022) demonstrated that providing advice to subjects can increase the rate of sincere bidding from 20% to 47%. In their study, they assessed subjects' comprehension of Vickrey auction rules through a quiz similar to Quiz 1 in our study; however, their quiz did not measure or aim to enhance subjects' understanding of SP. To investigate the effects of advice in our experimental environment, we designed two additional treatments. These two treatments follow the design of HHhint and HRhint, both of which include administering Quiz 2 w/ hints to subjects and providing them with the same advice used in the study by Masuda et al. (2022). In other words, we perform the following additional treatments:

- Treatment HHhintA: only human subjects competed, and each subject was given Quiz 2 with SP hints and advice
- Treatment HRhintA: each subject competed with two robot rivals and was given Quiz 2 with SP hints and advice

Figure B1 illustrates the flow of the experiments in HHhintA and HRhintA. The procedure for these experiments closely resembles that of HHhint and HRhint, with one exception. After the subjects completed Quiz 2 with hints and listened to an audio explanation of the answer key, we distributed a paper containing the written advice. The text of the advice is as follows:

> "The following advice is about the auction in which you are participating. Please consider carefully whether this advice is true or false. It is completely up to you whether you follow the advice or not."

You can maximize your earnings by bidding your valuations as they are, regardless of what others bid.

Subsequently, the subjects listened to an audio recording of this advice.

Figure B1: Flow of the experiment

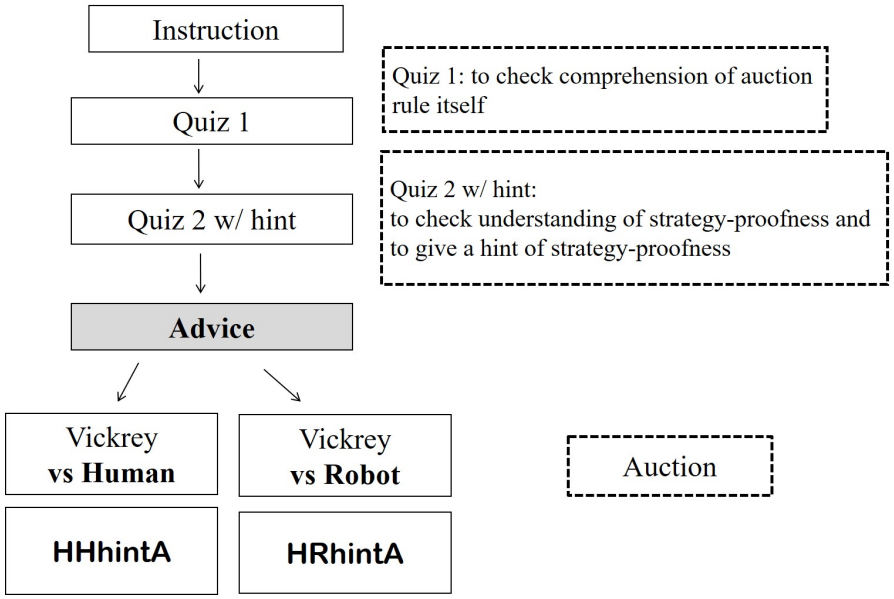

Table B1: Summary of treatments

Treatments	HHhintA	HRhintA
Type of Quiz 2	w/ hints	w/ hints
Nature of rivals	human	robot
No. of sessions	2	2
Duration (min)	150	150
No. of rounds	20	20
No. of subjects	42	40
Avg. payment (JPY)	5083	5089
Avg. score of Quiz 1	9.310	9.725
Avg. score of Quiz 2 w/ hints	8.786	9.650

Table B1 summarizes the basic data for HHhintA and HRhintA. Table B2 lists the sincere bidding rates for HHhint, HRhint, HHhintA, and HHhintA. Using data from both units displayed in Panel (a), we examine whether the advice leads to higher rates of sincere bidding among subjects with a better understanding of SP. Specifically, we use two-sample t-tests to compare the rates of sincere bidding between HHhint and HHhintA when rivals are human and between HRhint and HRhintA when rivals are robots.

Overall, our findings indicate that providing advice effectively increases the rate of sincere bidding, although the effect in our experiment is less than that in Masuda et al.

(2022). The mean increase from HHhint to HHhintA is 8.675% (95% confidence interval, 5.367% to 11.982%), and that from HRhint to HRhintA is 13.094% (95% confidence interval, 10.019% to 16.169%). As mentioned in Appendix A, approximately one-third of subjects reported that they overbid to increase their winning probabilities rather than their earnings. Therefore, there is a limit to increasing sincere bidding through understanding SP. We hypothesize that this limit made the effect of advice in our experiment less effective than that in Masuda et al. (2022) because the sincere bidding rates in HHhint and HRhint were already high and had less potential for further improvement.

This advice has been demonstrated to be highly effective when we focus on data pertaining to subjects who do not achieve perfect scores. For subjects with imperfect scores in Quiz 2 w/ hints, the mean increases from HHhint to HHhintA are 17.679% (95% confidence interval, 11.903% to 23.454%), and those from HRhint to HRhintA are 34.481% (95% confidence interval, 28.073% to 40.888%). For subjects with perfect scores in Quiz 2 w/ hints, the mean increase from HHhint to HHhintA is 4.519% (95% confidence interval, 0.495% to 8.543%). The mean increase from HRhint to HRhintA is 4.713% (95% confidence interval, 1.610% to 7.816%). This outcome aligns with our hypothesis, suggesting that subjects with imperfect scores had lower initial sincere bidding rates and more potential for improvement.

Our results suggest that the advice effectively promotes sincere bidding. This positive effect is observed among subjects with higher and lower levels of understanding of SP. Moreover, the advice appears to be particularly impactful for those with imperfect scores—a lower understanding of SP.

Table B2: Sincere bidding rates by treatment, Quiz 2 scores, and unit

Treatments	(1) HHhint	(2) HRhint	(3) HHhintA	(4) HRhintA	(3) − (1)	(4) − (2)	(4) − (3)
(a)Both units							
All	0.489	0.617	0.576	0.748	0.087***	0.131***	0.172***
(S.E.)	(0.012)	(0.011)	(0.012)	(0.011)			
obs.	1800	1920	1680	1600			
Perfect score	0.522	0.751	0.567	0.798	0.045**	0.047***	0.232***
(S.E.)	(0.014)	(0.011)	(0.015)	(0.011)			
obs.	1240	1480	1120	1320			
Imperfect score	0.418	0.166	0.595	0.511	0.177***	0.345***	−0.084**
(S.E.)	(0.021)	(0.018)	(0.021)	(0.030)			
obs.	560	440	560	280			
(b)Unit 1							
All	0.461	0.606	0.562	0.759	0.101***	0.153***	0.197***
(S.E.)	(0.017)	(0.016)	(0.017)	(0.015)			
obs.	900	960	840	800			
Perfect score	0.508	0.736	0.555	0.808	0.047	0.071***	0.252***
(S.E.)	(0.020)	(0.016)	(0.021)	(0.015)			
obs.	620	740	560	660			
Imperfect score	0.357	0.168	0.575	0.529	0.218***	0.360***	−0.046
(S.E)	(0.029)	(0.025)	(0.030)	(0.042)			
obs.	280	220	280	140			
(c)Unit 2							
All	0.518	0.628	0.590	0.738	0.073***	0.109***	0.147***
(S.E.)	(0.017)	(0.016)	(0.017)	(0.016)			
obs.	900	960	840	800			
Perfect score	0.535	0.766	0.579	0.789	0.043	0.023	0.211***
(S.E)	(0.020)	(0.016)	(0.020)	(0.016)			
obs.	620	740	560	660			
Imperfect score	0.479	0.164	0.614	0.493	0.136***	0.329***	−0.121**
(S.E)	(0.030)	(0.025)	(0.029)	(0.042)			
obs.	280	220	280	140			

Notes: a) In HHhint, subjects compete against human rivals and take Quiz 2 w/ hints. In HRhint, subjects compete against robot rivals and take Quiz 2 w/ hints. In HHhintA, subjects compete against human rivals, take Quiz 2 w/ hints, and receive advice. In HRhintA, subjects compete against robot rivals, take Quiz 2 w/ hints, and receive advice. b) We compare the sincere bidding rates between treatments by using two-sample t-tests. c) * ** and *** denote significance at the 10%, 5%, and 1% levels, respectively. d) Numbers in parentheses are standard errors. e) The unit of observations is the decision-making in each period. The total number of observations is the number of subjects × number of periods × number of units in each treatment.

C Cognitive ability, risk aversion, and loss aversion

Understanding SP may be related to subjects' cognitive abilities. We examine the correlation between subjects' cognitive abilities and their quiz scores. Approximately half of the subjects participated in an experiment conducted by Hanaki et al. (2022). From their dataset, we obtained data on the subjects' cognitive abilities, risk aversion, and loss aversion.

For cognitive ability, we used the subjects' International Cognitive Ability Resource (ICAR) scores, as proposed by Condon and Revelle (2014)[1]. Hanaki et al. (2022) used a three-dimensional (3D) rotation measure (four questions) and a matrix reasoning measure (four questions) from those included in ICAR-16 (Condon and Revelle 2014, Table 4). Subjects were given 40 seconds to answer each of the 3D rotation questions and 30 seconds to answer each matrix reasoning question. The maximum possible score was 8, and the subjects correctly answered an average of 2–3 questions.

For risk aversion, we collected the subjects' risk attitudes from Hanaki et al. (2022)'s experiments, in which they used the designs of Noussair et al. (2014) and Masuda and Lee (2019). The elicitation task comprised five questions related to risk aversion. For each question, subjects were asked to choose between two lotteries. The measure of risk aversion is the number of safe options that a subject chooses from five questions. The maximum score was 5, and the subjects selected an average of three safe options.

For loss aversion, Hanaki et al. (2022) used the experimental task proposed by Köbberling and Wakker (2005) to measure the degree of loss aversion. They asked subjects to choose between a sure zero payment and a lottery in which they would get 600 JPY with a 50% chance or lose X JPY with a 50% chance, where X = 120, 240, 360, 480, 600, or 720. They assumed that loss-averse individuals tend to choose a sure zero-payment option. Loss aversion was measured as the number of safe options in the six questions. The maximum score was 6, and the subjects selected an average of three safe options.

We report the correlations between ICAR and quiz scores using pairwise correlation analyses, specifically the Spearman correlation method. We found no correlation between ICAR scores and Quiz 1 scores ($\rho = 0.085$, $p = 0.399$) or between ICAR scores and Quiz 2 scores w/o hints ($\rho = -0.024$, $p = 0.864$). However, we found a significant correlation between ICAR and Quiz 2 w/ hints scores ($\rho = 0.373$, $p < 0.01$). We conclude that achieving a perfect score in Quiz 2 w/ hints requires cognitive ability. Thus, understanding SP also appears to require cognitive abilities.

[1]See the ICAR team website, https://icar-project.com, for further details.

Table C1: Demographic data

Treatments	HHnohint	HHhint	HRnohint	HRhint
(i) Cognitive ability (ICAR scores)	2.129	2.318	3.143	2.815
obs.	31	22	21	27
(ii) Risk aversion (Noussair et al., 2014)	3.323	3.182	3.217	3.586
obs.	31	22	23	29
(iii) Loss aversion (Köbberling & Wakker, 2005)	3.226	2.727	2.381	3.852
obs.	31	22	21	27
Total number of subjects	48	45	43	48

Table C2: Regression analysis of treatment dummy on sincere bidding by controlling preferences

	Both (1)	Unit 1 (2)	Unit 2 (3)
SP hint	1.279***	1.036**	1.528***
	(0.488)	(0.528)	(0.495)
Robot	0.159	-0.284	0.534
	(0.524)	(0.590)	(0.551)
SP hint × Robot	-0.045	0.622	-0.647
	(0.741)	(0.820)	(0.767)
Cognitive ability	0.147	0.167	0.130
	(0.125)	(0.133)	(0.124)
Risk aversion	0.030	0.0452	0.0143
	(0.140)	(0.146)	(0.145)
Loss aversion	-0.130	-0.136	-0.125
	(0.118)	(0.126)	(0.122)
Constant	-1.177*	-1.280*	-1.076
	(0.699)	(0.727)	(0.698)
Observations	3,920	1,960	1,960
Wald Chi2	13.81	12.61	14.34
Prob >Chi2	0.032	0.050	0.026

Notes: a) We conducted logit regression of the sincere bidding dummy on the SP hint dummy and robot dummy conditional on cognitive ability, risk aversion, and loss aversion with robust standard error clustered at the individual level. b) Sincere bidding dummy equals 1 if subjects submitted a sincere bid in a period and 0 otherwise. SP hint dummy equals 1 if subjects take Quiz 2 w/ hints and 0 if they take Quiz 2 w/o hints. Robot dummy equals 1 if subjects compete against robot rivals and 0 if they compete against human rivals. Cognitive ability ranges from 0 to 8, risk aversion ranges from 0 to 5, and loss aversion ranges from 0 to 6. c) * ** and *** denote significance at the 10%, 5%, and 1% levels, respectively. d) Numbers in parentheses are standard errors. e) The total number of observations is the number of subjects × number of periods × number of units in each treatment.

Some may argue that factors other than understanding SP, such as subjects' prefer-

ences, could affect bidding behavior. To address this, we run the regression presented in Table 4 of the main paper, which additionally controls for subjects' cognitive ability levels, risk aversion, and loss aversion. Table C2 presents these results. These results confirm our original findings—the SP hint dummy has a statistically significant positive impact on sincere bidding. This suggests that providing SP hints in Quiz 2 w/hints promotes sincere bidding, even after controlling for cognitive ability, risk aversion levels, and loss aversion levels.

D Experimental instruction and quizzes

This section contains experimental materials. The materials are originally in Japanese and translated to English. From next page, subsection titles and page numbers are now in the header of each page.

Instructions

Notice:

· Please follow the instructions of the experimenter, but do not operate PC otherwise.
· Please do not communicate or exchange memos with other subjects.
· Please do not watch the behaviors and screens of other subjects.
· Please turn off your mobile phone and put it into your bag.
· Please raise your hand when you have a question.
· You can take a memo using the pen on your desk. You can also use the calculator on your desk.

Overview of experiment

- Today's Experiment is a sequence of auctions. In an auction, subjects bid for items that they wish, and subjects with the highest bids win the items. Subjects' bids also determine the winners' payment. Hereafter, a subject bidding for items is called a "bidder."
- In this experiment, auctions are conducted for 20 rounds, and three bidders participate in each auction. You play the role of one of the three bidders, and the other two bidders are other subjects. You will be randomly matched with the other two subjects in each round of auction. You will not know who you are matched with either during or after the experiment.
- Your reward after the experiment is based on the results of 20 rounds of auction in which you participate.

Procedure of experiment

(1) Two units of an identical object are auctioned off in every period. Three bidders, including yourself, participate in each round of the auction.
(2) If a bidder wins an item, they will draw satisfaction from the item. Such satisfaction is assumed to be measured by money, and the satisfaction as measured by money is called "valuation." The satisfaction from the first unit is called *the valuation of the first unit*, and that from the second unit is called *the valuation of the second unit*.
(3) In this experiment, your valuations in each round of auction are chosen by PC. In each round, PC randomly draws two values from the interval 10 JPY to 1,000 JPY in increments of 10 JPY. The higher value is your valuation of the first unit, and the lower one is your valuation of the second unit. This assumes that your satisfaction with the second unit is less than that obtained from the first.

The valuations of the other subjects are determined similarly in each round. Thus, different subjects have different valuations. However, in each round, the valuation of each bidder from the second unit is lower than that of the first unit. The other bidders will not know your valuations, and you will not know others' valuations.

(4) In this experiment, you are required to submit your "bid for the first unit" and "bid for the second unit" to the experimenter. Please note the following three points:

· Your "bid for the first unit" must exceed your "bid for the second unit."

· Your bids must be at least 0 JPY.

· Your bids must be in increments of 10 JPY.

(5) In this experiment, each of the three bidders submit two bids. Thus, there is a total of six bids. The two highest bids are winning bids, and a bidder who submits the winning bid(s) wins the corresponding object(s). In the scenario of a tie among the highest bids, the program selects the winning bids with equal probabilities. This procedure determines the number of units won by each bidder.

(6) How to determine the payments of winning bidders is explained later. The *earnings* of a winning bidder is the sum of the valuations of the units they win minus their payment. The *earnings* of a non-winning bidder is zero.

Calculation of payments and earnings

We explain how to calculate a bidder's payments and earnings using numerical examples. There are three bidders: A, B, and C. Here, we focus on bidder A. In the following examples, amounts displayed are in JPY.

(1) In the scenario where a bidder wins one unit: A bidder who wins one unit pays the highest bid among the other bidders' losing bids.

Example 1. Suppose A's valuations for the first and second units are 680 and 480, respectively. The table below shows the bids from the three bidders.

Bidder	Bid for the first unit	Bid for the second unit
A	500	450
B	600	300
C	400	250

The winning bids are "A's 500" and "B's 600." The losing bids are "A's 450," "B's 300," "C's 400," and "C's 250." Thus, for bidder A, the other bidders' losing bids are "B's 300," "C's 400," and "C's 250." Bidder A pays the highest bid among these losing bids—400. This payment differs from A's bid for the first unit. Bidder A earns the following amount:

$$680 \text{ (valuation for the first unit)} - 400 \text{ (payment)} = 280$$

Example 2. Suppose A's values for the first and second units are 680 and 480, respectively. The table below displays the bids from the three bidders.

Bidder	Bid for the first unit	Bid for the second unit
A	800	350
B	750	300
C	700	250

The winning bids are "A's 800" and "B's 750." Thus, bidder A wins one unit. The losing bids are "A's 350," "B's 300," "C's 700," and "C's 250." Thus, for bidder A, the other bidders' losing bids are "B's 300," "C's 700," and "C's 250." Bidder A pays the highest bid among these losing bids—700. Note that this payment differs from A's bid for the first unit. Subsequently, bidder A earns the following amount:

$$680 \text{ (valuation for the first unit)} - 700 \text{ (payment)} = -20$$

(2) In the scenario where a bidder wins two units: A bidder who wins two units pays the sum of the highest and second-highest bids from among the losing bids.

Example 3. Suppose A's values for the first and second units are 680 and 480, respectively. The table below displays the bids from the three bidders.

Bidder	Bid for the first unit	Bid for the second unit
A	600	550
B	500	300
C	400	250

The winning bids are "A's 600" and "A's 550." The losing bids are "B's 500," "B's 300," "C's 400," and "C's 250." Bidder A pays the sum of the highest and second-highest bids among the losing bids—$400 + 500 = 900$. This payment differs from that in A's bids. Subsequently, bidder A earns the following amount:

$$680 \text{ (valuation for the first unit)} + 480 \text{ (valuation for the second unit)} - 900 \text{ (payment)} = 260$$

Example 4. Suppose A's values for the first and second units are 680 and 480, respectively. The bids of the three bidders are as follows:

Bidder	Bid for the first unit	Bid for the second unit
A	900	850
B	800	600
C	700	550

The winning bids are A's 900 and A's 850. The losing bids are "B's 800," "B's 600," "C's 700," and "C's 550." Thus, bidder A pays 1,500, the sum of the highest bid of 800 and the second highest bid of 700 from the losing bids. A's payment differs from A's bids. A's earnings are calculated as follows:

680 (valuation for the first unit)+480 (valuation for the second unit) -1500 (payment) $= -340$

The earnings calculation method is summarized as follows:

• In the scenario where you win one unit, and the third highest bid is yours:

$$\text{Your earnings} = \text{your valuation for the firs tunit} - \text{fourth highest bid}$$

• In the scenario where you win one unit, and the third highest bid is not yours:

$$\text{Your earnings} = \text{your valuation for the first unit} - \text{third highest bid}$$

Note that when the payment is higher than the value of the first unit, your earnings are negative.

• In the scenario where you win two units:

$$\begin{aligned}\text{Your earnings} \;=\; & (\text{your valuation for first unit} + \text{your valuation for second unit}) \\ & - (\text{third highest bid} + \text{fourth highest bid})\end{aligned}$$

Note that when your payment is higher than the sum of your values of the first and second units, your earnings will be negative.

• If you do not win anything, your earnings are 0.

Rewards.

• We pay the sum of your earnings over all 20-round auctions as a reward.

• Before the auctions, you will answer Quizzes 1 and 2. Each quiz comprises ten questions. In addition to the earnings from auctions, you will be paid according to your scores in Quizzes 1 and 2.

• The total reward is the sum of your earnings from auctions and rewards based on quiz scores.

Instructions

Notice:

· Please follow the instructions of the experimenter, but do not operate PC otherwise.
· Please do not communicate or exchange memos with other subjects.
· Please do not watch the behaviors and screens of other subjects.
· Please turn off your mobile phone and put it into your bag.
· Please raise your hand when you have a question.
· You can take a memo using the pen on your desk. You can also use the calculator on your desk.

Overview of experiment

- Today's Experiment is a sequence of auctions. In an auction, subjects bid for items that they wish, and subjects with the highest bids win the items. Subjects' bids also determine the winners' payment. Hereafter, a subject bidding for items is called a "bidder."
- In this experiment, auctions are conducted for 20 rounds, and three bidders participate in each auction. You play the role of one of the three bidders, and the other two bidders are played by PC.
- Your reward after the experiment is based on the results of 20 rounds of auction in which you participate.

Procedure of experiment

(1) Two units of an identical object will be auctioned off in every period. Three bidders, including yourself, participate in each round of the auction. However, bidders other than you are robots.
(2) If a bidder wins an item, they will draw satisfaction from the item. Such satisfaction is assumed to be measured by money, and satisfaction as measured by money is called "valuation." The satisfaction from the first unit is called *the valuation from the first unit*, and that from the second unit is called *the valuation of the second unit*.
(3) In this experiment, your valuations in each round of auction is chosen by PC. In each round, PC randomly draws two values from the interval from 10 JPY to 1,000 JPY in increments of 10 JPY. The higher value is your valuation from the first unit, and the lower one is your valuation from the second unit. This assumes that your satisfaction with the second unit is less than that with the first.
(4) In this experiment, you will submit your "bids for the first " and "second units" to the experimenter. Please note the following three points:

· Your "bid for the first unit" must exceed your "bid for the second unit."
· Your bids must be at least 0 JPY.
· Your bids must be in increments of 10 JPY.

(5) As a bidder, a robot will randomly draw two values from the interval 10 JPY to 1,000 JPY with increments of 10 JPY. The higher value is the bid for the first unit of the robot as a bidder, and the lower one is the bid for the second unit. The bids of the other bidder (also a robot) are determined similarly.
(6) In this experiment, you are required to submit two bids, and the other two bidders (played by robots) also submit two bids. Thus, there will be a total of six bids. The two highest bids are winning bids, and a bidder who submits the winning bid(s) wins the corresponding object(s). In case of a tie among the highest bids, the program selects the winning bids with equal probabilities. This procedure determines the number of units won by each bidder.
(7) How to determine the payments of winning bidders is explained later. The *earnings* of a winning bidder is the sum of the valuations of the units that they win minus their payment. The *earnings* of a non-winning bidder is zero.

Calculation of payments and earnings

We explain how to calculate a bidder's payments and earnings using numerical examples. There are three bidders: A, B, and C. Here, we focus on bidder A. In the following examples, amounts displayed are in JPY.

(1) In the scenario where a bidder wins one unit: A bidder who wins one unit pays the highest bid among the other bidders' losing bids.

Example 1. Suppose A's valuations for the first and second units are 680 and 480, respectively. The table below shows the bids from the three bidders.

Bidder	Bid for the first unit	Bid for the second unit
A	500	450
B	600	300
C	400	250

The winning bids are "A's 500" and "B's 600." The losing bids are "A's 450," "B's 300," "C's 400," and "C's 250." Thus, for bidder A, the other bidders' losing bids are "B's 300," "C's 400," and "C's 250." Bidder A pays the highest bid among these losing bids—400. This payment differs from A's bid for the first unit. Bidder A earns the following amount:

$$680 \text{ (valuation for the first unit)} - 400 \text{ (payment)} = 280$$

Example 2. Suppose A's values for the first and second units are 680 and 480, respectively. The table below displays the bids from the three bidders.

Bidder	Bid for the first unit	Bid for the second unit
A	800	350
B	750	300
C	700	250

The winning bids are "A's 800" and "B's 750." Thus, bidder A wins one unit. The losing bids are "A's 350," "B's 300," "C's 700," and "C's 250." Thus, for bidder A, the other bidders' losing bids are "B's 300," "C's 700," and "C's 250." Bidder A pays the highest bid among these losing bids—700. Note that this payment differs from A's bid for the first unit. Subsequently, bidder A earns the following amount:

$$680 \text{ (valuation for the first unit)} - 700 \text{ (payment)} = -20$$

(2) In the scenario where a bidder wins two units: A bidder who wins two units pays the sum of the highest and second-highest bids from among the other bidders' losing bids.

Example 3. Suppose A's values for the first and second units are 680 and 480, respectively. The table below displays the bids from the three bidders.

Bidder	Bid for the first unit	Bid for the second unit
A	600	550
B	500	300
C	400	250

The winning bids are "A's 600" and "A's 550." The losing bids are "B's 500," "B's 300," "C's 400," and "C's 250." Bidder A pays the sum of the highest and second-highest bids among the losing bids—$400 + 500 = 900$. This payment differs from A's bids. Subsequently, bidder A earns the following amount:

$$680 \text{ (valuation for the first unit)} + 480 \text{ (valuation for the second unit)} - 900 \text{ (payment)} = 260$$

Example 4. Suppose A's values for the first and second units are 680 and 480, respectively. The bids of the three bidders are as follows:

Bidder	Bid for the first unit	Bid for the second unit
A	900	850
B	800	600
C	700	550

The winning bids are A's 900 and A's 850. The losing bids are "B's 800," "B's 600," "C's 700," and "C's 550." Thus, bidder A pays 1,500, the sum of the highest bid of 800 and the second highest bid of 700 from the losing bids. A's payment differs from A's bids. A's earnings are calculated as follows:

680 (valuation for the first unit)+480 (valuation for the second unit) -1500 (payment) $= -340$

The earnings calculation method is summarized as follows:

• In the scenario where you win one unit, and the the third highest bid is yours:

$$\text{Your earnings} = \text{your valuation for the firs tunit} - \text{fourth highest bid}$$

• In the scenario where you win one unit, and the third-highest bid is not yours:

$$\text{Your earnings} = \text{your valuation for the first unit} - \text{third highest bid}$$

Note that when your payment is higher than your value for the first unit, your earnings will be negative.

• In the scenario where you win two units:

$$\begin{aligned}\text{Your earnings} \quad = \quad & (\text{your valuation for first unit} + \text{your valuation for second unit}) \\ & - (\text{third highest bid} + \text{fourth highest bid})\end{aligned}$$

Note that when your payment is higher than the sum of your values for the first and second units, your earnings will be negative.

• If you do not win anything, your earnings are 0.

Rewards

• We pay the sum of your earnings over all 20-round auctions as a reward.

• Before the auctions, you will answer Quizzes 1 and 2. Each quiz comprises ten questions. In addition to the earnings from auctions, you will be paid according to your scores from Quizzes 1 and 2.

• The total reward is the sum of your earnings from auctions and rewards based on quiz scores.

Quiz 1

Seat number_____

Please answer all the following questions. You will earn 100 JPY for each correct answer. Please refer to the instructions if necessary.

Assume that the bids from the three bidders and bidder A's evaluation are as given in the table below. Please answer Questions 1–4 based on the table.

	First unit	Second unit
Bidder A's bid	800	500
Bidder B's bid	1000	700
Bidder C's bid	600	500
Bidder A's evaluation	900	700

[Question 1] (Two) Winning bids Answer:_____ _____

[Question 2] Bidder A's payment Answer:_____

[Question 3] Bidder A's earning (Their evaluation on the items they win – Payment)

Answer:_____

[Question 4] Bidder C's payment Answer:_____

Assume that the bids of the three bidders and bidder B's evaluation are as given in the table below. Please answer Questions 5–7 based on the table.

	First unit	Second unit
Bidder A's bid	650	500
Bidder B's bid	1000	700
Bidder C's bid	600	500
Bidder B's evaluation	950	800

[Question 5] (Two) Winning bids Answer:_____ _____

[Question 6] Bidder B's payment Answer:_____

[Question 7] Bidder B's earning (Their evaluation on the items they win – Payment)

Answer:_____.

Assume that the bids of the three bidders and bidder C's evaluation are as given in the table below. Please answer Questions 8–10 based on the table.

	First unit	Second unit
Bidder A's bid	800	500
Bidder B's bid	1000	700
Bidder C's bid	900	500
Bidder B's evaluation	500	400

[Question 8] (Two) Winning bids Answer:_____ _____

[Question 9] Bidder B's payment Answer:_____

[Question 10] Bidder B's earning (Their evaluation on the items they win – Payment)

Answer:_____

Seat number_____

Quiz 2

Please answer all the following questions. You will earn 100 JPY for each correct answer. Please refer to the instructions if necessary.

Assume that you are bidder B, and your valuations of the first and second units are 700 and 400, respectively. Maintain these assumptions for Questions 1–10 below. For each question, select the correct answers from the choices provided in the table below, where the the first and second figures in each choice are the bids of the first and second units, respectively. If several choices are correct, select all of them.

Choice a: (900, 820)	Choice b: (780, 500)	Choice c: (700, 400)
Choice d: (400, 390)	Choice e: (310, 200)	Choice f: (660, 200)

The calculation sheets for these questions are attached on pages 4–6. Use them if necessary. (However, the calculation sheets will not be marked.)

In Questions 1 and 2, assume that you expect the other two bidders (A and C) to bid as shown in the table below. The calculation sheet for the two questions is shown on page 4.

Bidder	Bid for 1st unit	Bid for 2nd unit
A	380	300
C	300	250

[Question 1] Select the choices that make your earnings (the sum of valuations of the units you win - your payments) zero. If no such choice exists, answer "none."

Answer:_____

[Question 2] Select the choices that maximize your earnings (the sum of valuations of the units you win – your payments). (Note that if the earnings from all choices are nonpositive, the maximized earnings may be zero.) Answer:_____

Seat number_____

In Questions 3–6, assume that you expect the other two bidders (A and C) to bid as shown in the table below. The calculation sheet for the three questions is shown on page 5.

Bidder	Bid for 1st unit	Bid for 2nd unit
A	650	300
C	750	450

[Question 3] Select the choices that make your earnings (the sum of valuations of the units you win – your payments) zero. If no such choice exists, answer "none."

Answer:_____

[Question 4] Select the choices that make your earnings (the sum of valuations of the units you win – your payments) negative. If no such choice exists, answer "none."

Answer:_____

[Question 5] Select the choices that maximize your earnings (the sum of valuations of the units you win – your payments). (Note that if the earnings from all choices are nonpositive, the maximized earnings may be zero.)

Answer:_____

[Question 6] Select the choices that are the correct answers of both Questions 2 and 5—the choices that maximize your earnings for both of the two expectations about the bids of the two other bidders. If no such choice exists, answer "none."

Answer:_____

Seat number_____

In Questions 7–9, assume that you expect the other two bidders (A and C) to bid as shown in the table below. The calculation sheet for the three questions is shown on page 6.

Bidder	Bid for 1st unit	Bid for 2nd unit
A	800	660
C	750	500

[Question 7] Select the choices that make your earnings (the sum of valuations of the units you win - your payments) zero. If no such choice exists, answer "none."

Answer:_____

[Question 8] Select the choices that make your earnings (the sum of valuations of the units you win - your payments) negative. If no such choice exists, answer "none."

Answer:_____

[Question 9] Select the choices that maximize your earnings (the sum of valuations of the units you win - your payments). (Note that if the earnings from all choices are nonpositive, the maximized earnings may be zero.)

Answer:_____

[Question 10] Select the choices that are the common answers of all of Questions 2, 5, and 9—the choices that maximize your earnings for all of the three expectations about the bids of the two other bidders. If no such choice exists, answer "none."

Answer:_____

Seat number_____

Calculation sheets for Questions 1 and 2

	Bid for 1st unit	Bid for 2nd unit
Bidder A	380	300
Bidder C	300	250
Choice a	900	820
Choice b	780	500
Choice c	700	400
Choice d	400	390
Choice e	310	200
Choice f	660	200
Your evaluation	700	400

Computation for Choice a: (900, 820)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice b: (780, 500)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice c: (700, 400)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice d: (400, 390)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice e: (310, 200)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice f: (660, 200)

Units you win	Sum of valuations of units you win	Payment	Earning

Seat number_____

Calculation sheets for Questions 3–6

	Bid for 1st unit	Bid for 2nd unit
Bidder A	650	300
Bidder C	750	450
Choice a	900	820
Choice b	780	500
Choice c	700	400
Choice d	400	390
Choice e	310	200
Choice f	660	200
Your evaluation	700	400

Computation for Choice a: (900, 820)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice b: (780, 500)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice c: (700, 400)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice d: (400, 390)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice e: (310, 200)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice f: (660, 200)

Units you win	Sum of valuations of units you win	Payment	Earning

Seat number_____

Calculation sheets for Questions 7–9

	Bid for 1st unit	Bid for 2nd unit
Bidder A	800	660
Bidder C	750	500
Choice a	900	820
Choice b	780	500
Choice c	700	400
Choice d	400	390
Choice e	310	200
Choice f	660	200
Your evaluation	700	400

Computation for Choice a: (900, 820)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice b: (780, 500)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice c: (700, 400)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice d: (400, 390)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice e: (310, 200)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice f: (660, 200)

Units you win	Sum of valuations of units you win	Payment	Earning

Seat number_____

Quiz 2

Please answer all the following questions. You will earn 100 JPY for each correct answer. Please refer to the instructions if necessary.

Assume that you are Bidder B in Questions 1–10. For each question, select the correct answers from the choices given in the table below, where the first and second figures in each choice are the bids of the first and second units, respectively. If several choices are correct, select all of them.

Choice a: (900, 820)	Choice b: (780, 500)	Choice c: (700, 400)
Choice d: (400, 390)	Choice e: (310, 200)	Choice f: (660, 200)

The calculation sheets for these questions are attached on pages 4–6. Use them if necessary. (However, the calculation sheets are not marked.)

In Questions 1–3, assume that your valuations of the first and second units are 500 and 300, respectively, and you expect the other two bidders (A and C) to bid as shown in the table below. The calculation sheet for the three questions is shown on page 4.

Bidder	Bid for 1st unit	Bid for 2nd unit
A	380	300
C	300	250

[Question 1] Select the choices that make your earnings (the sum of valuations of the units you win - your payments) zero. If no such choice exists, answer "none."

Answer:_____

[Question 2] Select the choices that make your earnings (the sum of valuations of the units you win - your payments) negative. If no such choice exists, answer "none."

Answer:_____

[Question 3] Select the choices that make your earnings (the sum of valuations of the units you win - your payments) positive. If no such choice exists, answer "none."

Answer:_____

Seat number_____

In Questions 4–6, assume that your valuations of the first and second units are 710 and 290, respectively, and you expect the other two bidders (A and C) to bid as shown in the table below. The calculation sheet for the three questions is shown on page 5.

Bidder	Bid for 1st unit	Bid for 2nd unit
A	650	300
C	750	450

[Question 4] Select the choices that make your earnings (the sum of valuations of the units you win - your payments) zero. If no such choice exists, answer "none."

Answer:_____

[Question 5] Select the choices that make your earnings (the sum of valuations of the units you win - your payments) negative. If no such choice exists, answer "none."

Answer:_____

[Question 6] Select the choices that make your earnings (the sum of valuations of the units you win - your payments) positive. If no such choice exists, answer "none."

Answer:_____

Seat number_____

In Questions 7–9, assume that your valuations of the first and second units are 730 and 370, respectively, and you expect the other two bidders (A and C) to bid as shown in the table below. The calculation sheet for the three questions is shown on page 6.

Bidder	Bid for 1st unit	Bid for 2nd unit
A	800	660
C	750	500

[Question 7] Select the choices that make your earnings (the sum of valuations of the units you win - your payments) zero. If no such choice exists, answer "none."

Answer:_____

[Question 8] Select the choices that make your earnings (the sum of valuations of the units you win - your payments) negative. If no such choice exists, answer "none."

Answer:_____

[Question 9] Select the choices that make your earnings (the sum of valuations of the units you win - your payments) positive. If no such choice exists, answer "none."

Answer:_____

[Question 10] Select the choices that are the common answers of all of Questions 1, 4, and 7—the choices that make your earnings zero for all of the three expectations about the bids of the two other bidders. If no such choice exists, answer "none."

Answer:_____

Seat number_____

Calculation sheets for Questions 1 and 2

	Bid for 1st unit	Bid for 2nd unit
Bidder A	380	300
Bidder C	300	250
Choice a	900	820
Choice b	780	500
Choice c	700	400
Choice d	400	390
Choice e	310	200
Choice f	660	200
Your evaluation	500	300

Computation for Choice a: (900, 820)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice b: (780, 500)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice c: (700, 400)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice d: (400, 390)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice e: (310, 200)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice f: (660, 200)

Units you win	Sum of valuations of units you win	Payment	Earning

Seat number_____

Calculation sheets for Questions 4–6

	Bid for 1st unit	Bid for 2nd unit
Bidder A	650	300
Bidder C	750	450
Choice a	900	820
Choice b	780	500
Choice c	700	400
Choice d	400	390
Choice e	310	200
Choice f	660	200
Your evaluation	710	290

Computation for Choice a: (900, 820)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice b: (780, 500)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice c: (700, 400)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice d: (400, 390)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice e: (310, 200)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice f: (660, 200)

Units you win	Sum of valuations of units you win	Payment	Earning

Seat number_____

Calculation sheets for Questions 7–9

	Bid for 1st unit	Bid for 2nd unit
Bidder A	800	660
Bidder C	750	500
Choice a	900	820
Choice b	780	500
Choice c	700	400
Choice d	400	390
Choice e	310	200
Choice f	660	200
Your evaluation	730	370

Computation for Choice a: (900, 820)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice b: (780, 500)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice c: (700, 400)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice d: (400, 390)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice e: (310, 200)

Units you win	Sum of valuations of units you win	Payment	Earning

Computation for Choice f: (660, 200)

Units you win	Sum of valuations of units you win	Payment	Earning

E Post-experiment survey

1. Please indicate your seat number for today's experiment. _____
2. Please select your gender. ☐ Female ☐ Male ☐ Do not answer
3. Please select your major. _____
4. Did you understand the rules of today's auction before it started?
   ☐ Very well
   ☐ Well
   ☐ Not so much
   ☐ Little
   ☐ Other: _____
5. How did you bid in the auction?
   ☐ Bid the amount of valuation
   ☐ Bid higher than valuation
   ☐ Bid lower than valuation
   ☐ Other: _____
6. Select the reason for bidding as you did in 5) from the choices below.
   ☐ To maximize your earnings in the auction.
   ☐ To maximize your winning probability rather than to maximize your earnings in the auction.
   ☐ To make the earnings of other bidders smaller.
   ☐ To make the earnings of other bidders larger.
   ☐ Other: _____

References

Condon, D. M., and W. Revelle (2014): "The international cognitive ability resource: Development and initial validation of a public-domain measure," *Intelligence*, 43, 52–64.

Cooper, D. J., and H. Fang (2008): "Understanding overbidding in second price auctions: An experimental study," *The Economic Journal*, 118, 1572–1595.

Hanaki, N., K. Inukai, T. Masuda, and Y. Shimodaira (2022): "Comparing behavior between a large sample of smart students and Japanese adults," *The Japanese Economic Review*, 1–39.

Köbberling, V., and P. P. Wakker (2005): "An index of loss aversion," *Journal of Economic Theory*, 122, 119–131.

Masuda, T., and E. Lee (2019): "Higher order risk attitudes and prevention under different timings of loss," *Experimental Economics*, 22, 197–215.

Masuda, T., R. Mikami, T. Sakai, S. Serizawa, and T. Wakayama (2022): "The net effect of advice on strategy-proof mechanisms: an experiment for the Vickrey auction," *Experimental Economics*, 25, 902–941.

Noussair, C. N., S. T. Trautmann, and G. Van de Kuilen (2014): "Higher order risk attitudes, demographics, and financial decisions," *Review of Economic Studies*, 81, 325–355.