Taking risks by flying paper airplanes

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June 2021

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Abstract

We report the results of an outdoor activity conducted in game theory courses where students were invited to throw airplanes in order to win a prize. They flew self-made paper airplanes to earn points in three trials. The main purpose of these outdoor classroom experiments was to incentive students to learn by experiencing concepts of uncertainty in the gain domain (risk aversion). After throwing the airplanes, the students thought about decisions under uncertainty. Specifically, we provide a theoretical model to explain the subjects' decisions, optimal behavior, and deviations from that behavior. Overall, our activity creates a setting to foster students' interest in the study of decision making under uncertainty.

Keywords: Classroom experiments, flipped classroom, expected utility theory, risk taking

JEL codes: A22, C70, C99

[1] We thank Pablo Brañas Garza, Ana Hernández Roldán, Sarah Jacobson, Diego Jorrat, Dunia López Pintado, and SEA 2020 for their helpful comments. I also wish to thank the students who participated in the experiment. Funding provided by the Ministry of Spain PGC2018-093506-B-100, the Regional Government of Andalusia PY18-FR-0007, and Loyola 205565 PID is also gratefully acknowledged.

1. Motivation

Decision making under uncertainty and risk attitudes are at the core of the economics discipline. However, concepts related to uncertainty (and ambiguity) require students to have a basic understanding of probabilities and expected payoffs. In this regard, several authors have shown that subjects face problems when computing probabilities (Delavande and McKenzie 2011; Mkondiwa 2020), but it is unclear whether they might also have learning issues with expected utility.

The literature on the elicitation of risk preferences is extensive. The traditional risk elicitation method makes use of multiple price lists (Holt and Laury 2002; Eckel and Grossman 2007; Gneezy and Potter 2010) where subjects face different pairs of lotteries with changing payoffs or probabilities. These experiments report a large number of inconsistent subjects who state that they did not properly understand the task (Heimer et al. 2021; Pedroni et al. 2017; Amador-Hidalgo et al. 2021). Another common way to measure risk preferences is by means of auctions where subjects can buy insurance to reduce risk (Charness, Gneezy, and Imas 2013).

Indeed, some experimental "lab" tasks have been proven to work well with students. For instance, both the Balloon Analogue Risk Task (BART) developed by Lejuez et al. (2002) and the "bomb" risk elicitation task designed by Crosetto and Filippin (2013) seem to be friendly tasks since subjects' experience risk (or at least anticipated risk) in intuitive contexts. In the bomb task, students are given 100 objects and must decide how many objects to collect, one of which contains a bomb. The students' points increase with the number of items collected, but if they collect the bomb, they earn zero. In the BART task, students are asked to pump up a balloon several times by clicking a button. With each click, their points increase and cause the balloon to incrementally inflate. If the balloon explodes, they lose all their points. However, these tasks are difficult to implement without computers.

In this paper, we present a simple, fun, and easy-to-understand task to measure individual attitudes toward risk. Our task allows students to experience the trade-off between risk and payoffs. Subjects are asked to throw a paper airplane at a target and are paid based on the distance they choose and their outcome. Since students are not expected to know how to build and fly their own airplanes or to compute expected payoffs, their decision problem and the observed choices entail ambiguity on top of uncertainty. Here, however, we concentrate on the issue of risk taking in the gains (risk aversion) and leave the concept of ambiguity for further research. Interestingly, our task led students to discover different learning outcomes autonomously, such as prospect theory (Kahneman and Tversky 1979) and expected utility theory (Schechter 2007). Moreover, the students gained insight into their own behavior; for instance, by self-identifying as risk or loss averse. Thus, our task raises students' awareness of their own and others' behavioral types.

Several attempts have been made to encourage students to "play" with economics concepts such as risk attitudes and violations of the expected utility; topics they often find challenging. For instance, Johnson and Staveley-O'Carroll (2020) ran an experiment where risk arises from the exchange of multiple currencies. Servátka and Theocharides (2011) ran a game on credit risk. Other classroom experiments intended to motivate students' understanding of behavior toward risk and its effect on money demand have been performed by Ewing, Kruse, and Thompson (2010).

Introductory microeconomics courses increasingly use the learning to learn by playing methodology (see Ng 2019; Korneychuk and Bylieva 2018; Davis 2019). For example, Mendez-Carbajo and Malakar (2019) used "www.econlowdown.org" videos to motivate students to take economics courses. The classroom game discussed in Grogan (2018) provides students with a thorough understanding of some of the policy options under debate in an economics course. The flipped classroom strategy, in which the experiment is developed before the theory is presented, has been shown to increase scores on medium-term assessments (Wozny, Balser, and Ives 2018). Moreover, the recent meta-analysis of Strelan et al. (2020), which includes 198 studies with 33,678 students, showed that flipped classrooms exert a moderate positive effect on student performance.

2. The outdoor activity

2.1 Participants

We invited 103 university students (85 Spaniards and 18 international students) from an Andalusian university (southern Spain) to participate in an outdoor activity. All the participants were enrolled in the course Game Theory for Social Sciences, which is offered to communications, international relations, business administration, and law students, as well as Erasmus/international students.

Participation was not compulsory (3 students, all of whom were Spanish nationals, did not participate). The subjects were not aware of the instructions prior to the experiment. The final sample comprised 100 university students (62% females) with a mean age of 22.23 years ($SD = 0.140$). The experiment was run in two sessions: 49 students participated at the Cordoba campus and 51 at the Seville campus. Each student made 3 individual decisions, adding up to a total of 300 decisions.

2.2 The task

The objective of the task was to provide students with a teaching-learning experience on risky decision making, particularly regarding attitudes toward risk in gains environments.

The main idea of the task is simple: each student is asked to throw a paper airplane in order to hit an object. If she hits the target, she will earn a certain amount of points, where the number of points is equivalent to the selected distance. Hence, the only decision the participant must make is the distance to the target. Figure 1 shows the main idea.

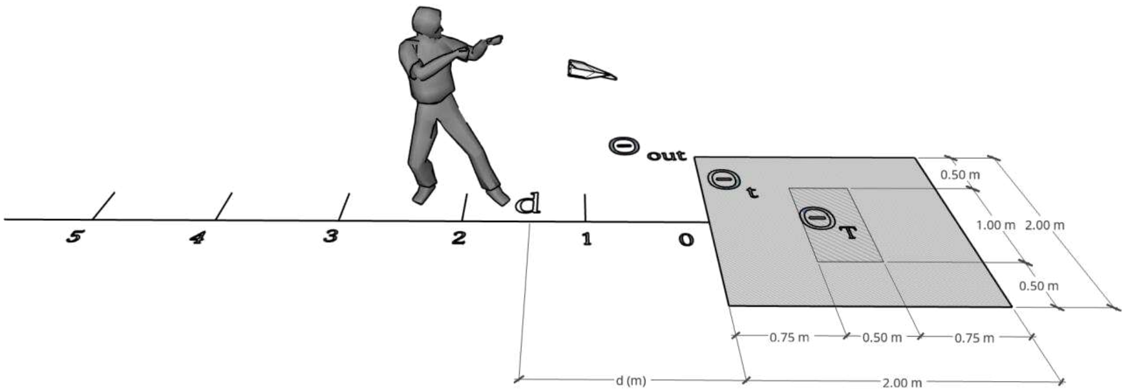

Figure 1. Graphical illustration of the task.

There are two targets: a large one, *t* (where points = *distance*), and a small one, *T* (where points = 2**distance*). The game is played over 3 trials.

Our task has certain features that should be emphasized. First, we do not expect students to have prior experience in a similar task (i.e., throwing airplanes to try to hit a particular location). Hence, the first trial is based only on the students' intuition and not on the result of an observation. Second, we do not expect them to have a particular skill in this task. Third, and most importantly, we do not expect them to be aware of these skills. Therefore, if there are individual differences in skills, they cannot anticipate them prior to the first throw. In fact, the decisions were not observed to be correlated with the participants' gender (p = .428) or age (p = .362).

2.3 Instructions

The activity was conducted at the sports grounds of the two campuses where we built a landing area, a main target that consisted of a closed box measuring 0.5 x 1 meters, and a secondary target consisting of a closed box measuring 2 x 2 meters (see Figure 1).

Prior to performing the task, the students were asked to build a paper airplane out of recycled paper. They were given the option of consulting instructions on the internet to build the planes.

After the students had built the airplanes, they were instructed about the rules of the game as follows: first, each student had to decide what distance to throw the airplane before the other classmates threw their airplanes and write down the distance in meters on the airplane. After throwing, an enumerator noted in writing the distance in meters (*d*), the result (*T, t, out*), and the points earned. When all students had thrown their airplanes, they moved on to the next trial where all of them marked their next decision before the first student started throwing again. The students had 3 opportunities (*trials*) to reach the target, and the best result of the three throws was selected for the final payoff.

Since the decision was made (and marked) before anyone threw a plane in each trial, the subjects have incentives to choose a specific, optimal distance depending on their (expected) abilities. When choosing the distance, they need to consider that if the airplane lands on the main target (*T*) they will earn double the points, but if the airplane lands on the secondary target (*t*), they will earn the same points as the distance. Otherwise, if the airplane lands outside (*out*) the chosen distance, the student earns zero points in the trial (see Appendix)

Students were given 0–30 points for their results. Thirty points might have an impact of 0.10% on their final score (max = 3,000 points). On average, they earned 4.25 points (*SD* = 0.309). Although the payments may seem small and the incentives insufficient, Brañas-Garza et al. (2021) has shown that paying real incentives is not relevant for the measurement of risk preferences.

3. Theory

3.1 General framework

A rational subject is often modelled through the assumption of perfect rationality and it is assumed that students will always act in a way that maximizes their utility. In our setting, this implies that each student will calculate the distance (*d*) that entails the highest expected payoff. The subject knows that moving further away increases the amount of points she will earn when the task is accomplished (i.e., the airplane lands on one of the targets). Moving closer, however, increases the probability of earning a positive payoff. Therefore, the subject chooses the distance (in meters) at which she expects to earn the maximum number of points.

We consider next a stylized model of individual rational choice with the following ingredients:

- Let λ be the maximum cumulative payoff in previous periods.[2]
- The payoffs associated with each distance are:
  - (*i*) $\theta_T(d) = max(2d, \lambda)$ is the payoff a student gets when landing her plane on the main target,
  - (*ii*) $\theta_t(d) = max(d, \lambda)$ is the payoff a student gets when landing her plane on the secondary target, and
  - (*iii*) $\theta_{out}(d) = \lambda$ is the payoff that a student gets when landing her plane outside the targets.

  Note that payoffs are increasing with distance ($\theta'_T(d) \geq 0$, $\theta'_t(d) \geq 0$, and $\theta'_{out}(d) = 0$).
- Assume that the probability of hitting each target from a certain distance (*d*) is a linear approximation:
  - (*i*) $p_T(d) = max(A\text{-}Bd,0)$ for landing on target *T*
  - (*ii*) $p_t(d) = max(a\text{-}bd,0)$ for landing on target *t*, and
  - (*iii*) $p_{out}(d) = 1\text{-}\ p_T(d)\text{-}p_t(d)$ for landing outside either target *T* or *t.*

  The probability function is decreasing in distance (i.e., $p'_T(d) \leq 0$ and $p'_t(d) \leq 0$) and such that the probability of hitting the secondary target (p_t) is higher than the probability of hitting the main target (p_T) given a certain distance (see Figure 1). Therefore, $0 \leq A \leq a \leq 1$, $0 < b \leq B$ and $\frac{A}{B} \leq \frac{a}{b}$.
- The distance (*d*) has to be a value greater than 0, as the students could not throw the airplanes inside the targets. Additionally, there is a maximum distance beyond which hitting the targets is impossible. Assuming that it is easier to land on the big target than the small one, the distance must be less than $\frac{a}{b}$, beyond which the probability of hitting the secondary target (*t*) is zero.

[2] If a subject is in Trial 1, then $\lambda = 0$ is the payoff; if a subject is in Trial 2, then λ is the payoff obtained in Trial 1, and if a subject is in Trial 3, then λ is the maximum payoff obtained in Trials 1 and 2.

The previous assumptions determine an expected gains function as follows:

$$G(d) = p_T(d)\cdot\theta_T(d) + p_t(d)\cdot\theta_t(d) + (1 - p_T(d) - p_t(d))\cdot\theta_{out}$$

Analogously, the expected gains can be expressed as:

$$G(d) = max(A-Bd,0)\cdot max(2d,\lambda) + max(a-bd,0)\cdot max(d,\lambda) + (1-(max(A-Bd,0)) - (max(a-bd,0)))\cdot\lambda$$

The distance that optimizes the expected gains is:

$$d^* = \begin{cases} \frac{2A+a}{4B+2b} + \frac{B+b}{4B+2b}\lambda & if\ 0 \le \lambda \le \frac{2A+a}{3B+b} \\ \frac{A}{2B} + \frac{\lambda}{4} & if\ \frac{2A+a}{3B+b} < \lambda \le \frac{A}{B} \\ \frac{a}{2b} + \frac{\lambda}{2} & if\ \frac{A}{B} < \lambda \le \frac{a}{b} \end{cases}$$

Otherwise, all distances provide the same gains, which is equal to λ.

Assuming that the probability structure is common knowledge, this indicates that the optimum d^* from which the agents must throw is $d^* = \frac{2A+a}{4B+2b}$ when their cumulative gains are 0 ($\lambda = 0$).

The utility function (*U(G(d))*) widely used in rational choice measures participants' welfare as a function of their decision, which allows us to classify subjects into different risk attitudes. Applying the expected utility theory, we obtain that:

$$U(G(d)) = p_T(d)\, U(\theta_T(d)) + p_t(d)\, U(\theta_t(d)) + (1 - p_T(d) - p_t(d))\, U(\theta_{out}).$$

Based on this utility function, we might have different theoretical predicted behaviors:

- Risk neutral $d_u = d^*$. Subjects choose the distance that maximizes the expected gains.
- Risk averse $d_u < d^*$. Subjects choose a smaller distance than the optimal one, thus sacrificing a higher possible gain to increase their probability of success.
- Risk lover $d_u > d^*$. Subjects select a greater distance than the optimal one because they prefer higher payoffs despite being riskier.

3.2 Empirical distribution of probability of success

In what follows, we analyze the behavior of a risk-neutral individual assuming that the probability of success (for *T* or *t* targets) is known and constant throughout the experiment. To calibrate such a linear probability function, we used the empirical observations of the 300 decisions the students made in our experiment. We find that $A = 0.13$, $B = 0.02$, $a = 0.52$, and $b = 0.05$.

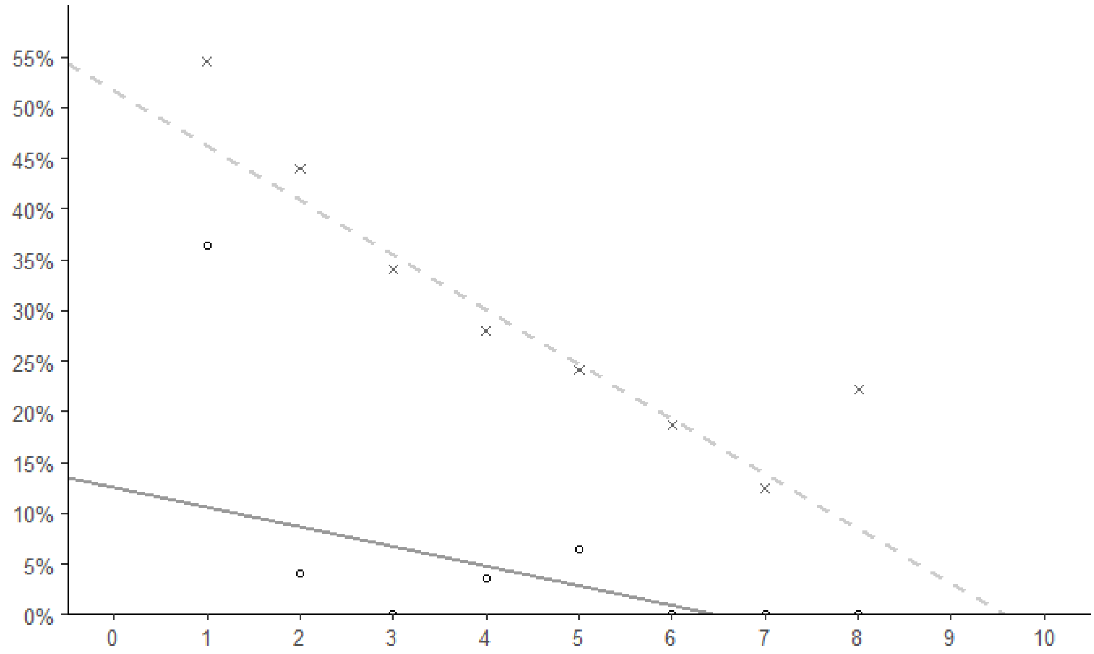

Figure 2. Linear approximation of the probabilities of hitting the target (*t* or *T*) by distance. Empirical distribution: $p_T(d) = max(0.13 - 0.02\ d,0)$ represented by the solid line and $p_t(d) = max(0.52 - 0.05 \cdot d,0)$ by the dashed line.

3.3 The decision problem

Given the calibrated probability function shown above, we now describe the decision tree for a risk neutral agent and her optimal choice (see Figure 3). The distance that optimizes the expected gain function ($G(d)$) in the first trial, where $\lambda = 0$ points, is equal to 4.12 meters. Notice that, as predicted by our model, subjects who choose a distance of less than 4.12 meters (when $\lambda = 0$) exhibit risk aversion, whereas longer distances would imply risk loving.[3]

[3] Prospect theory states that in gain scenarios, subjects tend to choose risk-averse decisions in a higher proportion than risk lover ones (Kahneman and Tversky 1979).

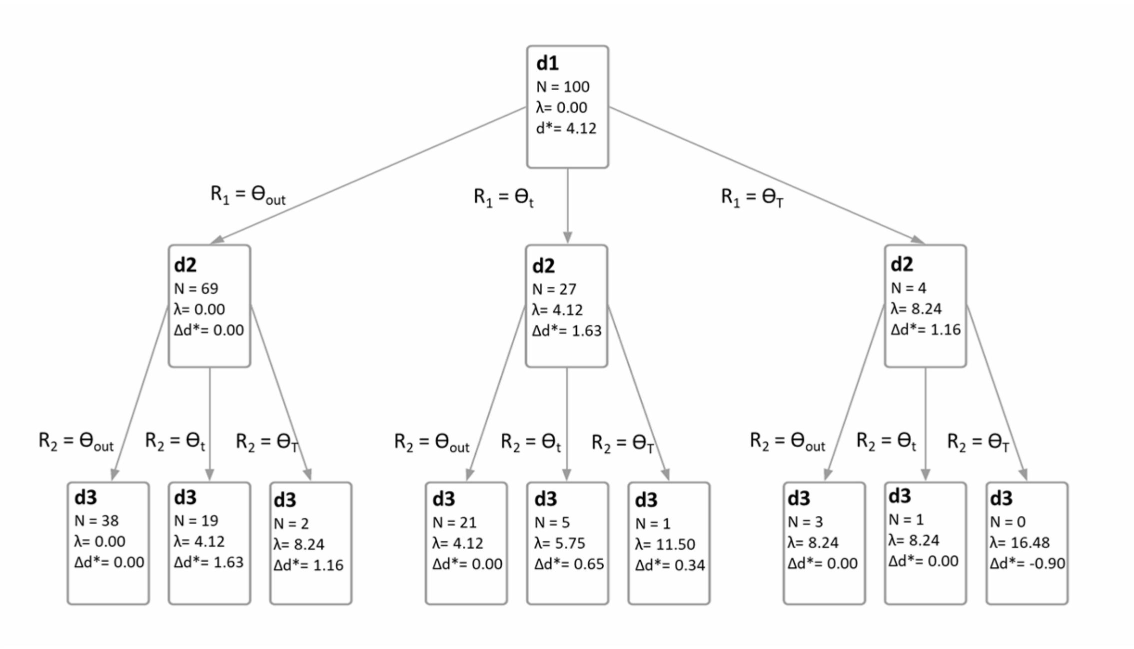

Figure 3. Decision tree with theoretical results using empirical probabilities.

First, a subject who failed (i.e., does not hit either of the targets) on the first trial begins the second trial with $\lambda = 0$ points.

This happens with a probability $p_{out}(4.12 \text{ m}) = 66.17\%$. These individuals face the same decision as in the first trial, and the rational choice remains the same: 4.12 meters. This implies that they do not need to adjust ($\Delta d = 0$).

Second, a subject who successfully hits the secondary target (i.e., $\lambda = 4.12$ points) in the first trial, which occurs with a probability $p_t(4.12 \text{ m}) = 29.35\%$, needs to adjust for the second trial. Specifically, the option that maximizes her expected gains is $d = 5.75$ meters, which increases the distance (Δd) by 1.63 meters.

Third, if a subject hits the main target ($\lambda = 8.24$), which happens with a probability $p_T(4.12 \text{ m}) = 4.48\%$, she has to make a greater adjustment since the highest expected gain for the second trial is $d = 5.28$ meters ($\Delta d = 1.16$ meters).

In the third and last trial, the possible scenarios are related to the cumulative payoffs ($\lambda = 0$, 4.12, or 8.24 points) and the optimal adjustments of the distance are 0, 1.63, and 1.16 m for $\lambda = 0$. For higher levels of λ (5.75, 8.24, 11.50, or 16.48 points), the optimal distance would be 6.40, 5.28, 6.09, and 7.34 meters.[4]

In reality, the probability function is unknown to the participants, and therefore they need to make a guess to make the decision. In particular, agents had no information about the values (A, B, a, b) of the function p_T or p_t. The simplification of this function

[4] In the last case, the distance is smaller compared to the previous trial, since if the airplane is thrown a distance of 8.24 meters, the probability of landing it at T is zero.

is only used to calibrate the model and show some possible results. This assumption is not necessary for the main results of the experiment.

Indeed, there are many factors that could influence participants' success in the game: their ability to throw airplanes (as we do not believe that the subjects have information about how to do so prior to the start of the task), the technical capacity of their airplane, information on current weather conditions, their self-perception of their luck or self-confidence, their ambiguity attitude, and their risk attitude.

4. Experimental results

The data collected in the experiment enable us to compare subjects' behavior and the theoretical results. First, we will focus on the first decision and classify subjects according to their choices. Then, we will report the behavior of the students who failed the first and the second trial ($\lambda = 0$) since their optimal behavior is not expected to change across the game.

4.1 First trial

For the first trial, subjects decided what distance (in meters) they wished to throw their airplane. This decision is made without any additional information aside from the instructions. All subjects wrote the meters individually without observing their partners. It is important to mention that the first decision was uncorrelated with gender ($p = .899$), hence the task can be considered gender free.[5] Additionally, the first shot was uncorrelated with the participants' age ($p = .880$). This result differs from those reported in the literature where age is found to have robust and consistent associations with risk preference (see Frey et al. 2021). However, it is important to remark that there were minimal differences in age between our students. Finally, we observe that the empirical probability of success did not change[6] across the trials, which implies that the subjects did not learn at all.

In what follows, we assume that subjects maximize their utility, $U(G(d))$, rather than their pure expected gains, $G(d)$. We also assume that they know the probabilities and therefore their choices reflect their behavior type.

[5] This result coincides with Filippin and Crosetto's (2016) meta-analysis of risk taking including 54 published studies that found no gender differences.

[6] The significance test of the difference in the probability of hitting the main target between Trial 1 and Trial 2 was $p = .252$ (between Trial 1 and Trial 3, $p = .502$). In the case of the secondary target, it was between Trial 1 and Trial 2, $p = .224$, (between Trial 1 and Trial 3, $p = .776$).

Looking at the results of the 300 decisions, we draw a decision tree (similar to Figure 3) but including the empirical results. Note that this new tree includes standard deviations since there is heterogeneity in the adjustment, that is, not all individuals adjust similarly (see Figure 4).

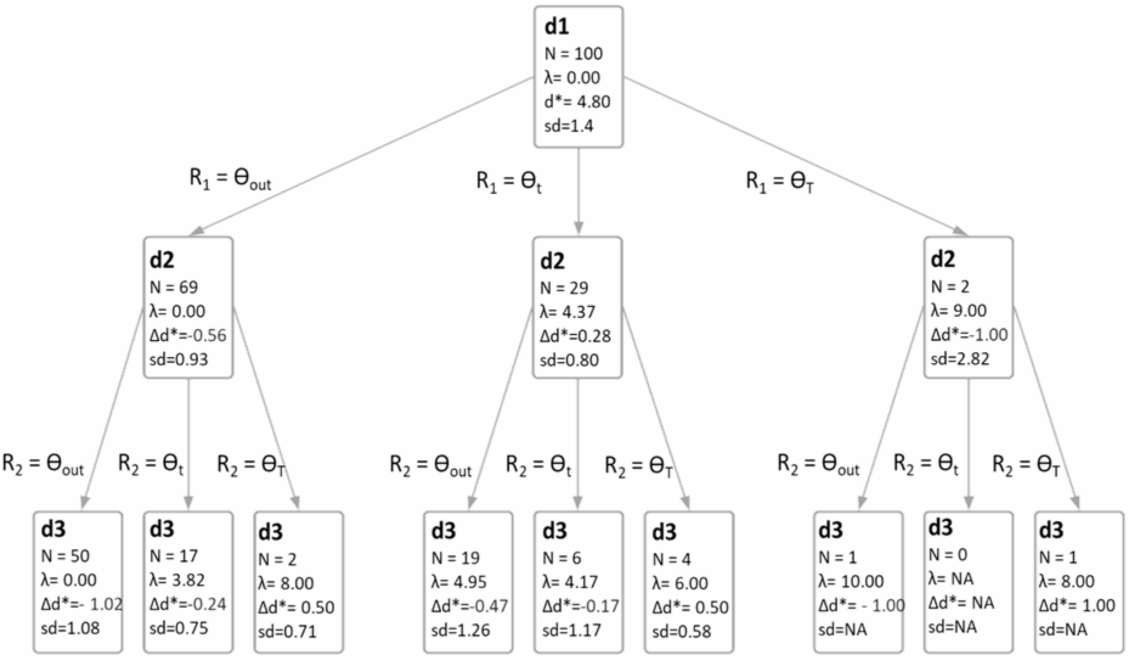

Figure 4. Decision tree with observed results of the experiment.

In the first trial, the theoretical model suggests that the distance providing the highest expected value was 4.12 meters. We need to assume that subjects compute the probability function (and that the error of those who overestimate was compensated for by those who underestimate). As shown in Figure 5, the average distance was 4.8 meters ($SD = 1.41$). Specifically, 33 of the 100 subjects threw the airplane from a distance of 4 meters; 13 threw from a position closer to the target and may therefore be assumed to exhibit risk averse attitudes[1] (Kahneman and Tversky 1979), and 54 chose a distance greater than 4.12 meters and could be considered risk lovers.[7] (Kahneman and Tversky 1979), while 54 out of the 100 subjects could be considered risk lovers, since they chose a distance greater than 4.12 meters.

[7] Compared to the existing literature, this share of risk averse subjects is low. A plausible explanation is that subjects were aware of a second (and even third) change to improve their outcomes. As Cox et al. (2015) showed, risky behavior is sensitive to the payment method.

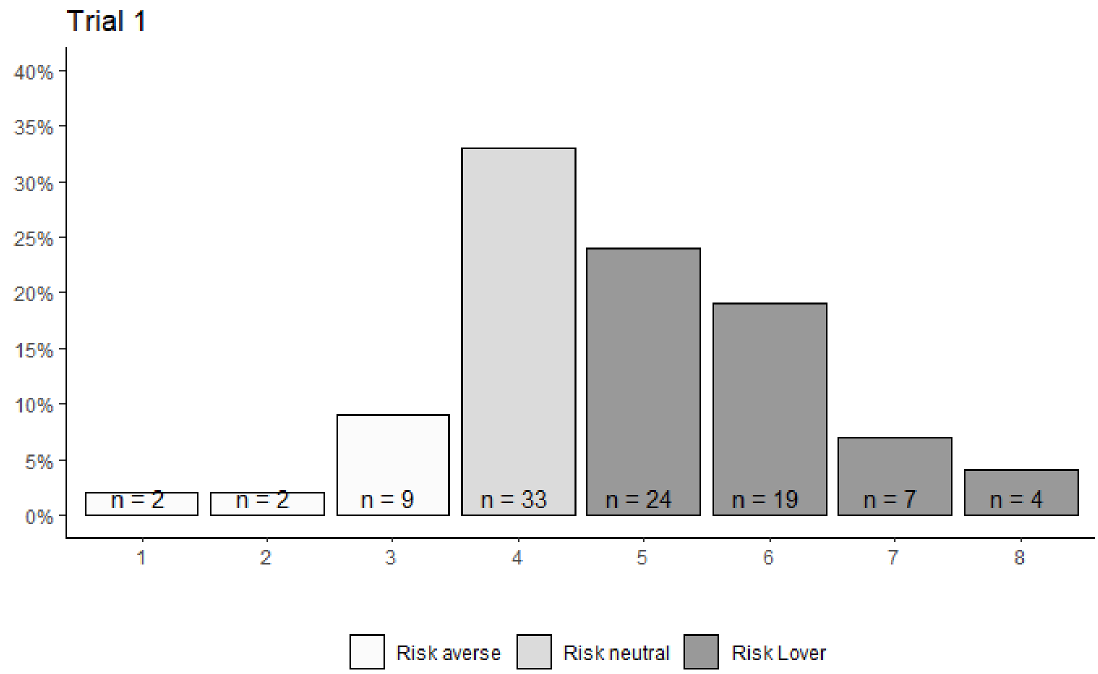

Figure 5. Decisions in Trial 1 and classification of subjects.

We also found that subjects who managed to hit the target and those who did not differ in terms of the chosen distance. Those who hit the target (31 out of 100) threw from 4.39 meters (*SD* =1.358), while those who did not (69 out of 100) threw from 4.99 meters (*SD* = 1.409). This difference is significant ($p = .08$). Hence, those who chose to throw farther we were less likely to win.

5.2. Subjects with λ = 0 (cumulative payoffs = 0)

Now we study the behavior of subjects who faced exactly the same maximization problem three times. Fifty subjects failed in the first and second trial, so their cumulative gain was zero ($\lambda = 0$) in all decisions. Recall that, optimally, they should not adjust the distance but keep their original choice.

Figure 6 shows that these 50 participants reduced (on average) the distance across trials. Between the first trial and the second, there was an adjustment of -0.52 meters ($p = .002$), while between the second and the third trial the adjustment was -1.02 meters ($p = .001$).[8]

[8] Interestingly, 4 subjects went the opposite direction (trying a greater distance). This pattern might be consistent with a behavior referred to as "in for a penny, in for a pound" (Campbell-Meiklejohn et al. 2012).

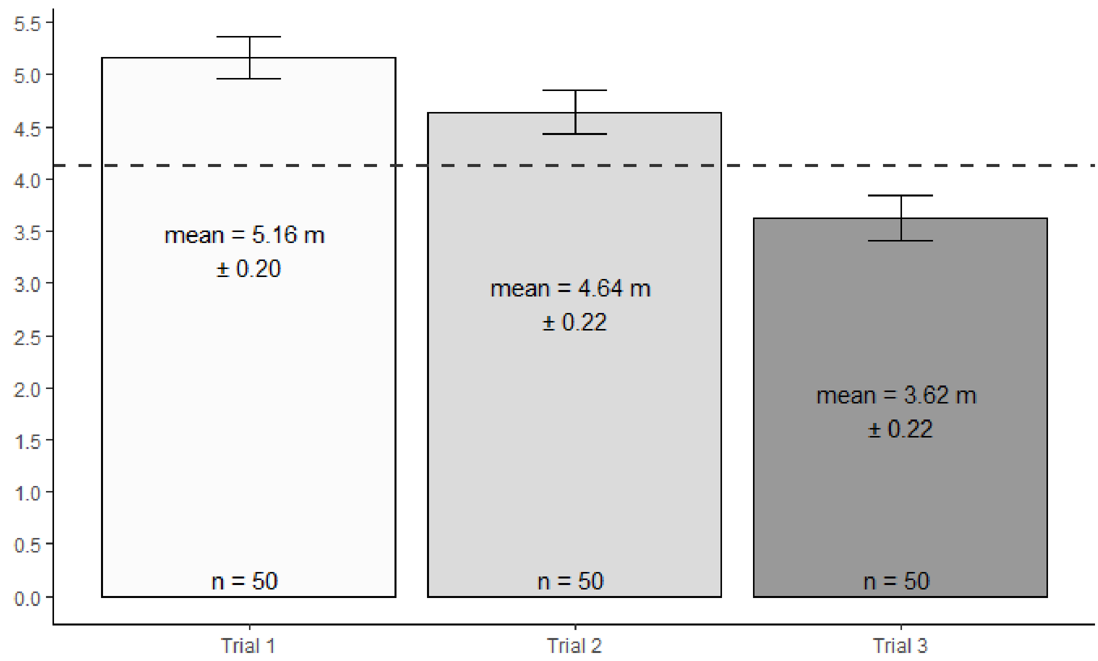

Figure 6. Average decisions by trial for the 50 subjects with $\lambda = 0$. The dashed line shows the theoretical prediction for $\lambda = 0$.

One way to explain these non-optimal choices is to assume that subjects are trying to learn about their own abilities. When subjects failed, they decreased the distance to improve their chances of hitting the target. However, this process proved to be unsuccessful since they failed again. Another explanation is that the subjects changed their behavior across trials, implying that subjects were risk lovers when they had more opportunities and risk averse (mean = 3.62) in the last trial. On top of that, another plausible explanation is that subjects are not maximizing utility but taking into account other considerations such as social reputation or self-respect (Bénabou and Tirole 2006)

4.3 Econometric analysis

In this section, we study subjects' choices (*distance*) using linear regression (OLS). The list of independent variables includes: (*i*) cumulative payoffs, λ; (*ii*) age and gender; (*iii*) learning (trials); *iv*) $\lambda = 0$ points (and 1 otherwise); (*vi*) the theoretical threshold: $\lambda > \frac{A}{B}$ points (1 and 0 otherwise).[9] We use robust standard errors in all regressions.

[9] As explained in the model, the theoretical thresholds define the distance that maximizes the probability of getting the higher payoff (*T*). For the regression we use the highest one.

	distance (d)				
	(1)	(2)	(3)	(4)	(5)
cumulative (λ)	0.07	0.07	0.12***	0.48***	0.89***
female		-0.03	-0.04	-0.09	-0.13
age		-0.005	0.001	-0.02	-0.05
trial 2			-0.51**	-0.37*	-0.45**
trial 3			-1.11***	-0.94***	-0.85***
zero (λ=0)				2.12***	3.57***
threshold ($\lambda > \frac{A}{B}$)					-3.24***
constant	3.83***	3.96***	4.32***	2.73*	2.08
Controls	Yes	Yes	Yes	Yes	Yes
Observations	300	300	300	300	300
Adjusted R^2	0.09	0.09	0.16	0.22	0.25

Table 1. OLS regression models. We use robust standard errors in all regressions. Controls include weather conditions. * $p < .10$, ** $p < .05$, *** $p < .01$.

We focus on the last model (5). We observe that (*i*) the distance is increasing with λ ($p < .001$). (*ii*) Gender ($p = .428$) and age ($p = .362$) are not correlated with decisions. (*iii*) Subjects reduce the distance across trials (Trial 2, $p = .028$; Trial 3, $p < .001$); in other words, subjects become cautious as the game progresses. (*iv*) Subjects with no success ($\lambda = 0$ points) choose farther targets ($p < .001$). (*v*) Those who pass the theoretical threshold ($\lambda > \frac{A}{B} = 6.43$ points) chose closer targets ($p < .001$).

5. Conclusions

This paper shows an outdoor activity designed for students to experience decision making under uncertainty and introduce them to concepts of risk, payoffs, expected payoffs, and attitudes toward risk.

Students were first asked to make a paper airplane and then throw it in order to hit a large target or a small one (double points). They were given three chances to hit the targets. Overall, we find that subjects who are more cautious are more likely to hit the target and there is no gender bias. On average, those who hit the target increased the distance in the next round, while those who do not hit the target decreased the distance.

We present a model to explain subjects' behavior across the game and classify them according to their choices as neutral, averse or risk lovers. Our model predicts that successful subjects will increase the distance, but those who do not hit the target will not decrease the distance. Using subjects' choices across the outdoor activity, we classify them according to the model and show whether they play optimally or not. Interestingly, our results are informative to explain behavior according to the theory and deviations from it.

Overall, out setting was successful in incentivizing students to perform all the tasks and later fostering their interest in this topic, which, as we said before, is typically too abstract for undergraduate students to grasp.

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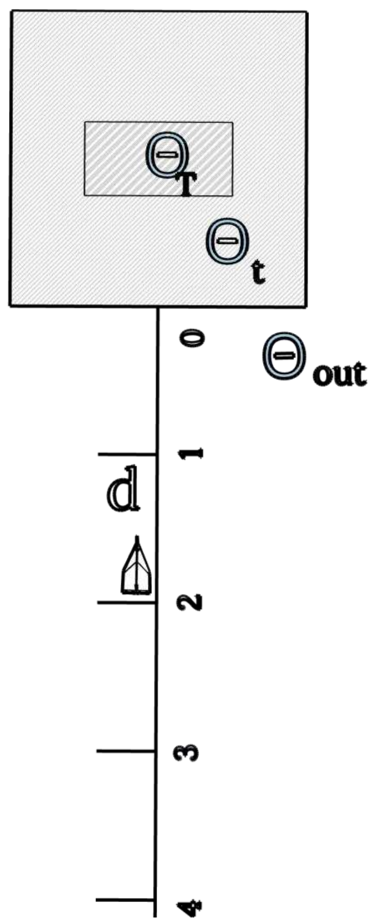
Appendix

Instructions

Build an airplane with the paper we have given you. Consult a tutorial on the internet if you do not know how to make one. Copy this table on the wing of your airplane.

	Trial 1	Trial 2	Trial 3
Name:	d1= ( ) R1 = ( )	d2= ( ) R2 = ( )	d3= ( ) R3 = ( )

Before starting the trial you need to decide from what distance (*d*) you are going to throw your airplane. Please write down the number (*d* in meter) on the airplane.



The points you earn will depend on the distance and the place where your airplane lands.

- $\Theta_T = 2 \times distance$
- $\Theta_t = distance$
- $\Theta_{out} = 0$

Write your decision (*d*) on the airplane wing.
Throw your airplane and write down the result.
R = *T, t,* or *out.*

Wait for all your teammates to throw their airplanes.
Later, you will repeat this step again twice (Trial 1, Trial 2, and Trial 3).

Your score for this task is the maximum trial points.