# Measuring Attitude towards Risk Treatment Actions amongst Information Security Professionals: an Experimental Approach

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**Abstract**

Risk management lies at the core of information security. Professionals need to assess risk and make decisions on how to treat risk. Risk perception and judgement of individuals are inherently involved in this process. This paper examines information security professionals' attitude to risk. We conduct an online experiment and survey which solicits preferences using risky lotteries. We also test whether framing of decisions as gains, losses, or individually separated losses has an effect on their risk attitude. Framing is found to diversify professionals' risk behaviour significantly. Our findings suggest that professionals reveal a preference for paying to reduce risk instead of paying to eliminate it. They also prefer to reduce the expected loss of threat scenarios rather than reducing the vulnerability associated with this loss. Overall, professionals are risk averse when they face lotteries with small probabilities of loss and risk seeking for lotteries with large probabilities.

## 1 Introduction

Perception of risk and attitude towards risk are concepts that have been extensively studied in the field of behavioural economics [35, 37]. Individual

*risk perception* refers to people's judgement and evaluation of a hazard. *Risk attitude* is the individual's intention to evaluate and act on a risky situation [43]. Behavioural research has revealed systematic violations of expected utility theory [52] suggesting that decision-makers as rational agents are rarely observed in real-world decision-making scenarios.

Individual risk perception is important in information security because it constitutes a critical factor in decision-makers attempts to optimise spending on security measures designed to avoid or mitigate against security breaches. A large literature in information security has shown that these breaches can be large and costly [17, 36, 38] and managing their associated risk is thus important to firms' profitability[1].

However, the context of information security is more complicated and it involves a number of decision points that require separate attention. For this reason, in this paper we examine whether risk attitude of professionals hinders expected value optimisation of decision-making in the risk management process. Our contribution is to specify the points that allow for the manifestation of potential biases throughout the risk management process (Sections 4.1 and 4.2) by measuring variations of risk attitude from the expected value maximisation model. We also show that framing of risk decisions as gains or losses can have a measurable effect on risk attitudes (Section 4.3). This is important for decision-making within firms as distorted risk perceptions are very likely to become a direct or indirect influence for investment decisions.

For example, an information security professional in an organisation needs to protect an asset of specific value against a threat. She possesses historical data on the frequency of this threat materialising, but data provides only an estimation of the threat probability. She has conducted an assessment on how vulnerable the asset is and she needs to decide whether additional protection is needed based on the expected value of loss. She might consider accepting the risk and do not invest or she might propose investing in security measures for reducing the identified vulnerability. Alternatively, she can choose to implement measures for containing the potential damage in case it occurs, instead of making the asset less vulnerable. Finally, she can buy insurance in order to transfer the risk. In this scenario the professional might have preferences over the available actions, even if the expected value of the alternative choices is the same. The professional can view protection of the asset as a necessary cost subtracted form the budget, or she can view it as an investment with business return. Her view, might

[1]However, we need to be sceptical on the interpretation of information security survey data [16] and the number and size of security breaches [12].

diversify her willingness to invest. In addition, the entire budget for protecting all assets might be initially allocated or a per-project budget could be allocated instead. The investment decision that the professional makes is potentially influenced both by these factors and by her individual attitude to risk. In such a case, decisions are very likely to be suboptimal by not maximising the organisation's profits.

Risk attitude can be examined by willingness-to-pay (WTP) and is the most obvious point for the manifestation of biases in preferences that are measured over prospects, i.e. lotteries with assigned likelihood and outcomes. A lottery or prospect is defined as "a list of consequences with associated probabilities"[10]. As Bruce Schneier phrased it, "Probabilities permeate cryptography, computer security, risk assessment, countermeasures... Risk is a probability. Security is a probability."[45]. But, assessing risk – at least in a practical, quantitative fashion – is subject to three limitations [14]:

1. Many approximations are involved in the process, e.g. due to uncertainty and unknown risks;

2. These approximations can be biased by the decision-maker's perception of risk, and;

3. Involved calculations conducted by the decision-maker can be easily manipulated.

In previous work [39] we investigated decision-making biases and risk attitude of information security professionals in terms of WTP in order to avoid risky and ambiguous lotteries. We examined risk attitude of security professionals in comparison with the general population and we found behavioural patterns of professionals to be measurably diversified from these of the general population. We also found that professionals are risk and ambiguity averse and that they consider small losses as inevitable and we confirmed the four-fold pattern of risk attitudes that was introduced by Kahneman and Tversky [34]. Professionals are risk-averse for small probability losses ($p \leq 0.15$) and become risk-seeking when losses are associated with large probabilities ($p = 0.5$). In this experiment, we intend to expand on previous findings by examining professionals' behaviour in information security related tasks. Namely, we present professionals with both abstract and scenario losses-only lotteries asking for their WTP in order to either reduce loss probabilities or reduce negative outcomes or eliminate risk completely. We also place professionals randomly into three groups in which decisions are framed as gains, losses, or individually separated losses.

The rest of the paper is organised in the following way. In Section 2 the background and theoretical framework of the study is presented. Section 3 presents the methodology, hypotheses and design of the experiment and survey. Detailed data analysis along with findings constitute Section 4. A discussion of the main findings and their potential implications takes place in Section 5 and we conclude in Section 6.

# 2 Approach and Background

## 2.1 Approach

Economic aspects of information security with behavioural extensions were initially pointed out by Anderson [4, 5]. Subsequently, studies on various behavioural aspects of information security [3, 13, 21] have become more frequent. Researchers have focused on the decision-making process [2, 30] and proposed models for security investment [11, 22]. However, real world investment can be environment-specific depending on the organisational structure [7] and the roles of the involved risk owners and stakeholders [8]. Risk management and policy [9, 23, 32] constitute the framework in which investment decisions are made. Decisions are inherently related with perception of risk, which entails a variety of dimensions [31, 41].

In this study we show that throughout the risk management process there are certain decision points that are susceptible to individuals' subjective and potentially biased risk perception. We examine experimentally elicited risk attitude of information security professionals and analyse their behaviour against expected utility theory [52]. We target two activities in the risk management process: risk analysis and risk treatment.

The ultimate goals of this study, are to provide a clearer understanding of the role of professionals' "judgement" in risk management and to indicate approaches to minimising the effects of potential decision-making biases.

## 2.2 The Risk Management Process

The International Organization for Standardization (ISO) is probably the most widely accepted, independent, non-governmental membership organisation and largest developer of international standards. The ISO/IEC 27000 series of standards is dedicated to information security and is published collaboratively by ISO and the International Electrotechnical Commission (IEC). These standards have been embraced by the information security industry [29], and certification against certain standards in the series has been made mandatory by a number of governments worldwide.

Risk management is defined in ISO Guide 73 [27] as the "coordinated activities to direct and control an organization with regard to risk". The overall process of risk management is defined as "a systematic application of management policies, procedures and practices to the activities of communicating, consulting, establishing the context and identifying, analysing, evaluating, treating, monitoring and reviewing risk". The set of activities that comprise the risk management process can be broadly categorised as either risk assessment or risk treatment. Risk assessment, consists of:

1. Risk identification: where threats and vulnerabilities are found, identified, and described.
2. Risk analysis: where the nature and level of risk is estimated.
3. Risk evaluation: where the risks are evaluated against the organisation's risk criteria.

Risk treatment consists of "what to do with the risks at hand", e.g. implementing controls in order to reduce, retain, avoid, or share risks depending on expected costs and benefits [28].

The four risk treatment actions are defined in the following way. Risk *reduction* or *modification* refers to the action of reducing the probability of loss, or the loss itself. The action of *retaining* risk, is the choice by which the decision-maker *accepts* the identified risk as it is. Risk *avoidance* is usually the business decision by which the scope of the organisation changes, and therefore there is no exposure to certain threats. Finally, risk *transfer* refers to the action in which risk is *shared* with some other party, usually by purchasing insurance.

It is widely accepted that "judgement" is not only unavoidable, but also necessary for managing risk successfully. There are two clear, albeit very general, suggestions in ISO 27005 [28] for efficient risk treatment:

- Judgement should be exercised in certain cases for the justification of decisions, and;
- Perception of risk by affected parties should be taken into account.

However, individual expert judgement cannot be easily "put into moulds" and worryingly has been shown to be far from optimal in many areas of expertise [15, 20, 24, 25, 49], mostly because experts reveal subjective preferences, choice inconsistencies and cognitive limitations [47].

One further factor that needs careful consideration is how to find the "most appropriate ways to communicate risk" to involved parties [28]. However, just as there is no unified approach to measuring perceived risk, neither is there a well-defined methodology for risk communication. To our knowledge, behavioural issues associated with the decision points of the risk management process, have not been extensively studied, especially, from the perspective of the ISO 27000-series.

# 3 Methodology

## 3.1 Research Hypotheses

We conducted an online experiment and survey, in order to analyse behaviour of security professionals based on the following hypotheses:

1. *Information security professionals reveal preferences over risk treatment actions*: In this hypothesis, our intention is to examine whether security professionals are favourably dispositioned towards accepting, eliminating or reducing risk. We examine whether professionals prefer to eliminate risk completely (e.g. buy insurance) rather than reducing either the probability or the outcome of a lottery, if the expected value of the outcomes of the alternative actions is the same. Consequently, we expect participants to be willing-to-pay relatively more for eliminating risk (avoiding the lottery) completely, instead of minimising it. The means by which we examine whether professionals accept risk is by comparing their WTP against the expected loss of each lottery; in case participants are willing to pay less than the expected loss (or state a zero WTP) they are risk seeking and thus, in a sense, they accept risk.

2. *Information security professionals reveal preferences between reduction of probabilities and reduction of outcomes*: Based on expected value maximisation, a rational decision-maker is not expected to differentiate between reducing the probability of a loss and reducing the loss itself in a case where both reductions reduce expected losses by the same amount. We hypothesise that professionals will exhibit behavioural traits to favour the reduction of probabilities over the reduction of negative outcomes. The reason is that probabilities, but not consequences, dominate choices in "good or bad" lotteries. This can be explained by the existence of an experiential form of thinking involved in decisions (proportion dominance), as well as an analytical one [46]. Traditional information security approaches are mostly focused on prevention of losses (proactive security). A more recent approach highlights the importance of loss containment as well (reactive security

[6, 48]). Perception and consequently preference between reduction of probability and reduction of losses, is vital in information security, it has not attracted proper attention, however. We test such a potential preference via WTP for reducing risk in abstract lotteries.

3. *Framing of decisions as gains or losses influences the risk attitude of professionals*: We test the effects that framing of lotteries as losses or gains has on risk attitude. In other words, whether the manner of presentation or communication of a risk situation affects professionals' choices.
   A common view in information security is that investment in a security measure is perceived as a loss and that the maximum "gain" is a zero loss. However, information security can be also viewed as a gains-generating business component. Our goal is to examine differences in the risk attitude of professionals, by randomly assigning them to groups of different framing and asking for their WTP to avoid lotteries or reduce risk in abstract lotteries. We use three conditions for framing: losses, gains and a step-by-step losses procedure which will be explained in detail in Section 3.2.3. Previous research on framing effects, starting from Kahneman and Tversky [51], concludes that decision-makers are generally risk averse in choices involving gains and risk seeking in choices involving losses.

4. *Four-fold pattern of risk behaviour*: The prediction of prospect theory states that decision-makers are risk-averse for small-probability losses and large-probability gains and risk-seeking for small-probability gains and large-probability losses [34]. Risk aversion for large-probability gains is caused by fear of disappointment whereas risk aversion for small-probability losses is caused by fear of loss. In contrast, risk-seeking behaviour for large-probability losses and small-probability gains is caused by hope to avoid loss and hope to receive a gain, respectively. We expect to detect this pattern for the lotteries used throughout the experiment.

### 3.2 Design

The majority of the 78 participants in the experiment and survey are working information security professionals who are current students and alumni of the on-campus and distance learning MSc programmes in Information Security offered by Royal Holloway, University of London (RHUL). Replies were collected online between 22/01/2016 and 14/02/2016.

We use abstract lotteries in order to examine context-free risk attitude of subjects and scenario-type lotteries framed as information security problems to examine decisions in context. The lotteries used to elicit risk attitude are

an adjusted version of those used in our previous study [39]. We set three probabilities of loss ($p_1 = 0.05$, $p_2 = 0.15$ and $p_3 = 0.5$) to reflect a realistic range of breach probabilities in information security[2]. Participants were presented with 27 lotteries in three treatment groups (nine in each group), nine abstract lotteries that are common to all subjects and another nine common-for-all scenario-based lotteries; there was also one lottery used for participants' payments. A complete list of the lotteries can be found in Appendix A.1.

Participants were informed that their reward was choice-dependent, but they did not know which lottery they would be paid for. Payment was based on their choice in one specific lottery in which they were asked to chose between three mean preserving spreads (see "Payment Lottery" in Appendix A.1). Participants' choice indicated the range of potential outcomes and a pseudo-random javascript function determined the amount of payment. All payments were sent to participants in the form of an Amazon gift certificate (via the Amazon website of their preference).

### 3.2.1 Hypothesis 1: Preferences over risk treatment

For the first hypothesis we used nine abstract lotteries labeled as $L_{ij}$ and another nine scenario-based lotteries labeled $SL_{ij}$, with $i = 1, 2, 3$ and $j = A, B, C$ (see all lotteries in Appendix A.1 and definitions of variables in Appendix C). Each of the six lotteries $L_1$ to $L_3$ and $SL_1$ to $SL_3$ was presented to participants followed by three risk treatment actions: A, B and C. "A" refers to a lottery that proposes reduction of the *probability* of loss, and was phrased as: *"What is the maximum amount that you are willing to pay in order to reduce probability of loss from $p_1$% to $p_2$%?"*.

In a similar fashion, "B" refers to the reduction of the *negative outcomes* of the lottery: *"What is the maximum amount that you are willing to pay in order to reduce potential loss from \$$x_1$ to \$$x_2$?"*.

"A" and "B" represent risk reduction (modification) actions. Lotteries with label "C" represent risk elimination (avoiding playing the lottery) and were phrased in the following way: *"What is the maximum amount that you are willing to pay in order to avoid playing the lottery completely?"*[3].

In particular, for scenario lotteries $SL_{ij}$ we consider an asset of spe-

[2]The instrument follows the design logic of the Holt and Laury instrument [26] and shares similarities with the alternative instrument of Moore and Eckel [40].

[3]Reducing risk is related to the term "risk modification" and paying in order to eliminate risk (i.e. paying for not playing the lottery) is related to "risk transfer", as will be argued in the Discussion Section 5.

cific value and we ask participants to state their WTP in order to modify or eliminate the risk from a potential breach of confidentiality, integrity or availability (Appendix A.1). We use asset value as the potential loss of the scenario, as it is common practice to assess risk considering the overall value of an asset [18, 50].

For the purposes of this study, we do not consider the risk treatment action of risk *avoidance* (as defined in ISO 27005 [28]), as it is usually related to changing business operations in order to keep away from certain threats. The risk treatment action of risk *acceptance* is also available to participants, represented by a WTP of zero[4].

### 3.2.2 Hypothesis 2: Preferences between probabilities and outcomes

The design of this hypothesis is embedded in the design of the first hypothesis. The scope here is to examine the pairs that only have to do with risk modification, i.e. with WTP for reducing probability of loss and WTP for reducing the magnitude of the negative outcomes. What is examined here is the differences amongst lottery pairs ($L_{iA}$, $L_{iB}$), for the abstract lotteries, and ($SL_{iA}$, $SL_{iB}$), for the information security scenario lotteries, for $i = 1, 2, 3$.

### 3.2.3 Hypothesis 3: Framing of decisions as gains or losses

This hypothesis is tested in the experiment by creating the following treatment: subjects were randomly divided into three groups. Each group was presented with nine lotteries, with a different framing. The first group of participants, *Group A*, was presented with the following setting:

"In the first stage of the experiment you are asked to make decisions in three lotteries. The lotteries have potential losses and you have an initial amount of money = \$30. In each lottery, you have to specify the maximum amount that you are willing-to-pay so that you can modify lottery values or avoid the lottery completely."

This constitutes the loss-framing, as participants had to face either zero losses or suffer losses that were to be reduced from their given amount. In a similar fashion, *Group B*, the gain-framing group, presented participants with lotteries that involved gains-only, and participants started without any

[4]No lottery from the three treatment groups was used in this hypothesis, although group-lotteries have the same structure. This is because group-lotteries were not fully randomised and participants often try to be consistent in their replies when they face similar questions.

monetary amount (see Appendix A.1). Finally, the third group, *Group C*, was a mixture of gains and losses, in the following way: participants were given an amount of \$10 to play before they made choices in each of the three lotteries. The lotteries involved losses-only again, so this condition can be considered as a "step-by-step" loss-framing, in order to model decisions that are considered by decision-makers one at a time and independently from one another.

All group lotteries had a maximum gain or loss outcome of \$10 in order to diversify the outcome level from other hypotheses (that have a maximum loss of \$50). The nine lotteries of each group were presented in collections of three. The characteristic that we measure across the three groups is the difference between WTP and the change in the expected value of each lottery from $L_i$ to $L_{ij}$: $RA\_L_{ij} = L_{ij} - EV\_L_{ij}$ for $i = 1, 2, 3$ and $j = A, B, C$; equivalent variables are used for the scenario-type lotteries $SL_{ij}$ (see Definitions in Appendix C). Positive values of the $RA\_L_{ij}$ variables imply risk aversion, whereas negative values denote risk-seeking behaviour.

### 3.2.4 Hypothesis 4: Four-fold pattern of risk behaviour

The design used for the last hypothesis is the creation and use of the "risk aversion variables" ($RA$) mentioned in the previous hypothesis. These variables are analytically convenient as they have zero as a reference point, against which risk attitude is measured.

### 3.2.5 Order Effects

The whole design includes randomisation of certain parts, in order to avoid order effects. Firstly, the three framing groups were randomly assigned to participants. A counter was used to check the number of replies in each group so that groups could be kept at similar sizes. The number of valid responses was $N = 78$, and these were split into $N_A = 25$, $N_B = 28$ and $N_C = 25$ for groups A, B and C, respectively. The lotteries of each group were then presented in a fixed order.

The nine abstract lotteries and the nine scenario-type lotteries spanned across three levels of probabilities ($p_1 = 0.05$, $p_2 = 0.15$ and $p_3 = 0.5$), with three lotteries being assigned into each probability level (see Appendix A.1). Lotteries were presented in ascending probability level order. The presentation order of lotteries inside each level was fully randomised, i.e. for lotteries $L_{ij}$ and $SL_{ij}$ presentation order of $L_iA$, $L_iB$ and as $L_iC$ was randomised for each $i = 1, 2, 3$ (see Appendix A.4).

# 4 Analysis and Findings

Analysis for each hypothesis is presented in this section. In all hypotheses except one, we use non-parametric tests since these do not require any assumptions about the sample distribution (e.g. normality)[5].

## 4.1 Preferences over risk treatment actions

**Finding 1**: Information security professionals reveal a preference for paying to reduce risk compared to paying to eliminate risk, in information security scenarios.

**Finding 2**: The possibility of eliminating risk by paying does not have an additional effect on professionals' risk attitude compared to the option of reducing risk.

**Finding 3**: Information security professionals are willing to accept some risk by being risk-seeking for large probabilities of loss.

The scope of the first hypothesis is to examine whether there is a preference amongst actions by which risk can be treated. In particular, participants were presented with losses-only lotteries and they were asked about their WTP regarding the risk treatment actions of risk reduction, elimination and acceptance. Risk reduction is expressed by two variables (lotteries) and risk elimination by another one, so we need to examine WTP differences per individual across these three variables (see Table 1). Risk acceptance corresponds to WTP that is less than the expected loss of a lottery.

The absolute difference between the expected value of the original lotteries $L_i$, $i = 1, 2, 3$ and the expected value of lotteries with modified risk (lotteries with index "A" and "B") is the same for each $L_i$, and we symbolise these differences as "$Delta\_EV\_$". The equivalent absolute difference for lotteries of type "C" is double that of "A" and "B" (Table 1). For this reason, for the analysis, we halved the WTP values that correspond to $L_{iC}$ and $SL_iC$, $i = 1, 2, 3$ (variables indicated by "*_half*"; see definitions of variables in Appendix C). This way we compare WTP of each participant indirectly. We use the non-parametric within-subjects Friedman test [19] which is used to compare differences between more than two conditions for continuous or ordinal dependent variables. A risk neutral decision-maker with a linear utility function should reveal multiple WTP for dealing with multiple expected losses. In this case, risk elimination allows for avoiding the lottery completely, whereas risk modification (reduction) only halves the expected

[5]The sample size $N = 78$ is sufficient for the parametric one-sample t-test at level $p = 0.05$ with statistical power 0.8, for observed values of $\mu$ and $\sigma$ [44].

loss of the lotteries (see all lotteries in Appendix A.1); therefore objective decision-makers are expected to be willing-to-pay double in the risk elimination lotteries compared to their WTP in the risk reduction lotteries.

**Table 1:** Initial and adjusted lotteries with probability $p$ and loss $x$. $\Delta$EV is the expected value difference between initial and adjusted lottery.

| **Experiment (Abstract) Lotteries** $L_{ij}$ | | | |
|---|---|---|---|
| Variable | Initial Lottery | Adjusted Lottery | $\lvert\Delta EV\rvert$ |
| $L_1A$ | $p = 0.05,\ x = -50$ | $p = 0.025,\ x = -50$ | 1.25 |
| $L_1B$ | | $p = 0.05,\ x = -25$ | 1.25 |
| $L_1C$ | | $p = 1,\ x = 0$ | 2.5 |
| $L_2A$ | $p = 0.15,\ x = -50$ | $p = 0.075,\ x = -50$ | 3.75 |
| $L_2B$ | | $p = 0.15,\ x = -25$ | 3.75 |
| $L_2C$ | | $p = 1,\ x = 0$ | 7.5 |
| $L_3A$ | $p = 0.5,\ x = -50$ | $p = 0.25,\ x = -50$ | 12.5 |
| $L_3B$ | | $p = 0.5,\ x = -25$ | 12.5 |
| $L_3C$ | | $p = 1,\ x = 0$ | 25 |

| **Survey (Scenario) Lotteries** $SL_{ij}$ | | | |
|---|---|---|---|
| Variable | Initial Lottery | Adjusted Lottery | $\lvert\Delta$EV$\rvert$ |
| $SL_1A$ | $p = 0.05,\ x = -75,000$ | $p = 0.025,\ x = -75,000$ | 1,875 |
| $SL_1B$ | | $p = 0.05,\ x = -37,500$ | 1,875 |
| $SL_1C$ | | $p = 1,\ x = 0$ | 3,750 |
| $SL_2A$ | $p = 0.15,\ x = -75,000$ | $p = 0.075,\ x = -75,000$ | 5,625 |
| $SL_2B$ | | $p = 0.15,\ x = -37,500$ | 5,625 |
| $SL_2C$ | | $p = 1,\ x = 0$ | 11,250 |
| $SL_3A$ | $p = 0.5,\ x = -75,000$ | $p = 0.25,\ x = -75,000$ | 18,750 |
| $SL_3B$ | | $p = 0.5,\ x = -37,500$ | 18,750 |
| $SL_3C$ | | $p = 1,\ x = 0$ | 37,500 |

Results indicate that WTP for eliminating risk is significantly *smaller* than for reducing risk. This is clearly depicted in the figures of Appendix B.2, as the smaller ranks of the "$C\_half$" lotteries, indicate lesser WTP. This difference is significant between all pairings of both probability and outcome reduction lotteries ("A" and "B") with the risk elimination lotteries "C". The result is depicted in Table 2, which specifies the significant pairs, and the associated z-scores (standard deviations from the mean, in a normalised distribution) of the Wilcoxon signed rank test[6]. Mean values of each variable also allow for an interpretation of the direction of the differences. For example, given that variables "$C\_half$" have smaller means than variables "A" and "B" for a given $i = 1, 2, 3$, this denotes that differences of the form $L_iA - LiC\_half$ and $L_iB - LiC\_half$ are always positive and so, subjects are willing to pay less for lotteries "$C\_half$". The same result holds for the scenario-type lotteries $SL_{ij}$.

The fact that halved WTP for eliminating risk is smaller than WTP for reducing risk implies an "indirect preference" for risk reduction. The interesting part is that in order to avoid double the expected loss and because risk is eliminated completely in lotteries "C", participants would be expected

[6]For samples with N>10 we have acceptable approximations of the Normal distribution.

**Table 2:** WTP mean values for all lotteries and Wilcoxon Signed Ranks Test for pairwise comparisons between the following within-subjects conditions:
Probability Reduction (lotteries $L_iA$, $SL_iA$), Outcome Reduction (lotteries $L_iB$, $SL_iB$) and Risk Elimination by WTP (lotteries $L_iC\_half$, $SL_iC\_half$).

**Experiment (abstract) lotteries**

| Lottery variable | Mean |
|---|---|
| $L_1A$ | 8.77 |
| $L1_B$ | 7.95 |
| $L_1C\_half$ | 4.28 |
| $L_2A$ | 8.63 |
| $L_2B$ | 9.03 |
| $L_2C\_half$ | 4.31 |
| $L_3A$ | 11.73 |
| $L_3B$ | 11.55 |
| $L_3C\_half$ | 6.53 |

| Compared Pairs | Z |
|---|---|
| ($L_1A$, $L_1B$) | -1.221 |
| ($L_1A$, $L_1C\_half$)*** | -4.771 |
| ($L1B$, $L_1C\_half$)*** | -4.916 |
| ($L_2A$, $L_2B$) | -1.503 |
| ($L_2A$, $L_2C\_half$)*** | -5.985 |
| ($L_2B$, $L_1C\_half$)*** | -6.392 |
| ($L_3A$, $L_3B$) | -.147 |
| ($L_1A$, $L_1C\_half$)*** | -5.847 |
| ($L_1B$, $L_1C\_half$)*** | -5.234 |

**Survey (scenario) lotteries**

| Lottery variable | Mean |
|---|---|
| $SL_1A$ | 7764.99 |
| $SL_1B$ | 10533.88 |
| $SL_1C\_half$ | 6070.60 |
| $SL_2A$ | 10753.14 |
| $SL_2B$ | 12783.05 |
| $SL_2C\_half$ | 8065.85 |
| $SL_3A$ | 17240.65 |
| $SL_3B$ | 19063.21 |
| $SL_3C\_half$ | 12846.50 |

| Compared Pairs | Z |
|---|---|
| ($SL_1A$, $SL_1B$)** | -2.912 |
| ($SL_1A$, $SL_1C\_half$)*** | -5.436 |
| ($SL_1B$, $SL_1C\_half$)*** | -3.511 |
| ($SL_2A$, $SL_2B$)*** | -3.536 |
| ($SL_2A$, $SL_2C\_half$)*** | -5.492 |
| ($SL_2B$, $SL_1C\_half$)*** | -3.453 |
| ($SL_3A$, $SL_3B$) | -.715 |
| ($SL_3A$, $SL_3C\_half$)*** | -4.859 |
| ($SL_3B$, $SL_3C\_half$)*** | -4.520 |

Asymp. Sig. (2-tailed): * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

to state more than double the WTP than in "A" and "B". That is, the certainty of risk elimination should have made participants more willing to pay to avoid the lotteries; but it did not. In other words, participants were not willing to increase their WTP in order to avoid lotteries completely, i.e. either risk elimination (lotteries "C") does not have an additional effect on them, or risk elimination is perceived similarly to risk reduction (lotteries "A" and "B") by the professionals. In this sense, we observe an insensitivity of decision-makers between risk reduction and elimination. The mean WTP for lotteries "C", not only is not double the mean WTP for lottery questions "A" and "B", but it is of similar magnitude. Thus, professionals either underestimate the choice of completely eliminating risk or overestimate the act of risk reduction.

At the same time, professionals remain risk averse for small probability lotteries and become risk seeking for large probabilities of loss (Section 4.4). Therefore, overestimation of risk reduction or underestimation of risk elimination is prevalent across all probability levels and for both risk-averse and risk-seeking behaviour.

The risk treatment action of *risk acceptance* can be considered equivalent to a WTP that is less that the expected loss of a lottery. Such behaviour was observed in lotteries with large probability of loss, as is explained in Section 4.4.

### 4.2 Preferences between probabilities and outcomes

**Finding 4**: Information security professionals reveal a preference for reducing losses in threat scenarios, instead of reducing the probabilities associated with these losses.

This second hypothesis is related to the previous one. In order to measure potential preferences between reduction of *probability* of loss and reduction of *loss* itself, we conduct a number of within-subjects tests in which it is the same subject that provides the input for each test condition. Namely, we compare WTP of each participant on the lottery pairs ($L_{iA}$, $L_{iB}$) and ($SL_{iA}$, $SL_{iB}$), with the corresponding variables serving as the independent variables of the tests. Lotteries with an "A" indicator refer to modification of probabilities and lotteries with a "B" refer to reduction of the potential negative outcomes. We use the non-parametric Wilcoxon signed rank test [53,54] to measure pairwise differences amongst the two conditions of risk modification. The test calculates the absolute differences between related pairs and ranks them in increasing order; it then adds the ranks of negative and positive differences separately. Differences in professionals' WTP amongst the two types of risk reduction are shown in Tables 3 (abstract lotteries) and 4 (scenario lotteries).

It is interesting that professionals revealed a statistically significant preference for the risk treatment action of reducing actual losses, instead of reducing the probability (vulnerability) that could lead to these losses. More importantly, this result is not revealed in professionals' risk attitude on any of the abstract lotteries, but only when professionals face decisions framed as information security scenarios (this is also indicated, but not explicitly stated, in Table 2 of the previous hypothesis).
However, there is no significant difference revealed in the third pair of scenario lotteries. A potential explanation for this fact could be that lotteries $SL_3j$ have a large probability of loss ($p = 0.5$), so perhaps professionals may estimate expected values more easily for these lotteries. Or it could be the case that professionals show such a preference only for small, and more realistic in terms of actual threat probabilities.

We thus see that there is no preference when abstract choices are concerned but, when it comes to information security scenarios, professionals

**Table 3:** Wilcoxon Signed Ranks Test for pairwise comparisons of abstract lotteries between the within-subjects conditions of probability reduction ($L_iA$) and outcome reduction ($L_iB$).

**Wilcoxon Signed Ranks Test**

| | | N | Mean Rank | Sum of Ranks |
|---|---|---|---|---|
| $L_1B$ - $L_1A$ | Negative Ranks | $23^a$ | 33.72 | 775.50 |
| | Positive Ranks | $38^b$ | 29.36 | 1115.50 |
| | Ties | $17^c$ | | |
| | Total | 78 | | |
| a: $L_1B < L_1A$, b: $L_1B > L_1A$, c: $L_1B = L_1A$ | | | | |
| $L_2B$ - $L_2A$ | Negative Ranks | $28^d$ | 32.09 | 898.50 |
| | Positive Ranks | $39^e$ | 35.37 | 1379.50 |
| | Ties | $11^f$ | | |
| | Total | 78 | | |
| d: $L_2B < L_2A$, e: $L_2B > L_2A$, f: $L_2B = L_2A$ | | | | |
| $L_3B$ - $L_3A$ | Negative Ranks | $32^g$ | 36.33 | 1162.50 |
| | Positive Ranks | $35^h$ | 31.87 | 1115.50 |
| | Ties | $11^i$ | | |
| | Total | 78 | | |
| g: $L_3B < L_3A$, h: $L_3B > L_3A$, i: $L_3B = L_3A$ | | | | |

**Table 4:** Wilcoxon Signed Ranks Test for pairwise comparisons of scenario lotteries between the within-subjects conditions of probability reduction ($SL_iA$) and outcome reduction ($SL_iB$).

**Wilcoxon Signed Ranks Test**

| | | N | Mean Rank | Sum of Ranks |
|---|---|---|---|---|
| $SL_1B$ - $SL_1A^{**}$ | Negative Ranks | $23^a$ | 30.28 | 696.50 |
| | Positive Ranks | $45^b$ | 36.66 | 1649.50 |
| | Ties | $10^c$ | | |
| | Total | 78 | | |
| a: $SL_1B < SL_1A$, b: $SL_1B > SL_1A$, c: $SL_1B = SL_1A$ | | | | |
| $SL_2B$ - $SL2A^{***}$ | Negative Ranks | $22^d$ | 26.05 | 573.00 |
| | Positive Ranks | $45^e$ | 37.89 | 1705.00 |
| | Ties | $11^f$ | | |
| | Total | 78 | | |
| d: $SL_2B < SL_2A$, e: $SL_2B > SL_2A$, f: $SL_2B = SL_2A$ | | | | |
| $SL_3B$ - $SL_3A$ | Negative Ranks | $34^g$ | 32.00 | 1088.00 |
| | Positive Ranks | $35^h$ | 37.91 | 1327.00 |
| | Ties | $9^i$ | | |
| | Total | 78 | | |
| g: $SL_3B < SL_3A$, h: $SL_3B > SL_3A$, i: $SL_3B = SL_3A$ | | | | |

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

reveal an inclination towards a reactive, i.e. "try to minimise losses if they occur", rather than a proactive, "try to avoid losses", approach for loss minimisation.

## 4.3 Framing of decisions as gains or losses

**Finding 5**: Information security professionals are significantly more risk-averse when risky choices are framed as gains compared to when choices are framed as losses, in the process of either securing gains or eliminating losses.

**Finding 6**: Information security professionals are significantly more risk-averse when losses are subtracted from individual budgets compared to when losses are reduced from a single budget, in the process of eliminating losses.

The purpose of the corresponding hypothesis is to examine whether the samples of the three condition groups, i.e. framing of decisions as gains, losses, or individually separated losses are drawn from identical populations (see also Section 3.2.3). That is, whether there are differences with respect to the *mean* amongst the three treatment Groups, A, B and C. To test this hypothesis, we used the non-parametric between-subjects Kruskal-Wallis test for all lotteries in the groups (Table 5). In particular, we set a flag variable to denote which group the participant was assigned to, then we unified replies of the three groups into a single variable called $Groups\_L_{ij}$, $i = 1, 2, 3$, $j = A, B, C$. Finally, we computed a new variable to express the difference of WTP from the expected value of each group lottery, symbolised by $RA\_Groups\_L_{ij}$. It was actually these "risk aversion variables" that were used in the non-parametric tests. These variables constitute a transformation of WTP around zero and allow for a comparison across groups, as group lotteries have the same absolute difference in expected value between their original version $Groups\_L_i$ and their modified versions $Groups\_L_{ij}$ (see all the lotteries in Appendix A.1).

Analysis revealed that there is significantly different WTP manifested amongst all questions of type "C" across the groups (see Appendix B.1).
For the lotteries that reveal significantly diversified WTP amongst the three groups, we can see the detailed differences in Figures 1, 2 and 3. Groups A, B and C, correspond to values 1, 2 and 3, respectively; numerical values on the triangle apexes indicate the sample average rank by the Wilcoxon signed rank test for matched-pairs, for lotteries $L_iC$ across the groups. Significantly different pairs are connected with a yellow line.

It is apparent from the average ranks in Figures 1, 2 and 3 that WTP of professionals is significantly larger in the second group, i.e. in the group of the gain-framing. Probabilities of winning in this group were all large ($p_1 = 0.95$, $p_2 = 0.85$ and $p_3 = 0.5$), so it was expected that participants would become very risk averse because of fear of disappointment of not winning anything. In the other groups where we have loss-framing, WTP is significantly smaller. In other words, increased risk aversion in the gain-framing group (denoted by "2" in the triangles), compared to the loss-framing group (denoted by "1") was expected. However, the interesting finding is that risk attitude is also significantly diversified between the loss-framing group ("1") and the step-by-step-loss-framing group ("3"). Distribution of WTP across

**Table 5:** Kruskal-Wallis Test for comparing WTP mean differences across the three independent framing groups (see also Appendix B.1).

| Kruskal-Wallis Test (N=78, df=2) | |
|---|---|
| Lottery | Test statistic |
| $RA\_Groups\_L_{1A}$ | .314 |
| $RA\_Groups\_L_{1B}$ | 2.413 |
| $RA\_Groups\_L_{1C}$ | 23.015*** |
| $RA\_Groups\_L_{2A}$ | .314 |
| $RA\_Groups\_L_{2B}$ | 1.824 |
| $RA\_Groups\_L_{2C}$ | 26.611*** |
| $RA\_Groups\_L_{3A}$ | 5.873 |
| $RA\_Groups\_L_{3B}$ | .466 |
| $RA\_Groups\_L_{3C}$ | 25.616*** |

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

**Figure 1:** Wilcoxon Signed Rank Test pairwise risk aversion comparisons for $L_1C$ (risk elimination) across the three groups.

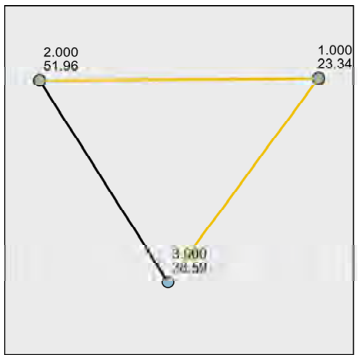



**Figure 2:** Wilcoxon Signed Rank Test pairwise risk aversion comparisons for $L_2C$ (risk elimination) across the three groups.

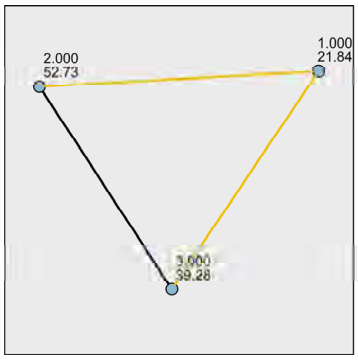
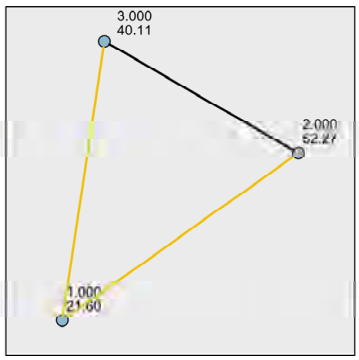



**Figure 3:** Wilcoxon Signed Rank Test pairwise risk aversion comparisons for $L_3C$ (risk elimination) across the three groups.



the three groups is depicted in Figures 4, 5 and 6.

**Figure 4:** Risk Aversion Boxplots for Lottery $Groups\_L_1C$ across the three independent groups. Wilcoxon Signed-Rank Test significant values for comparisons of pairs: Groups A-C ($Z = -2.53$, $p = 0.034$), Groups A-B ($Z = -4.797$, $p < 0.01$).

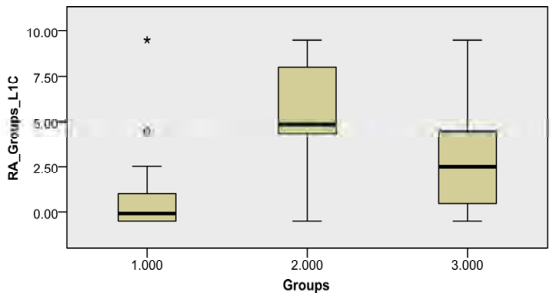



**Figure 5:** Risk Aversion Boxplots for Lottery $Groups\_L_2C$ across the three independent groups. Wilcoxon Signed-Rank Test significant values for comparisons of pairs: Groups A-C ($Z = -2.706$, $p = 0.02$), Groups A-B ($Z = -5.158$, $p < 0.01$).

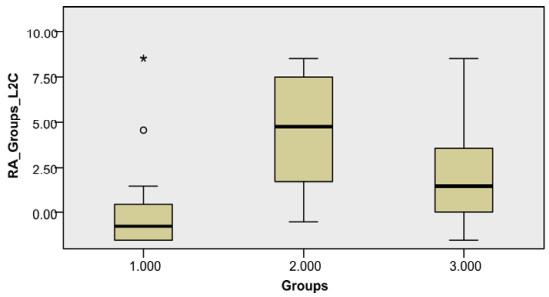
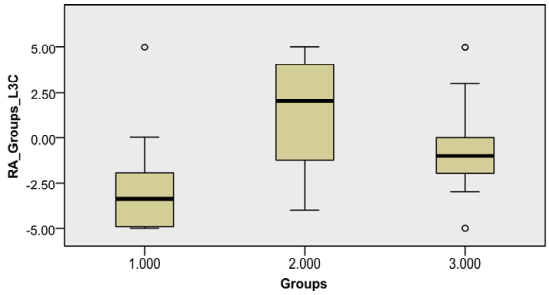



**Figure 6:** Risk Aversion Boxplots for Lottery $Groups\_L_3C$ across the three independent groups. Wilcoxon Signed-Rank Test significant values for comparisons of pairs: Groups A-C ($Z = -2.665$, $p = 0.08$), Groups A-B ($Z = -5.061$, $p < 0.01$).




Although the lotteries involved in the three treatment groups were not randomised in order, the risk attitude pattern that is manifested in all other

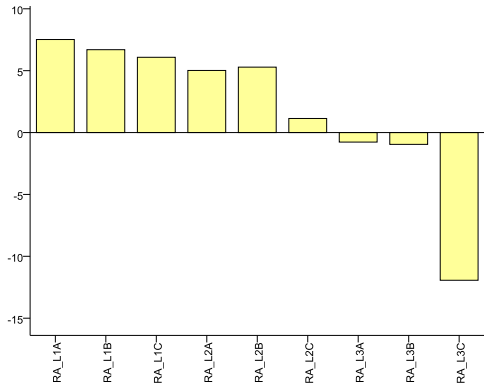
lotteries also holds for the group lotteries. Manifested behaviour confirms the four-fold pattern of risk behaviour that is presented in detail in Section 4.4 (Table 6).

### 4.4 Four-fold pattern of risk attitude

**Finding 7**: Information security professionals behave according to the four-fold pattern of risk attitudes: they are risk-averse for small probabilities of loss and risk-seeking for large probabilities.

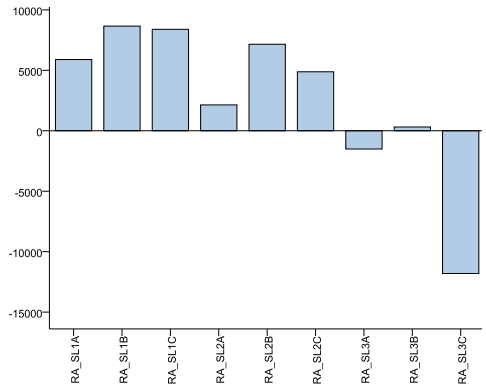
As we observe in Figures 7 and 8, professionals are risk averse for small probability levels ($p_1 = 0.05$ and $p_2 = 0.15$). Risk aversion gradually diminishes from level $p_1$ (first three lotteries in each figure) to $p_2$ (lotteries four to six), until it switches to risk-seeking behaviour (significant for some of the lotteries) at probability level $p_3 = 0.5$ (last three lotteries in the figures). The finding reproduces the prediction of prospect theory [34] for professionals which we also detected in previous research [39].

**Figure 7:** Mean Risk Averse (positive) and Risk Taking (negative) WTP of Professionals per Abstract Lottery. Bars represent participants' mean WTP minus the $\Delta$(Expected Value) between initial and modified lotteries.




Significance of risk aversion in WTP for the lotteries is measured with the parametric one-sample t-test on the "risk aversion variables" and is presented in Table 7 for both abstract and scenario lotteries. The test determines whether the sample belongs to a population of a specific mean, with the mean in our case being the test value zero, which would be the choice of risk neutral decision-makers. The statistical requirements for the parametric test are met. Namely, the dependent variable is measured at least at interval level, data is independent (i.e. between-subjects), significant outliers are of restricted number and, finally, distribution of the dependent variable is approximately normal.

**Figure 8:** Mean Risk Averse (positive) and Risk Taking (negative) WTP of Professionals per Scenario Lottery. Bars represent participants' mean WTP minus the $\Delta$(Expected Value) between initial and modified lotteries.




It is noteworthy that the pattern also persists in the group-lotteries of the previous hypothesis (Table 6), including lotteries with high-probability gains, although presentation order of these lotteries was not randomised.

**Table 6:** Mean differences of risk aversion values $RA\_Groups\_L_i$ from test value zero with the one-sample t-test ($TestValue = 0$, $N = 78$).

| **Group Lotteries (Unified Variables)** ($df = 77$) | | | | |
|---|---|---|---|---|
| Lottery | $\lvert\Delta EV\rvert$ | $\mu$ difference | 95%CI of difference | |
| | | | Lower | Upper |
| $RA\_Groups\_L_1A$ | .25 | $2.30^{***}$ | 1.72 | 2.87 |
| $RA\_Groups\_L_1B$ | .25 | $2.52^{***}$ | 1.99 | 3.04 |
| $RA\_Groups\_L_1C$ | .5 | $3.24^{***}$ | 2.47 | 4.02 |
| $RA\_Groups\_L_2A$ | .75 | $1.80^{***}$ | 1.22 | 2.37 |
| $RA\_Groups\_L_2B$ | .75 | $1.87^{***}$ | 1.41 | 2.32 |
| $RA\_Groups\_L_2C$ | 1.5 | 2.42 | 1.65 | 3.19 |
| $RA\_Groups\_L_3A$ | 2.5 | .38 | -.08 | .85 |
| $RA\_Groups\_L_3B$ | 2.5 | $.55^{*}$ | .08 | 1.01 |
| $RA\_Groups\_L_3C$ | 5 | -.67 | -1.38 | .02 |

$^{*}$ $p \leq 0.05$, $^{***}$ $p \leq 0.001$

**Table 7:** Mean differences of risk aversion values $RA\_L_i$ and $RA\_SL_i$ from test value zero with the one-sample t-test ($TestValue = 0$, $N = 78$).

| **Experiment (Abstract) Lotteries** $L_{ij}$ ($df = 77$) | | | | |
|---|---|---|---|---|
| Lottery | \|ΔEV\| | $\mu$ difference | 95%CI of difference | |
| | | | Lower | Upper |
| $RA\_L_1A$ | 1.25 | 7.52*** | 5.06 | 9.97 |
| $RA\_L_1B$ | 1.25 | 6.69*** | 4.99 | 8.39 |
| $RA\_L_1C$ | 2.5 | 6.08*** | 3.43 | 8.73 |
| $RA\_L_2A$ | 3.75 | 5.02*** | 2.56 | 7.47 |
| $RA\_L_2B$ | 3.75 | 5.28*** | 3.58 | 6.99 |
| $RA\_L_2C$ | 7.5 | 1.14 | -1.12 | 3.39 |
| $RA\_L_3A$ | 12.5 | -.77 | -2.68 | 1.14 |
| $RA\_L_3B$ | 12.5 | -.95 | -2.76 | .86 |
| $RA\_L_3C$ | 25 | -11.93*** | -14.35 | -9.51 |

| **Survey (Scenario) Lotteries** $SL_{ij}$ ($df = 77$) | | | | |
|---|---|---|---|---|
| Lottery | \|ΔEV\| | $\mu$ difference | 95%CI of difference | |
| | | | Lower | Upper |
| $RA\_SL_1A$ | 1,875 | 5,890*** | 3,899 | 7,880 |
| $RA\_SL_1B$ | 1,875 | 8,659*** | 6,296 | 11,022 |
| $RA\_SL_1C$ | 3,750 | 8,391*** | 5,217 | 11,565 |
| $RA\_SL_2A$ | 5,625 | 2,140* | 149 | 4,130 |
| $RA\_SL_2B$ | 5,625 | 7,158*** | 4,505 | 9,810 |
| $RA\_SL_2C$ | 1,1250 | 4,882** | 1,459 | 8,304 |
| $RA\_SL_3A$ | 18,750 | -1,509 | -4,158 | 1,139 |
| $RA\_SL_3B$ | 18,750 | 313 | -2,944 | 3,570 |
| $RA\_SL_3C$ | 37,500 | -11,807*** | -15,220 | -8,394 |

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

# 5 Discussion

In risk management, there is no standard procedure for treating risk and decisions very often depend on the subjective judgement of the decision-maker. The scope of this study was to examine risk behaviour of information security professionals with regards to risk treatment and risk communication.

In the results of the first hypothesis regarding preferences amongst risk treatment actions we observe that professionals preferred to reduce risk rather than eliminate it. These two choices are related with the risk treatment actions of *risk modification* and *risk transfer* (buying insurance), respectively. In the case of insurance buying, risk is transferred to another party. This preference was unexpected as eliminating risk completely should have an amplifying effect on professionals' risk aversion. Perhaps preference for risk modification is related with professionals' roles. It is, generally speaking, their job to modify risk by proposing and implementing security measures, not transfer it to some other party. Perhaps many security professionals see the very existence of their role as one of modification of risk. Another possible interpretation of this result is that professionals diminish

the benefits of transferring risk because they feel that risk cannot be completely eliminated. In addition, there might be a sense of uncertainty and lack of control on professionals' perception when they place security in somebody else's hands. It would be interesting to examine the effect of "having control of your own risk" on professional's risk perception.
This finding implies that professionals could be inclined to invest in security measures, even in situations in which buying insurance would be a more optimal solution in terms of expected returns.

In the second hypothesis we measured differences in WTP between reduction of probabilities and reduction of losses in risky lotteries. The results revealed significant differences between these two actions, in favour of losses reduction. This finding was also unexpected, as previous literature suggests that probability, as a value between zero and one, can be more easily "mapped" in the decision-maker's perception as "good or bad", which is not true for arbitrary outcome values. Thus, decision-makers can more easily characterise probabilities rather than outcomes as preferable or not [46]. However, effects were traced only in lotteries that were presented to the professionals as information security scenarios. This implies that professionals do not reveal such a bias in abstract lotteries, but it was the information security scenarios in which they changed their risk attitude. This means there must be context-related factors that cause preference for loss reduction.
Moreover, significant effects hold for realistically small and moderate probability levels only ($p_1 = 0.05$ and $p_2 = 0.15$). This result might have relevance to the debate between *proactive* and *reactive* security. Namely, measures that reduce probability of loss, i.e. vulnerability, effectively minimise the exposure of an asset to a threat and are therefore proactive. Reactive measures, on the other hand, focus on containing the damage caused, *after* a threat has materialised. Reactive security is constantly attracting attention in the industry [48] and academia [6]. Another explanation for the manifested preference for loss reduction could be that professionals consider security breaches inevitable. Such an argument is reinforced by findings on increased WTP for avoiding small probability lotteries, in our previous research [39]. It could be the case that small losses are perceived as inevitable by professionals and that this leads to amplified risk aversion as well as a tendency to adopt a reactive approach to security. Therefore, professionals could be dispositioned to spend more on business continuity or disaster recovery measures, in comparison to reducing vulnerabilities.

The third hypothesis targeted different forms of risk framing. Three framing groups were used: losses, gains and a mixture with a step-by-step loss-framing. Findings did not reveal differences in the risk reduction variables amongst the groups. However, variables that measure WTP for avoiding lotteries were all found to be significantly different amongst groups.

This difference is two-fold. Firstly, risk aversion is significantly larger for the gain-framing group, compared to the loss-framing group. These results are related to either the *possibility effect* or the *certainty effect* [34]. In the case of gains (Group B), the large probabilities of gaining (0.95, 0.85 and 0.5) accounted for professionals' fear of disappointment, fearing they would win nothing instead of securing the gains. So, they stated increased willingness to pay to secure lottery outcomes (certainty effect). In the case of losses (Groups A and C), the probabilities of loss (0.05, 0.15 and 0.5) also accounted for professionals' fear of disappointment, fearing they would lose something instead of securing a zero loss (possibility effect).

Findings indicate that the certainty effect for gains causes professionals to underweigh very probable gains relatively to certain gains. The possibility effect for losses causes professionals to overweigh unlikely losses. What was found is that the former underestimation is larger than the later overestimation, in absolute terms. Thus, distortion of risk perception in the process of changing risk probabilities for either securing gains or avoiding losses is larger for gains than losses. In this sense, findings comply with prospect theory and, in particular, with risk behaviour across the probability ranges of the four-fold pattern [33]. Additionally, findings allow for a comparison between the magnitude of perceived probability distortion for large-probability gains and small-probability losses. In any case, such risk perception constitutes a violation of expected value maximisation, a fact that should be a concern in risk management.

However, information security can be viewed in two ways: either as a necessary cost, i.e. a costly process with zero return, or as a business enabling operation with return of investment. Findings imply that professionals would be more risk averse and would invest more in the second case. The second interesting result in this hypothesis is that WTP for transferring risk is significantly larger in the step-by-step loss-framing group than in the loss-framing group. In the former group we rewarded participants with a monetary amount of \$10 before each lottery choice. In the latter, we gave them \$30 initially, and then presented them with the same three lotteries. Per-lottery payment made professionals more risk averse, whereas they were less risk averse when they were given the whole amount upfront. Actions of professionals on risk modification were not diversified by framing, but risk aversion was diversified in risk elimination. So, framing does not have effects on attitude towards risk reduction, but it affects perception when paying to eliminate risk. A potential extension of this design in the real world could be a variation in budget allocation. For example, security professionals could be supplied with their entire budget from the start, or they could receive a per-project budget. If we were to hypothetically extend our conclusions, professionals would be significantly more risk averse in eliminating risks by per-project budget allocation. A possible explanation is that the individual's attention on available budget becomes stronger if budget allocation is

more frequent, in contrast to a single initial allocation. Thus, such a budget setting would make professionals spend more on insurance as a security investment.

The manifestation of risk aversion in professionals' decisions underlies the whole experiment. We reproduced the so-called four-fold pattern of risk attitude [34], as subjects are found to be risk averse for small probabilities of loss and became risk-seeking for large probabilities. This pattern is observed in both abstract and scenario-type lotteries, as well as in the group lotteries. Observations also confirmed increased risk aversion for high-probability gains in the group-lotteries. So, for realistic small (to moderate) probabilities of security breaches, we expect professionals to act in a predictably risk-averse manner, by investing more on security measures than the estimated expected loss. However, risk taking for large probabilities of loss implies that professionals are willing to *accept* risk and this might be an issue of concern.

# 6 Conclusion

We conducted an online experiment in order to examine how professionals make decisions at certain decision-points of the risk management process.

Willingness to pay of professionals reveals a preference for paying to modify risk rather than paying to eliminate risk (risk transfer). Professionals are risk-averse for small probability losses only and become risk-seeking as probability of loss increases. Thus, professionals are willing to accept some risk for losses associated with large probabilities.
When presented with information security threat scenarios professionals reveal an inclination for reducing losses instead of minimising the probabilities that generated these losses. So, professionals have distinctive preferences for treating risk, although the expected value of alternatives is the same.

Framing of risk decisions as losses, gains or individually separated losses is shown to diversify risk attitude of professionals significantly. This could mean that targeted interventions in risk presentation and risk communication policies can "nudge" information security investment.

The study of behavioural factors that relate to risk and its treatment provides valuable information for understanding information security professionals' perception and preferences. Such information can be integrated in the design of risk management policies, so that the actual, manifested risk attitude of professionals can be incorporated in decision-making. The formation of such policies is the target of our future research.

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# A Appendix - Experiment Design

## A.1 All Experiment and Survey Lotteries

### Group A

GroupA L1 Lottery1: There is a 5% probability of losing $10 and a 95% probability of losing $0. Your current amount is $30.

GroupA L1A Situation 1: What is the maximum amount that you are willing to pay in order to reduce probability of loss from 5% to 2.5%?
GroupA L1B Situation 2: What is the maximum amount that you are willing to pay in order to reduce potential loss from $10 to $5?
GroupA L1C Situation 3: What is the maximum amount that you are willing to pay in order to avoid playing the lottery completely?

GroupA L2 Lottery2: There is a 15% probability of losing $10 and an 85% probability of losing $0. Your current amount is $30.

GroupA L2A Situation 1: What is the maximum amount that you are willing to pay in order to reduce probability of loss from 15% to 7.5%?
GroupA L2B Situation 2: What is the maximum amount that you are willing to pay in order to reduce potential loss from $10 to $5?
GroupA L2C Situation 3: What is the maximum amount that you are willing to pay in order to avoid playing the lottery completely?

GroupA L3 Lottery3: There is a 50% probability of losing $10 and a 50% probability of losing $0. Your current amount is $30.

GroupA L3A Situation 1: What is the maximum amount that you are willing to pay in order to reduce probability of loss from 50% to 25%?
GroupA L3B Situation 2: What is the maximum amount that you are willing to pay in order to reduce potential loss from $10 to $5?
GroupA L3C Situation 3: What is the maximum amount that you are willing to pay in order to avoid playing the lottery completely?

### GroupB

GroupB L1 Lottery1: There is a 95% probability of gaining $10 and a 5% probability of gaining $0. Your current amount is $0.

GroupB L1A Situation 1: What is the maximum amount that you are willing to pay in order to increase probability of gaining from 95% to 97.5%?
GroupB L1B Situation 2: What is the maximum amount that you are willing to pay in order to increase the potential outcome of gaining nothing to gaining $5?
GroupB L1C Situation 3: What is the maximum amount that you are willing to pay in order to avoid the lottery risk and gain $10 for sure?

GroupB L2 Lottery2: There is an 85% probability of gaining $10 and a 15% probability of gaining $0. Your current amount is $0.

GroupB L2A Situation 1: What is the maximum amount that you are willing to pay in order to increase probability of gaining from 85% to 92.5%?

GroupB L2B Situation 2: What is the maximum amount that you are willing to pay in order to increase the potential outcome of gaining nothing to gaining $5?

GroupB L2C Situation 3: What is the maximum amount that you are willing to pay in order to avoid the lottery risk and gain $10 for sure?

GroupB L3 Lottery3: There is a 50% probability of gaining $10 and a 50% probability of gaining $0. Your current amount is $0.

GroupB L3A Situation 1: What is the maximum amount that you are willing to pay in order to increase probability of gaining from 50% to 75%?

GroupB L3B Situation 2: What is the maximum amount that you are willing to pay in order to increase the potential outcome of gaining nothing to gaining $5?

GroupB L3C Situation 3: What is the maximum amount that you are willing to pay in order to avoid the lottery risk and gain $10 for sure?

**Group C**

GroupC L1 You are given $10 to play Lottery1: There is a 5% probability of losing $10 and a 95% probability of losing $0.

GroupC L1A Situation 1: What is the maximum amount that you are willing to pay in order to reduce probability of loss from 5% to 2.5%?

GroupC L1B Situation 2: What is the maximum amount that you are willing to pay in order to reduce potential loss from $10 to $5?

GroupC L1C Situation 3: What is the maximum amount that you are willing to pay in order to completely avoid the risk of losing $10?

L2 You are given $10 to play Lottery2: There is a 15% probability of losing $10 and an 85% probability of losing $0.

GroupC L2A Situation 1: What is the maximum amount that you are willing to pay in order to reduce probability of loss from 15% to 7.5%?

GroupC L2B Situation 2: What is the maximum amount that you are willing to pay in order to reduce potential loss from $10 to $5?

GroupC L2C Situation 3: What is the maximum amount that you are willing to pay in order to completely avoid the risk of losing $10?

GroupC L3 You are given $10 to play Lottery3: There is a 50% probability of losing $10 and a 50% probability of losing $0.

GroupC L3A Situation 1: What is the maximum amount that you are willing to pay in order to reduce probability of loss from 50% to 25%?

GroupC L3B Situation 2: What is the maximum amount that you are willing to pay in order to reduce potential loss from $10 to $5?

GroupC L3C Situation 3: What is the maximum amount that you are willing to pay in order to completely avoid the risk of losing $10?

**Payment Lottery:**

All lotteries beneath have non-negative potential outcomes. Which of the following lotteries do you prefer to play?
A) There is a 50% probability of gaining 0$ and a 50% probability of gaining $10.
B) There is a 50% probability of gaining 2$ and a 50% probability of gaining $8.
C) There is a 50% probability of gaining 4$ and a 50% probability of gaining $6.

**Common-for-all-participants Lotteries:**

L1 There is a 5% probability of losing $50 and a 95% probability of losing $0.

L1A What is the maximum amount that you are willing to pay in order to reduce probability of loss from 5% to 2.5%?

L1B What is the maximum amount that you are willing to pay in order to reduce potential loss from $50 to $25?

L1C What is the maximum amount that you are willing to pay in order to avoid playing the lottery completely?

L2 There is a 15% probability of losing $50 and an 85% probability of losing $0.

L2A What is the maximum amount that you are willing to pay in order to reduce probability of loss from 15% to7.5%?

L2B What is the maximum amount that you are willing to pay in order to reduce potential loss from $50 to $25?

L2C What is the maximum amount that you are willing to pay in order to avoid playing the lottery completely?

L3 There is a 50% probability of losing $50 and a 50% probability of losing $0.

L3A What is the maximum amount that you are willing to pay in order to reduce probability of loss from 50% to 25%?

L3B What is the maximum amount that you are willing to pay in order to reduce potential loss from $50 to $25?

L3C What is the maximum amount that you are willing to pay in order to avoid playing the lottery completely?

**Common-for-all-participants Survey-Lotteries:**

SL1 You need to protect an asset that is worth $ 75,000. There is a 5% probability that a (confidentiality/integrity/availability) threat will materialise.

SL1A What is the maximum amount that you are willing to pay in order to reduce probability of loss from 5% to 2.5%?
SL1B What is the maximum amount that you are willing to pay in order to reduce potential asset loss from $75,000 to $37,500?
SL1C What is the maximum amount that you are willing to pay in order to avoid the risk completely?

SL2 You need to protect an asset that is worth $ 75,000. There is a 15% probability that a (confidentiality/integrity/availability) threat will materialise.

SL2A What is the maximum amount that you are willing to pay in order to reduce probability of loss from 15% to 7.5%?
SL2B What is the maximum amount that you are willing to pay in order to reduce potential asset loss from $75,000 to $37,500?
SL2C What is the maximum amount that you are willing to pay in order to avoid the risk completely?

SL3 You need to protect an asset that is worth $ 75,000. There is a 50% probability that a (confidentiality/integrity/availability) threat will materialise.

SL3A What is the maximum amount that you are willing to pay in order to reduce probability of loss from 50% to 25%?
SL3B What is the maximum amount that you are willing to pay in order to reduce potential asset loss from $75,000 to $37,500?
SL3C What is the maximum amount that you are willing to pay in order to avoid the risk completely?

## A.2 Survey Questions

- Question: "Are you related with the profession or practice of Information Security in any way?"
- Question: 'What is your gender?'
- Question: 'What is your age?'
- Question: "What is your educational level?"
- Question: "What is your marital status?"
- Question: "What is the number of dependants in your family?"
- Question: "What is your approximate annual income in US dollars?"
- Question: "Approximately how many employees work in your company / organisation?"

- Question: “How willing are you to take risks in general?”
- Question: “Your job title most closely resembles:”
  - *Senior executive role (e.g. CEO, CIO, CISO, CSO etc.)*
  - *Managerial role (e.g. Project Manager, IT Director, Security Manager etc.)*
  - *IT & Security (e.g. Security Officer, System Administrator, Information Analyst etc.)*
  - *Compliance, Risk or Privacy role (e.g. Consultant, Auditor etc.)*
  - *Other*
- Question: “How many years of experience do you have in Information Security related tasks?”
- Question: “How long have you held your current job position for?”
- Question: “An information security incident is made up of one or more unwanted or unexpected information security events that could compromise security and weaken or impair business operations.
  An information security event implies that the security of a system, service, or network has been breached, indicating that a security policy has been violated or a safeguard has failed.
  Have you experienced any critical or worth-mentioning information security incidents?”
- Question: “Do you feel that your company / organisation needs to take more actions for protecting confidentiality, integrity or availability?”
- Question: “Do you feel that your job position allows you to make independent security related decisions?”
- Question: “How worried are you about new unidentified information security threats?”
- Question: “Is English your mother tongue?”
- Question: “Which Amazon website do you prefer for your gift certificate payment?
  (payment amount will be converted from US Dollars to the corresponding currency if needed)”
- Question: “Please, enter your email address:
  (this is to be used only for sending you an Amazon gift certificate code)”

  Note: Likert-scale questions presented participants with a bar, valued from 1 to 10, e.g. “*0: Not worried at all  10: Very worried*”.

## A.3 Consent Form

Thank you for taking part in this experiment and survey!
Your participation is very helpful for my cross-disciplinary PhD research in the Information Security Group and Economics Department at Royal Holloway University of London.
Konstantinos

**Procedure**:
You will be asked to make decisions about lotteries and fill out a survey with information security related questions and demographics. Duration is no more than about 20 minutes.

B**enefits and Scope of this Study**:
By completing this questionnaire, you have the opportunity to win up to $10.
At the end of the experiment, one of the lotteries in the questionnaire will be 'executed' by the computer. Your payment will be based on your choices in this lottery and the random draw of the computer. An email will be sent to your designated email address with your payment in the form of an Amazon gift certificate.
Please, note that for the payment to be processed, it is necessary that you do not just answer randomly and instead make all your decisions carefully. Your participation will allow us to collect valuable data for our research.

**Confidentiality**:
No identification of the participants is collected or maintained during or after the completion of the experiment and the survey and all data are fully anonymised. An email address is requested at the end of the survey only for the purpose of sending your payment. All data will be protected and kept completely confidential.

**Usage of the findings**:
The research findings will be used for academic purposes only. For example, they might be presented in academic conferences, and be published in research journals in the field of Information Security and Economics. Research findings will be made available to all participants upon request after data collection and data analysis.

**Contact information**:
In case of any concern or question, please contact Konstantinos at: konstantinos.mersinas.2011@rhul.ac.uk or call directly at +44... .
By beginning the survey you acknowledge that you have read this form and agree to participate in this research.

## A.4 Experiment Flow

**Figure 9:** Experiment Flow (Qualtrics Software [42]).

# B Appendix - Experiment Analysis

SPSS v21 [1] was used for data analysis.

## B.1 More Analysis on the Three Framing Groups

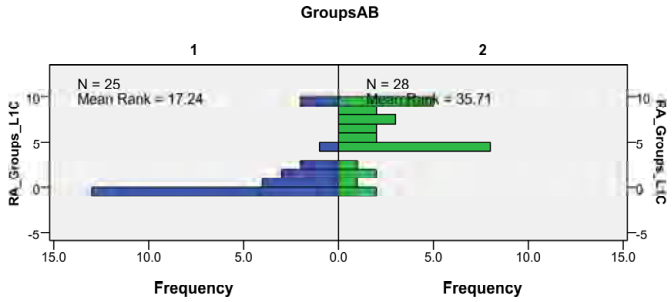
**Figure 10:** Mann-Whitney Test for Risk Aversion between Groups.

| | Null Hypothesis | Test | Sig. | Decision |
|---|---|---|---|---|
| 1 | The distribution of RA_Groups_L1A is the same across categories of Groups. | Independent-Samples Kruskal-Wallis Test | .855 | Retain the null hypothesis. |
| 2 | The distribution of RA_Groups_L1B is the same across categories of Groups. | Independent-Samples Kruskal-Wallis Test | .299 | Retain the null hypothesis. |
| 3 | The distribution of RA_Groups_L1C is the same across categories of Groups. | Independent-Samples Kruskal-Wallis Test | .000 | Reject the null hypothesis. |
| 4 | The distribution of RA_Groups_L2A is the same across categories of Groups. | Independent-Samples Kruskal-Wallis Test | .855 | Retain the null hypothesis. |
| 5 | The distribution of RA_Groups_L2B is the same across categories of Groups. | Independent-Samples Kruskal-Wallis Test | .400 | Retain the null hypothesis. |
| 6 | The distribution of RA_Groups_L2C is the same across categories of Groups. | Independent-Samples Kruskal-Wallis Test | .000 | Reject the null hypothesis. |
| 7 | The distribution of RA_Groups_L3A is the same across categories of Groups. | Independent-Samples Kruskal-Wallis Test | .053 | Retain the null hypothesis. |
| 8 | The distribution of RA_Groups_L3B is the same across categories of Groups. | Independent-Samples Kruskal-Wallis Test | .792 | Retain the null hypothesis. |
| 9 | The distribution of RA_Groups_L3C is the same across categories of Groups. | Independent-Samples Kruskal-Wallis Test | .000 | Reject the null hypothesis. |

In order to examine these differences in more detail amongst pairs of groups we created another three variables in the following way. In case Group A was presented to the participants we set variables AB and BC as equal to 1. If Group B was answered then AB and BC are set to 2 and if Group C was activated, variables AC and BC are set to 3. This way each participant has two of these Groups set to 1, 2 or 3 and, for example, by using Group AC we can compare between subjects only for subjects that are assigned to Group A or Group C. Mann-Whitney tests reveal a distribution-wise comparison between the three pairs of groups in Figures 11, 12, 13, 14, 15, 16, 17, 18

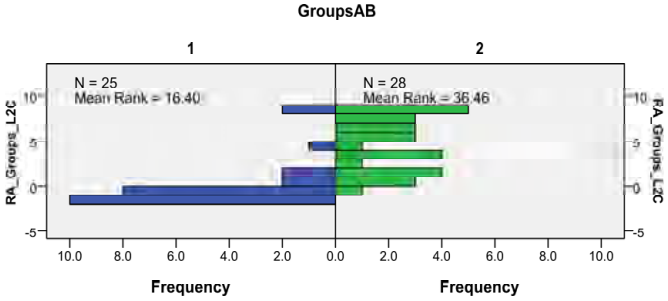
and 19.

**Figure 11:** Mann-Whitney Test for Risk Aversion between Groups.



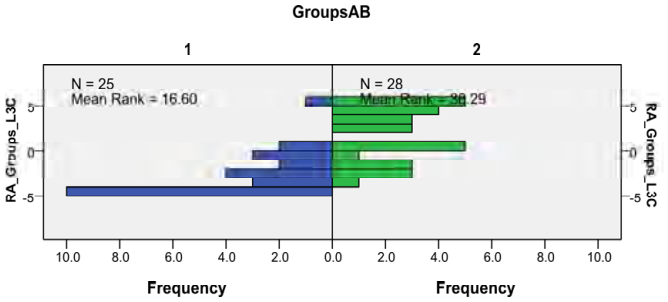

| | |
|---|---|
| Total N | 53 |
| Mann-Whitney U | 594.000 |
| Wilcoxon W | 1,000.000 |
| Test Statistic | 594.000 |
| Standard Error | 55.825 |
| Standardized Test Statistic | 4.371 |
| Asymptotic Sig. (2-sided test) | .000 |

**Figure 12:** Mann-Whitney Test for Risk Aversion between Groups.



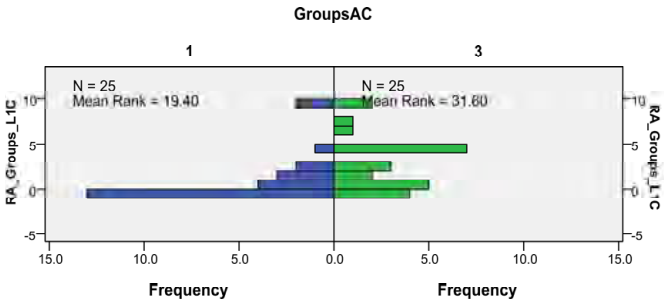

| | |
|---|---|
| Total N | 53 |
| Mann-Whitney U | 615.000 |
| Wilcoxon W | 1,021.000 |
| Test Statistic | 615.000 |
| Standard Error | 56.004 |
| Standardized Test Statistic | 4.732 |
| Asymptotic Sig. (2-sided test) | .000 |

**Figure 13:** Mann-Whitney Test for Risk Aversion between Groups.



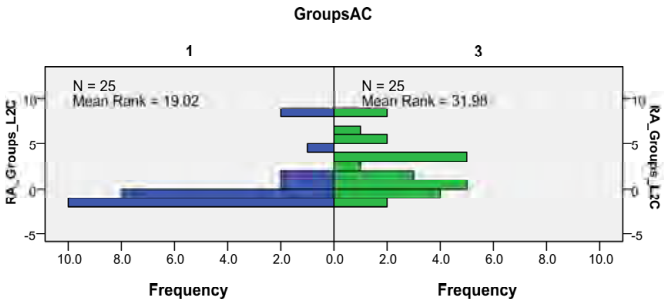

| | |
|---|---|
| Total N | 53 |
| Mann-Whitney U | 610.000 |
| Wilcoxon W | 1,016.000 |
| Test Statistic | 610.000 |
| Standard Error | 56.034 |
| Standardized Test Statistic | 4.640 |
| Asymptotic Sig. (2-sided test) | .000 |

**Figure 14:** Mann-Whitney Test for Risk Aversion between Groups.



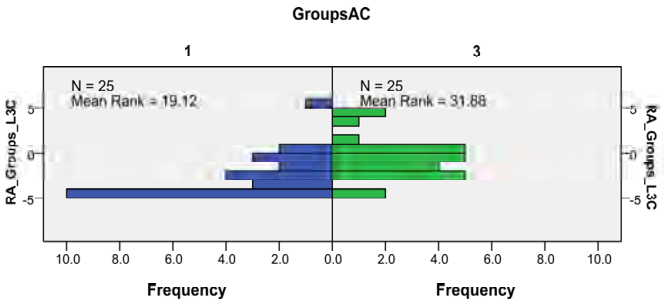

| | |
|---|---|
| Total N | 50 |
| Mann-Whitney U | 465.000 |
| Wilcoxon W | 790.000 |
| Test Statistic | 465.000 |
| Standard Error | 51.176 |
| Standardized Test Statistic | 2.980 |
| Asymptotic Sig. (2-sided test) | .003 |

**Figure 15:** Mann-Whitney Test for Risk Aversion between Groups.



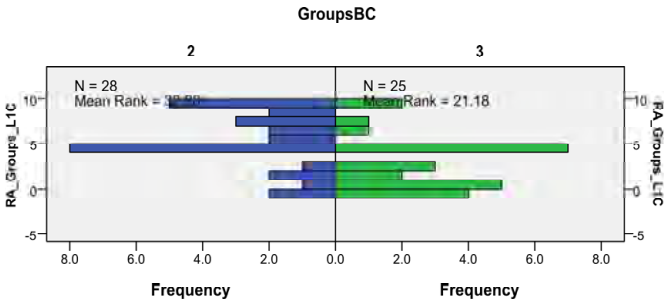

| | |
|---|---|
| Total N | 50 |
| Mann-Whitney U | 474.500 |
| Wilcoxon W | 799.500 |
| Test Statistic | 474.500 |
| Standard Error | 51.403 |
| Standardized Test Statistic | 3.152 |
| Asymptotic Sig. (2-sided test) | .002 |

**Figure 16:** Mann-Whitney Test for Risk Aversion between Groups.



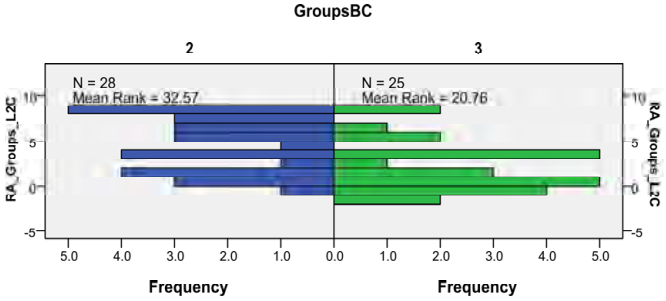

| | |
|---|---|
| Total N | 50 |
| Mann-Whitney U | 472.000 |
| Wilcoxon W | 797.000 |
| Test Statistic | 472.000 |
| Standard Error | 51.441 |
| Standardized Test Statistic | 3.101 |
| Asymptotic Sig. (2-sided test) | .002 |

**Figure 17:** Mann-Whitney Test for Risk Aversion between Groups.



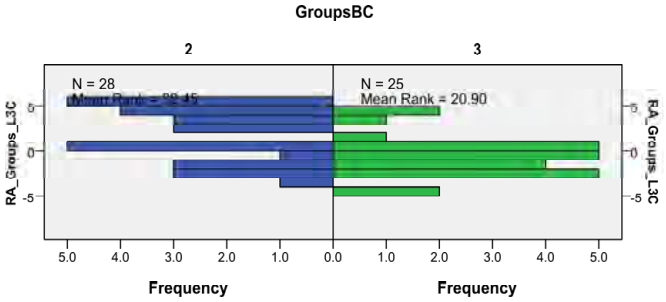

| | |
|---|---|
| Total N | 53 |
| Mann-Whitney U | 204.500 |
| Wilcoxon W | 529.500 |
| Test Statistic | 204.500 |
| Standard Error | 55.757 |
| Standardized Test Statistic | -2.610 |
| Asymptotic Sig. (2-sided test) | .009 |

**Figure 18:** Mann-Whitney Test for Risk Aversion between Groups.




| | |
|---|---|
| Total N | 53 |
| Mann-Whitney U | 194.000 |
| Wilcoxon W | 519.000 |
| Test Statistic | 194.000 |
| Standard Error | 66.030 |
| Standardized Test Statistic | -2.784 |
| Asymptotic Sig. (2-sided test) | .005 |

**Figure 19:** Mann-Whitney Test for Risk Aversion between Groups.




| | |
|---|---|
| Total N | 53 |
| Mann-Whitney U | 197.500 |
| Wilcoxon W | 522.500 |
| Test Statistic | 197.500 |
| Standard Error | 66.012 |
| Standardized Test Statistic | -2.723 |
| Asymptotic Sig. (2-sided test) | .006 |

## B.2 Risk treatment actions: Related Samples Friedman's Two-Way Analysis of Variance by Ranks

**Figure 20:** Ranks for $L_1A$, $L_1B$, $L_1C\_half$

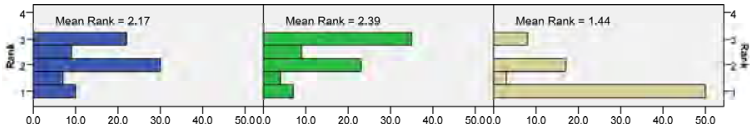



**Figure 21:** Ranks for $L_2A$, $L_2B$, $L_2C\_half$

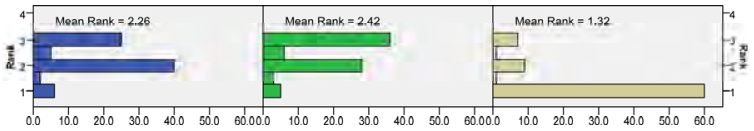



**Figure 22:** Ranks for $L_3A$, $L_3B$, $L_3C\_half$

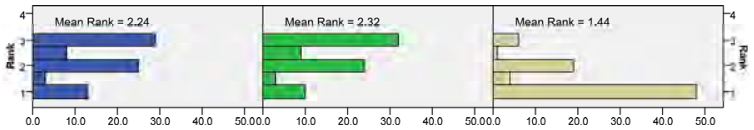



**Figure 23:** Ranks for $SL_1A$, $SL_1B$, $SL_1C\_half$

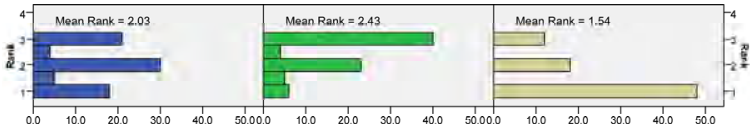



**Figure 24:** Ranks for $SL_2A$, $SL_2B$, $SL_2C\_half$

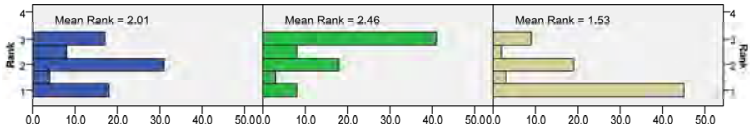
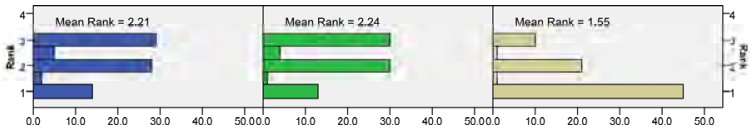



**Figure 25:** Ranks for $SL_3A$, $SL_3B$, $SL_3C\_half$



# C Definitions

| | |
|---|---|
| $L_{ij}$: | lottery $i = 1, 2$ or 3 and subquestion $j = A, B$ or $C$. Subquestion $A$ refers to reduction of probability, $B$ to reduction of outcome and $C$ corresponds to risk avoidance. |
| $SL_{ij}$: | the same as above, for survey lotteries. |
| $L_{iC}\_half$, $SL_{iC}\_half$: | halved WTP values for eliminating risk (not playing the lottery) lotteries, $i = 1, 2$ or 3. |
| $Groups$: | these are the three conditions that randomly assign participants to the framing of (A) gains, (B) losses and (C) mixed gains and losses. |
| $Group_k\_L_{ij}$: | lottery $i = 1, 2$ or 3, subquestion $j = A, B$ or $C$ for the framing group $k = A, B$ or $C$. The unified variable for the three groups is called $Groups\_L_{ij}$ and is used in the analysis in conjunction with a group-indicating variable. |
| $Delta\_EV\_\{lottery\}$: | for each lottery, the 'delta expected value' is the difference between the expected value of the original lottery and the expected value of the proposed modified lottery. |
| $RA\_\{lottery\}$: | for each lottery, the 'risk aversion' variable represents participant's elicited WTP minus $Delta\_EV\_lottery$. For example, if $WTP > Delta\_EV\_$ for some lottery, this means that the subject is willing to pay more than the objective reduction of the expected value between the original and the modified lottery, and therefore the subject is risk averse. |