

The Effect of Personality on the the Framing Bias in Information Visualization

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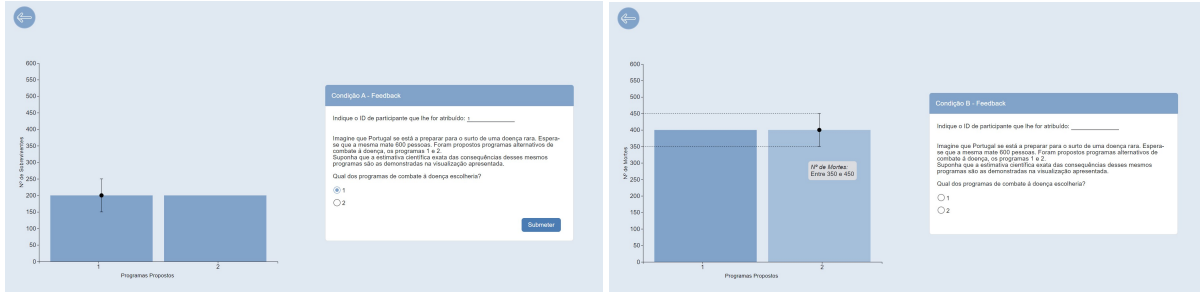


Figure 1: The two main study conditions from our study. The *positive* framing condition (*left*) indicates the survivors of each program. Participant's ID and choice are indicated, thus, showing the submit button. The *negative* framing condition (*right*) depicts each program through the deaths it would cause if chosen. Here, hovering a program and, therefore, showing the details about it. The order between these two study conditions was alternated from subject to subject. For each condition, the placement of risk was, likewise, arbitrary.

ABSTRACT

Undergoing complex cognitive thinking under uncertainty, individuals' judgments and decisions might rely on unconscious individual heuristics. These tend to suffer systematic deviations from rationality, designated as cognitive biases. The framing effect is a cognitive bias, consisting of the alteration of preference or behaviour under different framings of the same information. Recent research in the information visualization field has tackled how human rationale limitations affect visualization-supported decision-making. However, there is such a small body of evidence that it offers little guidance to practitioners. This study explores the framing effect in an information visualization context by depicting the decision problem of Tversky and Kahneman with visual encodings. Additionally, it delves into the influence of neuroticism within such an effect. This personality trait reflects one's tendency to feel negative emotions. We conducted user tests ($N = 91$), collecting personality data alongside user interaction metrics and the decision-making process between a set of options under different framing contexts. Our findings suggest that visualization helps mitigate the framing effect for most of the experiment sample. Moreover, our results reveal a general lack of significance from the neuroticism trait in such an effect. We believe that developing cognitive bias-aware decision support systems is of utmost importance to leverage the full potential of information visualization and make it widely available to jobs where visualization-supported decisions are critical.

Index Terms: Information Visualization, Cognitive Bias, Framing Effect, Personality Psychology, Neuroticism

1 INTRODUCTION

Notwithstanding striving to do so, humans have too limited cognitive abilities and are, hence, unable to truly make rational decisions without said limitations influencing the decision-making process. [32].

Ergo, humankind is forced to rely on *heuristics*. A *heuristic* consists of a mental strategy our brain forms to simplify all the information around us, where merely the parts each individual deems relevant to the situation or decision at hand are considered. While aiding us, said heuristics may also lead to systematic deviations from rationality in judgment, designated by Tversky and Kahneman [20, 33] as *cognitive biases*. Such deviations manifest in distinct ways, which led to the discovery of a broad variety of cognitive biases [13].

Research has shown cognitive limitations by exposing participants to a text narrative before seeing a visualization [38] or the position of data instances [37]. Moreover, some have attempted to begin to understand the impact of visualization in decision-making, such as Bancelhon et al. [2]. There has been a clear promising increased interest in cognitive biases [11, 35] and decision-making [3, 12] within the Information Visualization (InfoVis) community, but such an intersection of fields remains substantially unexplored nevertheless. In point of fact, there is only quite sparse research on said subject [13] and the existing petite number of studies leveraging cognitive biases in visualization leaves little empirical data to provide robust guidelines for practitioners.

We decided to focus our research on the *framing effect*. The **framing bias** is a cognitive bias where the *framing* of information leads to a deviation from a rational choice, i.e., there is a variation of outcomes in the decision-making process due to how information is presented. Therefore, the reference point used to evaluate the consequences of a decision is the key element of *framing* [30, 34]. Tversky and Kahneman [20, 33] assessed that in a **positive frame**, where information is presented as a gain, individuals tend to avoid risks. In contrast, a **negative frame** (information framed as a loss), leads to risk-seeking behaviour. The *framing effect* is a cognitive bias that shows a potential transfer of its priming effect to an InfoVis context. Nonetheless, there seems to be little work done, as evidenced by Dimara et al. [13] when classifying this bias as “discussed in visualization research as important, but not yet studied”.

A thriving collection of promising research has been establishing evidence which suggests that individual characteristics - namely, personality traits and cognitive abilities - can have a significant impact on the understanding, interaction and performance of data visual-

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izations [24]. For instance, results from Brown et al. [7] assessed how personality traits are correlated with mouse activity, namely neuroticism. Additionally, the works of Green and Fisher [18] and Ziemkiewicz et al. [39] proved how neurotic individuals present faster task execution times. Taking such results into account, we introduced the *neuroticism* of participants in our study. Despite the lack of a unifying definition for this personality trait, continuous research shows a prevalence of **neuroticism** as a basic dimension of personality. According to the Five-Factor Model (FFM), neuroticism consists of the tendency to experience negative emotions such as stress, depression, or anger.

Inspired by these findings, we developed a visual depiction of the decision problem by Tversky and Kahneman [34] using three bar chart visualizations - one for each framing type mentioned alongside an additional condition designed by us. Afterwards, we conducted user tests ($N = 91$) to understand whether the framing together with the neuroticism of individuals affected the decision-making process based on user interaction and reported choices. Our results suggest that visualization helps individuals be less susceptible to the *framing effect*. Moreover, our findings hint at no major significant effect of the neuroticism personality trait within our analysis. Considering the previously mentioned large gap in research regarding the framing effect within the InfoVis field, we prospect our contributions to provide further **understanding to future studies that leverage cognitive bias-aware mechanisms to promote more rational decision-making**.

1.1 Research Objective

Weighting how individual differences - namely, both personality and cognitive biases - affect one's interaction with visualizations, our research aims to **understand the effect of personality on the framing bias in information visualization**. In particular, focusing on the *neuroticism* personality trait from the FFM. In order to achieve our goal, it was imperative to define some intermediate steps such as the collection of individual's personality data, development of visualizations that set up the priming effect of framing, user testing and further analysis of the collected data.

Furthermore, we submitted a short paper to a top venue in our research area, VIS 2022¹, and are currently awaiting notification of submission.

2 METHODOLOGY

A rational choice requires that the preference between options should not reverse with changes in frame. However, Tversky and Kahneman [34] observed systematic reversals of preference by variations in the framing of acts, contingencies, or outcomes. Such deviations occur due to imperfections present in humankind's cognitive abilities, both regarding human perception and decision. Our aim began with **exploring whether the framing effect transfers to InfoVis by applying priming techniques using well-known graphical encodings**.

Upon studying the framing effect, Tversky and Kahneman applied a brief questionnaire to participants. Subjects were asked to choose between two alternative treatments to combat a hypothetical Asian disease, which was expected to affect 600 people. *Problem 1* presented the consequences of its two programs through a *positive* frame, whereas *Problem 2* stated its outcomes with a *negative* frame [34]. Problems were identical in terms of the consequences, the only difference being the framing variations of the outcomes of each program. From this, Tversky and Kahneman [34] assessed that in a problem presented through a *positive* frame the choice tends to be **risk-averse**. In contrast, decisions taken upon a *negative* frame favour **risk-taking** behaviour. Therefore, the researchers [34] concluded that changes to the reference point of the framing can have a significant impact on the way a subject makes decisions.

¹ <http://ieevis.org/year/2022/info/call-participation/shortpapers>

Table 1: Framing conditions and respective options of our study.

<i>Framing</i>	<i>Description</i>
Positive	A: If adopted, 200 people will be saved
	B: If adopted, 150 to 250 people will be saved
Negative	C: If adopted, 400 people will die
	D: If adopted, 350 to 450 people will die

For our research, we based our decision-making problem on the original one from their work - a hypothetical disease expected to affect 600 people -, with minor modifications (see Table 1). The same two framing conditions were employed: the *positive* and *negative* framing conditions. These consisted of the two main conditions of our study. Equally, each of these two conditions presented two options, a risky - option B or D - and a not risky one - option A or C. For each condition, participants would choose a single one.

Once decided on the setting of the study itself, the next step was to choose a chart type to represent it. Based on Bancelhon et al. [2], we opted for a bar chart to understand the impact of visualization in decision-making. In particular, such research showed that depicting the possible choices through bar encodings was the approach which exhibited behaviour that was most similar to showing the information solely through text. Hence, it represents the expected behaviour and, as argued by the researchers themselves, the *bar* group presented as the most relevant finding in the InfoVis context. Considering the aforementioned gap of research regarding the framing bias within this context [13] together with, to the best of our knowledge, the absence of prior work specifically mentioning visualizations when studying the framing effect, we decided to use bar charts to represent the programs of our study. Regarding the risk factor of the choices, i.e. whether an option is risky or not risky, we leveraged error bars (confidence intervals) to represent the uncertainty of outcomes - present in options B and D. The two main visualizations of our study are represented in Figure 1 - *positive* study condition (*left*), and the *negative* one (*right*).

From this, our research began its exploratory goal with the following **research question**:

RQ1. Does the framing condition affect decisions presented by bar charts with error bars?

We additionally opted to explore the possible impact personality - namely, *neuroticism* - might have on the interaction of users with visualization systems. Individuals high on the neuroticism scale are more prone to experiencing negative emotions, such as stress [39]. These tend to be more pessimistic [36], anxious, and depressed [10, 31], and show a tendency to pay more attention to negative information and less attention to positive information [28]. Moreover, high levels of neuroticism are correlated with low problem-solving skills [8]. These individuals have a hard time making decisions [15], notably when in risky situations [26] as they often feel more pressured to answer correctly [39]. Individuals with average neuroticism values are significantly faster on problem-solving tasks than the combined high and low scores ones [16, 39].

From these findings, we determined our **second research question**:

RQ2. Does neuroticism affect being primed by the different framings?

We aimed to explore the possible effect different framings of outcomes - *positive* and *negative* - might have with the established visualizations. Moreover, the possible effect neuroticism could bring to our research. Acknowledgement of the importance of decision-making along with cognitive biases over the visualization community has been showing a noticeable rising. Notwithstanding empirical

work on such remains to be comprehensive and there is only sparse dedicated research. In particular, the framing bias remains largely unexplored within the information visualization field [13]. Accordingly with the formerly remark of the work by Tversky and Kahneman [34], we expected decisions taken upon the *positive* framing condition of our study to be more risk-averse and the ones for the *negative* one to be risk-seeking. Consequently, we presumed participants would opt more for options A and D, respectively for each of the two conditions. Due to the gaps in research previously mentioned - namely regarding the framing effect within the InfoVis field - that was the single anticipated discovery for our work. Aside from it, we kept a general exploratory approach to our research.

As a result of the said experimental investigation, we designed a third study condition, which we designated as a *neutral* framing condition. In this, participants would have available all four options (see Table 1) - A, B, C, and D - from both framings together - *positive* and *negative* - at the same time and would be asked to, equivalently, choose a single one. The *neutral* framing condition of our study is shown in Figure 2. This third study condition led to our **third research question**:

RQ3. Do decisions taken in individual contexts hold when contexts are seen simultaneously?

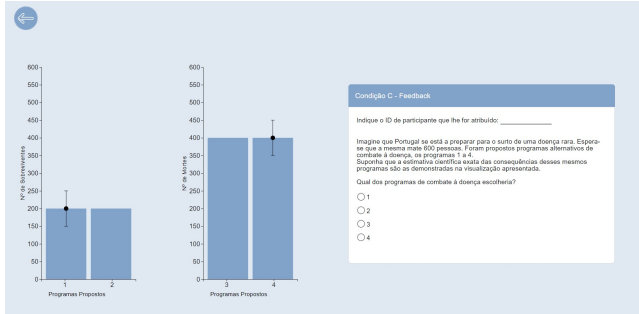


Figure 2: The *neutral* framing condition of our study, where participants would be presented with all four options simultaneously and asked to decide on a single one.

Each participant in our study was exposed to all three framing conditions - *positive*, *negative*, and *neutral*. Work by Kwak and Huettel [21] discovered that not only may the left-right positioning change the impact of the information shown has on the participants and, therefore, bias their choice, but also the sequence of visual information processing. In light of these findings, the order in which individuals underwent each of the conditions would be randomized, starting with either the *positive* or *negative* one. After that first decision, the other condition would be next. The *neutral* study condition would consistently be the last decision to be taken. Moreover, for each condition of our study, the position of the risky (B and D) and not risky (A and C) options was displayed randomly on either the left or right side of the visualization. Likewise, for our *neutral* framing, both the positioning of options - *risky* and *not risky* - for each visualization - *positive* and *negative* - together with the positioning of the visualization themselves was arbitrary. As indicated in Figure 1 (left) the submit button would only show once both the participant ID and choice fields were indicated. This was the same for all conditions in our research.

2.1 Framing Strategy

Not only is there a gap in research when considering the framing effect within the visualization context, but also regarding an (algorithmic) measure to evaluate the framing bias, i.e. a measure to

determine whether an individual has been a subject to it or not. To proceed with our study, it was required to define how we categorized an individual as primed. Taking into account that to the best of our knowledge such gaps remain present, we based this decision on utility theory. Thus, we opted to fix the expected value of each option within a frame condition as the same - as seen in Table 1, 200 survivors for the *positive* framing condition and 400 deaths for the *negative* one. Leveraging this approach implies the lack of an optimal decision since both options (per condition) are expected to provide the same outcome value. Therefore, the decision-maker would solely be deciding whether to follow a risk-averse (options A and C) or a risk-taking (options B and D) strategy.

To identify whether a participant was primed in the individual evaluation, we considered that we primed the participant if they changed their decision between the *positive* and *negative* frames. For instance, if the participant chose the risky option in the positive framing and the not risky choice in the negative framing, we assume that the frame primed the individual.

2.2 Measures

Plucking inspiration from the reviewed literature work mentioned throughout this document, we collected data not only regarding the personality of users but also related to user interaction and self-assessment to have a better understanding of how the framing context affects the decision-making process:

Independent Variables Our research focused specifically on the framing of outcomes of the programs - A, B, C and D -, as Tversky and Kahneman [34] did in their originally posed problem. Our study had three framing conditions - **positive**, **negative**, and **neutral**. The *positive* and *negative* were the focus of our work. Given the exploratory basis of this research, the *neutral* one was designed merely to draw some possible relevant information throughout the study. Alongside the framing effect, our study, too, aimed to explore the effect of personality within the InfoVis context. As mentioned in Section 1, the focus here was the **neuroticism** personality trait. Such was evaluated through the FFM and assessed through the Portuguese norm [23]. Each participant present in the study was assigned a neuroticism classification, in accordance with participants of the same age and gender, as explained further in this document.

User interaction Brown et al. [7] proved that the neuroticism trait correlates with mouse activity. Therefore, we decided to measure mouse activity through the **number of hovers per program** (bar) each participant triggered while taking their choice for each of the framing conditions. When hovering over each program, the tester had access to the exact values of the hovered program (Figure 1, right). For instance, if the user hovers option C, the exact value 400 is added with a tooltip to the bar. In case the hovered option is a *risky* one such as option D, the tooltip provides the upper and lower bounds of the confidence interval (see Figure 1, right)). We collected the number of hover events per option (bar) by counting them from the moment testers opened each of the study conditions until their final answer was submitted. Additionally, we collect the **decision completion time** in seconds based on the works of Green and Fisher [18] and Ziemkiewicz et al. [39]. These showed how neurotic participants execute tasks faster, due to their greater attentiveness [19]. We began counting after the student finished the explanation of the procedure to the participant and stopped the timer once the tester had submitted their decision.

Decision-Making Per framing context, we recorded the **choice** of each participant (*risky* or *not risky*). Regarding the decision taken in the *neutral* framing condition, we would do so indicating, too, the frame of the chosen option - *positive* or *negative*. For example, if a participant chose option A it was recorded as the *positive* + *not risky* option. Additionally, we collected the **perceived risk of the choice taken** since subjective feedback has proven to provide further insights into the decision process [17, 29]. In particular, participants

were asked to assess, per framing context, the riskiness of their choice through a seven-point Likert scale ranging from *Not risky at all* (1) to *Extremely risky* (7).

2.3 Research Questions and Hypotheses

Regardless the rising acknowledgment mentioned, empirical work on decision-making and cognitive biases in the InfoVis field has yet to be comprehensive. As previously mentioned, *framing bias* is a cognitive bias that, although widely known and already recognized as important in the InfoVis field, remains largely unexplored and is yet to be further studied [13]. Therefore, our research followed a generally exploratory approach throughout. To reach the goal of this study, declared in Section 1, and taking the aforesaid into account, our study began with the previously mentioned **RQ.1 research question**. In particular, we aimed to explore and focus on the possible effect different framings of outcomes - *positive* and *negative* - might have with the established visualization. As such, under this research question, we derived the following **hypotheses**:

H1.1 The type of frame influences the number of hovers made per program (A, B, C, D).

H1.2 The type of frame affects the amount of time users take to make a choice.

H1.3 The type of frame impacts the choice users take.

H1.4 The type of frame impacts the perceived risk of users.

After the focus on merely the framing of outcomes with our visualizations for the *positive* and *negative* framing conditions, we incorporated the personality of the participants - namely, their neuroticism scores - into our research.

Researchers have found that more neurotic individuals are more risk-averse [4, 6]. Additionally, it was found that in the domain of gains, more neurotic individuals show less risk-taking behaviour; yet, in the domain of losses, these are willing to take higher risks [22]. From such findings, researchers concluded that more neurotic individuals have a tendency to focus more on the negative consequences of the guaranteed losses and are therefore more willing to take risks as a way to avoid the guaranteed losses. As stated by Oehler and Wedlich [29], the empirical findings respecting the possible correlation between neuroticism and risk-taking behaviour, are quite diverse. Even so, the overall expected behaviour of more neurotic individuals is less risky. From the mentioned wide variety of findings, we determined our **second research question (RQ.2)**. For this research question, due to the aforementioned assortment of findings, our intent kept being to maintain a general approach to it. We studied not only the interaction effect between the personality trait alongside the framing condition - *positive* and *negative* - but also continuous and additionally explored the possible effects the personality trait itself might have. As such, we formulated the following **hypotheses**:

H2.1 Neuroticism influences the number of hovers made per program (A, B, C, D), depending on how risky an option is.

H2.2 Neuroticism has an effect on the time users take to make a choice, in different framing conditions.

H2.3 Neuroticism affects the choice users take, in different framing conditions.

H2.4 Neuroticism has an effect on the perceived risk of users, in different framing conditions.

Whereas the **RQ.1** of our work merely explores the effect of *framing* in itself in the measures of our study, our **RQ.2** adds the possible interaction *neuroticism* might have when playing an additional role together with the framing - *positive* and *negative*. Accordingly, each

of the *H1* hypotheses has a correspondent *H2* hypothesis, where the same study measure is being evaluated, adding the neuroticism personality trait to the analysis.

As above mentioned, the exploratory approach to our research led us to design a third study condition designated as a *neutral* framing condition. Here, participants would have to decide on a single program out of all four - A, B, C, and D - of them together. The possible information to be drawn that we considered relevant to assess from this condition was regarding the choices of participants. In particular, if the decision taken previously with either the *positive* and *negative* framings individually would hold or change for this *neutral* framing condition, according to the frame present in the third and final decision of each individual. Thus, we formulated our **third research question (RQ.3)**. Taking how the *neutral* framing condition consisted as an additional one to our study, we kept this research question open without any particular hypotheses for our investigation.

2.4 Data Collection

Participants were recruited for our study through standard convenience sampling procedures together with word of mouth. Once recruited, we solicited individuals to fill a personality survey which recorded data regarding various personality traits, namely neuroticism. Next, prior to any interaction with our visualizations, we presented a small questionnaire regarding general information - participation consent, visual impairments, overall willingness to take risks, and familiarity with both visualizations used in our research. During the test session itself, we would record the video conference - video and audio - to be analysed afterwards and extract the required measures for our study. The review of the test recordings additionally allowed for the discovery and correction of anomalies, as well as taking note of feedback given by the participants.

2.4.1 Procedure

We recruited 91 participants (51 females, 39 males, and 1 other) aged 17 – 59 ($M = 26.33$, $SD = 10.646$). Due to constraints from COVID-19, we conducted each user test as a Zoom video meeting with one experimenter at a time. Each Zoom session was done with one participant at a time, taking a maximum of 30 minutes. Each of the sessions began with an introductory text describing the research project - both what should be expected from the experiment together with what would be asked of individuals during - alongside the problem's context. Subsequent to the verbal consent to the participation, collection and further analysis of the recorded data, participants filled the demographics survey as well as the risk attitude ($M = 4.40$, $SD = 1.201$) and familiarity levels - *bar chart*: $M = 6.52$, $SD = 0.765$; *bar chart with error bar*: $M = 4.59$, $SD = 1.646$ - questions.

Following the flow of the Google Forms and prior to the interaction with the visualizations themselves, the tutorial images were then presented to the testers. There was one tutorial image per idiom used revealing how to interpret the data from each one. As aforementioned, these explanatory images presented abstract data unrelated to the problem of the study itself to prevent potential biasing. Such was additionally explicitly mentioned to the individuals, as well.

Thereafter, the interaction and decision-making part of the experiment would begin. Each participant was randomly assigned to start with either the *positive* or *negative* framing condition, and next received the opposite one. For each of these two framing conditions, participants would choose a single program between the two presented options (see Figure 1). For all the participants, the last study condition was the *neutral* framing condition (shown in Figure 2), where participants would equally choose a single option but now from all four. The order through conditions was so to minimize possible biasing.

Once the experiment was over and a participant had gone through all the framing conditions in our study, we would thank them for their time and explain the goal of our research - solely at the very end of the session to prevent potential bias. By participating in our study, individuals entered a contest to win one of three FNAC gift cards in the value of 20€ we had to offer.

For all framing conditions, both the number of hover events per program and decision completion time were collected during the study phase of reviewing the audio and video recordings of the Zoom sessions. The hover events had a counter which would show the results when the submission confirmation screen was presented to the individuals. However, limitations caused by the experiments being executed remotely (such as low or bad Wi-Fi connection) caused some anomalies in these counters. Therefore, this measure of our study was then collected manually by reviewing all the user tests. The decision completion time was, too, recorded when in the study phase of reviewing the Zoom sessions. The collection of each of the final choices together with the perceived risk of each one was done through the Google Forms used to guide the experiment.

2.5 Data Analysis

2.5.1 Outliers Removal Criteria

For each of the statistical analyses performed, we checked for outliers through boxplots or Studentized Residuals (SREs). The latter is specifically for the Two-Way Mixed and Repeated Measures ANOVAs carried out. Values more than 3 box-lengths from the end of a box are defined by SPSS Statistics as extreme and removed. Data points with SREs ± 3 standard deviations, too, are considered outliers. Values falling, in either case, were removed from each analysis individually. For the ANOVAs, we tested for sphericity (Mauchly's test) and we followed the ANOVAs with posthoc Tukey's range tests including Bonferroni corrections.

2.5.2 Personality Data

We established a division of participants into different levels of neuroticism through the European Portuguese version of the Revised NEO Personality Inventory (NEO PI-R) by Lima and Simões [23]. Two different possible divisions were explored: two and three neuroticism levels. Both according to the Portuguese Norm and, thus, each participant present in the study was assigned a neuroticism classification, in accordance with participants of the same gender and age. Regarding the age group, 21 years old individuals or younger are considered young adults and beyond that age are considered adults.

By performing the three-level classification in the participants' neuroticism scores using the Portuguese Norm, 41 participants presented a high ([75% – 100%] percentile) neuroticism classification. Additionally, 26 and 24 individuals with average ([25% – 75%] percentile) and low ([0% – 25%] percentile) neuroticism levels, respectively. The biggest difference between groups in this division was 17 participants, meaning that the balance between groups was slightly better as opposed to only two neuroticism levels - high and low. Upon leveraging a One-Way ANOVA, we determined that the three levels were statistically significantly different from each other, i.e. indicating that participants in different levels of neuroticism were always distinct across all facets of this personality trait.

3 RESULTS

We begin by demonstrating our findings in regards to our first research question (RQ.1), i.e., analysing merely the two main conditions - *positive* and *negative* framings - and not taking into account the personality of individuals. Afterwards, we bring the *neuroticism* level of participants into the investigation, under our second research question (RQ.2). Moreover, we explore our third research question

(RQ.3) and the *neutral* condition of our study. Data are presented as mean \pm standard deviation unless otherwise stated.

3.1 Effect of Framing

Ignoring individuals' personalities in the first instance, we studied the potential effect different framing of outcomes - *positive* and *negative* - might have with the established visualizations in the metrics of our work. Here, we focused merely on the said two main conditions of the study and neglected the third additional one (*neutral* framing condition).

3.1.1 User Interaction

Hover events We ran a Two-Way Repeated Measures ANOVA to understand the effects of *frame* - *positive* or *negative* - interaction with the *risky factor* of a program - *risky* or *not risky* - on the number of hovers per program - *A*, *B*, *C* and *D* (see Figure 3). There were four outliers detected through the inspection of SREs, and such data points were removed specifically from this analysis. There was not a statistically significant two-way interaction between the two factors, $F(1, 86) = 0.557, p = 0.457$, partial $\eta^2 = 0.006$. Therefore, we continued our analysis by determining whether there were any statistically significant main effects.

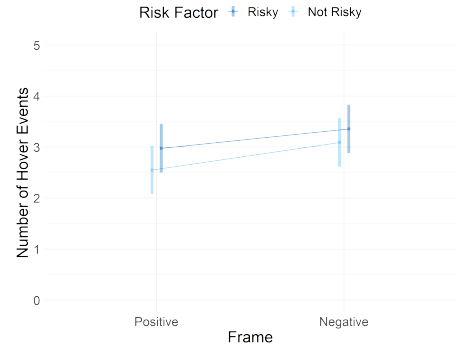


Figure 3: Estimated marginal means of the number of hover events triggered in each option across framing conditions.

We did not find a statistically significant main effect of the frame on the number of hovers, $F(1, 86) = 3.393, p = 0.069$, partial $\eta^2 = 0.038$. The mean number of hovers was 0.460 (95% CI, -0.956 to 0.036) hovers lower in the *positive* framing condition as opposed to the *negative* framing condition of the study. Additionally, there was a statistically significant main effect of risk factor on the number of hovers, $F(1, 86) = 7.793, p = 0.006$, partial $\eta^2 = 0.083$. The mean number of hovers was 0.345 (95% CI, 0.099 to 0.590) hovers higher in the *risky* option than in the *not risky* one. These findings go **against** our hypothesis **H1.1**.

Besides studying the effect of frame and risk factor on the number of hovers per program, we also decided to explore the possible interaction between the *choice* of each participant and the *risk factor* of each option on the same measure. Therefore, we conducted two Two-Way Mixed ANOVAs, one per framing condition - *positive* and *negative*. For the *positive* framing condition, there was a single outlier detected through SREs, which was removed from this particular analysis. The two-way interaction between the choice taken and the risk factor was statistically significant, $F(1, 88) = 19.743, p < 0.0005$, partial $\eta^2 = 0.183$. We continued by analysing the simple main effects. The only statistically significant one was the risk factor for the group of participants who opted for the *risky* option (*B*), $F(1, 55) = 28.031, p < 0.0005$, partial $\eta^2 = 0.338$. For the group of participants who made such a choice, the number of hovers was 0.875 (95% CI, 0.544 to 1.206) hovers higher for the *risky* option

(*B*, with 3.23 ± 2.123 hovers) as opposed to the *not risky* one (*A*, with 2.36 ± 1.813 hovers).

In contrast, there was not a statistically significant two-way interaction between the choice taken and the risk factor on the number of hovers per program for the *negative* framing condition of the study, $F(1, 86) = 1.661, p = 0.201$, partial $\eta^2 = 0.019$. For this analysis, three outliers were detected through SRE assessment and removed. Afterwards, we addressed the possible main effects. However, neither risk factor - $F(1, 86) = 0.876, p = 0.352$, partial $\eta^2 = 0.010$ - nor choice - $F(1, 86) = 0.006, p = 0.937$, partial $\eta^2 = 0.000$ - showed a significant main effect.

Decision Time In this analysis, there were no extreme outliers detected. A One-Way Repeated Measures ANOVA showed that there was insufficient evidence to reject the null hypothesis. There was an increase in the time taken to decide from 45.95 ± 24.324 seconds in the *positive* framing condition to 49.08 ± 26.954 seconds in the *negative* framing condition. In particular, the increase of 3.132 (95% CI, -8.883 to 2.619) seconds between the *positive* and *negative* framing conditions was not significantly different, $F(1, 90) = 1.170, p = 0.282$, partial $\eta^2 = 0.013$. These results **contradict** our hypothesis **H1.2**.

3.1.2 Decision-Making

User choice For the *positive* framing condition of the study, 57 participants (62.63%) chose the *risky* option (*B*), while 34 participants (37.36%) settled for the *not risky* one (*A*). As for the *negative* framing condition, the number of participants who picked out the *risky* program (*D*) was 62 participants (68.13%), with a concomitant reduction in the number of participants who opted to not take a risk in their choice (*C*) to 29 participants (31.87%). These changes were a consequence of 5.5% (i.e., $0.681 - 0.626 \times 100 = 5.5\%$) more participants choosing the *risky* option upon the *negative* framing condition of the study (see Table 2). 20 participants went for the *not risky* option upon the *positive* framing condition giving a different answer while in the *negative* one; whilst other 15 participants chose the *risky* option during the *positive* framing condition of the study and opted for the *not risky* one when in the *negative* framing condition. A McNemar's test [25] with continuity correction [14] was performed to determine if there was a difference in the proportion of participants who took a risk in their choice between the *positive* and *negative* framing conditions. The proportion of participants who opted for the *risky* option increased from 62.63% in the *positive* framing condition to 68.13% in the *negative* one, a not statistically significant difference, $\chi^2(1) = 0.457, p = 0.499$. With this, we concluded that the proportion of participants who chose to risk did not (significantly) differ between framing conditions - *positive* and *negative*. Thus, we could not reject the null hypothesis as the test results indicated there is not sufficient evidence to say that the differences in the dichotomous dependent variable - *choice* - between two related groups - *positive* and *negative* conditions - were not equal. These findings **refute** our hypothesis **H1.3**.

Table 2: Number of participants who chose each option, at each framing condition.

		<i>Negative Framing</i>		<i>Total</i>
		<i>Risky (D)</i>	<i>Not Risky (C)</i>	
<i>Positive Framing</i>	<i>Risky (B)</i>	42	15	57
	<i>Not Risky (A)</i>	20	14	34
	<i>Total</i>	62	29	91

Perceived risk A One-Way Repeated Measures ANOVA was

conducted to determine whether there were statistically significant differences in the perceived risk of the choices taken in the *positive* and *negative* framing conditions of our research. No outliers were detected for this analysis. There was an increase in the self-reported perceived risk from 3.96 ± 1.686 for the choice taken in the *positive* framing condition to 4.10 ± 1.674 for the choice taken in the *negative* framing condition of our study - an increase of 0.143 (95% CI, -0.499 to 0.213). Nonetheless, such an increase was not statistically significant, $F(1, 90) = 0.635, p = 0.428$, partial $\eta^2 = 0.007$. Accordingly, we were unable to reject the null hypothesis as there was not sufficient evidence to do so, i.e., these results **counteract** our study hypothesis **H1.4**.

3.2 Effect of Neuroticism

Subsequent to the investigation focusing solely on the different framing of outcomes - *positive* and *negative* - and their possible effect with the developed visualizations in the metrics of our work, we incorporated the personality of participants into our analysis. Namely, the neuroticism level of individuals. Accordingly, this analysis only took into account the *positive* and *negative* framings and discarded the *neutral* condition.

3.2.1 User Interaction

Hover events We leveraged a Three-Way Mixed ANOVA to understand the effects of *frame* - *positive* or *negative* -, the *risk factor* of a program - *risky* or *not risky* -, and the *neuroticism* level of participants - *low*, *average* or *high* - on the number of hovers per program (bar) - *A*, *B*, *C* and *D*. We found one extreme outlier and removed it. There was homogeneity of variances for all groups of the between-subjects factor - *neuroticism level* - for most combinations of the levels of the within-subjects factors - *frame* and *risk factor* -, as assessed by Levene's test for equality of variances. As the Three-Way Mixed ANOVA is somewhat robust to the heterogeneity of variances, we carried on with the analysis. There was not a statistically significant three-way interaction between the three factors, $F(2, 87) = 0.195, p = 0.823$, partial $\eta^2 = 0.004$. We continued by analysing the two-way interactions. There was not a statistically significant two-way interaction between frame and the neuroticism level of participants, $F(2, 87) = 1.557, p = 0.217$, partial $\eta^2 = 0.035$. Addressing again the interaction between the frame and risk factor, it remained as non-significant, $F(1, 87) = 0.601, p = 0.440$, partial $\eta^2 = 0.007$. However, we found a statistically significant two-way interaction between the risk factor and the neuroticism level of participants, $F(2, 87) = 3.365, p = 0.039$, partial $\eta^2 = 0.072$. In particular, there is a statistically significant simple main effect of risk factor for the *average* neuroticism level group - $F(1, 25) = 12.835, p = 0.001$, partial $\eta^2 = 0.339$. Afterwards, we address the main effects. We found a statistically significant main effect of frame on the number of hovers, $F(1, 87) = 4.592, p = 0.035$, partial $\eta^2 = 0.050$. The mean number of hovers was 0.559 (95% CI, -1.077 to -0.041) hovers lower in the *positive* framing condition as opposed to the *negative* framing condition of the study. The risk factor did show a statistically significant difference in the mean number of hovers $F(1, 87) = 8.096, p = 0.006$, partial $\eta^2 = 0.085$, where it was 0.350 (95% CI, 0.106 to 0.595) hovers higher in the *risky* options as opposed to the *not risky* ones. Finally, there were no statistically significant differences in the mean number of hover events between the neuroticism level groups, $F(2, 87) = 0.468, p = 0.628$, partial $\eta^2 = 0.011$. The biggest difference was between the *average* and *low* neuroticism groups, with a difference of 0.543 (95% CI, 0.834 to 1.919) hovers higher for the *average* one. The smallest one was 0.248 (95% CI, -1.005 to 1.501) between the *high* and *low* neuroticism levels. This collection of findings proved **against** our **H2.1** hypothesis.

Decision Time A Two-Way Mixed ANOVA showed no statistically significant interaction between the *neuroticism* level and

frame on the amount of time (in seconds) taken to make a choice, $F(2, 86) = 0.127, p = 0.881$, partial $\eta^2 = 0.003$. Two outliers were detected and removed from SREs inspection. Additionally, the main effect of frame did not show a statistically significant difference in the mean amount of time to make a choice, $F(1, 86) = 2.447, p = 0.121$, partial $\eta^2 = 0.028$. The mean amount of time to choose in the *positive* framing condition was 4.207 (95% CI, -9.552 to 1.139) seconds lower opposed to the one in the *negative* framing condition. Finally, there was also no main effect of neuroticism in the mean amount of time (in seconds) to choose a program, $F(2, 86) = 0.240, p = 0.787$ partial $\eta^2 = 0.006$. The biggest difference was between the *low* and *average* neuroticism levels, a difference of 3.870 (95% CI, -10.595 to 18.334) seconds. The results from this Two-Way Mixed ANOVA **contradict** our hypothesis **H2.2**.

3.2.2 Decision-Making

User Choice For this analysis, we leveraged a derived variable indicating whether a participant had reversed their final choice between the *positive* and *negative* framing conditions - i.e., takes the value of 1 when participants changed their answer between conditions and 0 when the final decision remained the same in both frames - regardless of it being from *risky* to *not risky* or *not risky* to *risky* between the two frames. A Chi-Square Test of Independence was conducted between said variable and the *neuroticism level* of participants. We defined both our alternative and null hypotheses - is there or not an association amid the variables, respectively.

As our two variables had two - yes or no - and three - low, average, and high - categories (i.e., 2 x 3 crosstabulation), there were 6 cells in our design that needed to be checked, as presented in Table 3. All indeed present expected count values greater than or equal to five, as required to obtain valid results. From our data, we can see that the majority of participants who did change their answers between the two framing conditions, mainly presented a *high* neuroticism level (i.e., 18 out of 35 participants who did change their answers between study conditions). Additionally, one can observe how the bulk of each neuroticism level group opted not to alter their choice between frames - i.e., 14 out of 24 participants with a *low* neuroticism level; 19 out of 26 participants from the *average* neuroticism level group; Lastly, 23 out of 41 participants presenting a *high* neuroticism level group. There was not a statistically significant result to our analysis, as $p = 0.354$ (i.e., it does not satisfy $p < 0.05$). This indicates there is no association between our two variables (i.e., an association between the *neuroticism level* of participants and the *changing choice* between the *positive* and *negative* framing conditions of our study), $\chi^2(2) = 2.079, p = 0.354$. The association was small [9], with Cramer's $V = 0.151$. These results indicate that there is insufficient evidence to reject the null hypothesis and accept the alternative one, going **against** our hypothesis **H2.3**.

Table 3: Chi-Square Test of Independence crosstabulation. In brackets are the expected count values for each cell.

		Neuroticism Level			Total
		Low	Average	High	
If a participant changed choice	No	14 (14.8)	19 (16.0)	23 (25.2)	56 (56.0)
	Yes	10 (9.2)	7 (10.0)	18 (15.8)	35 (35.0)
Total		24 (24.0)	26 (26.0)	41 (41.0)	91 (91.0)

Perceived Risk We ran a Two-Way Mixed ANOVA to determine the effect of different *neuroticism* level groups over different *framing* conditions - *positive* and *negative* - on the perceived risk of the

choices taken. There were no outliers for this analysis as assessed by examination of SREs. There was not a statistically significant interaction between the *neuroticism level* group of participants and *frame* on the perceived risk of the choice taken, $F(2, 88) = 0.517, p = 0.598$, partial $\eta^2 = 0.012$. Therefore, we carried out our analysis by determining whether there were any statistically significant main effects. The main effect of *frame* verified again that there is not a statistically significant difference in the mean perceived risk of the choice taken between conditions, $F(1, 88) = 0.669, p = 0.416$, partial $\eta^2 = 0.008$. The (mean) perceived risk of the choice taken in the *negative* framing condition was 0.152 (95% CI, -0.217 to 0.520) higher as opposed to the mean perceived risk of the one taken in the *positive* framing condition. Moreover, neither the main effect of *neuroticism* showed a statistically significant difference in the mean perceived risk of the choices taken, $F(2, 88) = 0.124, p = 0.884$, partial $\eta^2 = 0.003$. The lowest difference was 0.043 (95% CI, -1.052 to 0.966) between the *low* and *average* neuroticism level groups. The highest difference was between the *high* and *low* groups, one of 0.172 (95% CI, -0.744 to 1.088). These findings **refute** our hypothesis **H2.4**.

3.3 Neutral Condition

The additional *neutral* framing condition was designated as such due to it offering all four programs - *A*, *B*, *C* and *D* - at the same time. Hence, offering both frames - *positive* and *negative* - simultaneously. All the while, for each frame offering, equally, both the *risky* (*B* and *D*) and *not risky* (*A* and *C*) options. Considering how a subtle change in the framing of decision problems may have a large impact on behaviour - consisting of the *framing effect* - we deemed it interesting to assess if the choices taken in both the *positive* and *negative* frames isolated would hold (in risk) when receiving both at the same time (**RQ.3**). For example, an individual chooses option *B* and option *C* under the *positive* and *negative* conditions, respectively. If when undergoing the *neutral* study condition, the same participant opts for a *positively* framed program and chooses *B*, we considered that they held the answer taken (as in the one taken for the particular framing condition chosen in the *neutral* one).

34 testers decided on the *risky* program presented through a *positive* frame - option *B*. These findings immediately clash with the ones of Tversky and Kahneman [20, 33] seeing how a *positive* frame tends to trigger risk aversion. In contrast, next, we had 27 individuals choosing option *D*, the *risky* option deceived through a *negative* framing. Thus, going in harmony with the fact that said frame tends to be associated with risk-seeking behaviour. Of the total 91 participants, then 20 went for option *A* and 10 individuals chose option *C*, respectively. Additionally, we can assess that the majority of individuals (54) opted for a *positively* presented option (*B* or *A*), whereas 37 decided on a *negatively* one (*D* or *C*). A bigger contrast is seen when comparing the number of participants who decided to take a *risk* in this last choice (*B* or *D*) - 61 - with the number of ones who went for a *not risky* option (*A* or *C*) - 30.

Moreover, when assessing the comparisons between the choices taken in the *positive* and *negative* frames separated and the one taken in the *neutral* condition of our work, we determined that there were merely 4 participants whose choices did not hold between conditions. There were 3 were participants who had chosen option *B* for the *positive* framing condition and opted for option *A* in the last decision. A single participant did the opposite and initially decided on program *A* for the *positive* framing condition and switched to *B* when undergoing the *neutral* one. For the remaining 87 participants, the choice taken in the *neutral* condition was in accordance with the one taken in the correspondent isolated framing condition. Furthermore, we broadly investigated if when holding their decision, the perceived risk of such would hold as well or change to a higher or lower value. The majority did assign the same perceived risk (45 individuals). However, 15 and 27 participants assigned a lower and higher perceived risk of choice taken when in the *neutral* condition,

respectively. Out of the participants who accredited a lower perceived risk, 10 were ones who opted for a *risky* option. For the ones who elected a higher perceived risk when taking the same choice in the *neutral* condition, 17 out of the 27 decided on a *risky* option. These findings allowed us to explore our third and last condition of the study in a general manner.

3.4 Discussion

The gathered results evidence that framing bias is a worthy subject of further and deeper research within the InfoVis community. In particular, when the core function of these systems is to support the human decision-making process.

Our exploratory work began with the sole investigation of the *framing effect* within the established visualizations (**RQ.1**). For the *negative* framing condition, the majority of individuals opted to take a risk in their choice, having 62 out of the 91 subjects choosing option *D* (29 going for option *C*, see Table 4). This was in line with what was expected from the work of Tversky and Kahneman [20,33]. However, contrarily to what was anticipated, for the *positive* framing condition the bulk of participants, likewise, decided on the *risky* option (*B*) - 57 out of the total of 91 participants in our study (34 opting for *A*, see Table 4). We assume that we were able to prime 38.5% of the individuals since 56 (61.5%) participants did not change their decision. Despite the difference between proportions not being significantly different (*H1.3*), some participants appear to have been primed, reinforcing the possibility of framing bias within this context. Thus, the findings discussed in Section 3.1 support our **RQ.1** and how **the framing condition may affect decisions presented by bar charts with error bars**. In particular, how visualizations may aid **reducing** this bias upon interaction with visualization-supported decision-making systems.

Subsequent to the analysis of the framing effect by itself, we introduced the personality of the participants into it. Namely, by combining the *neuroticism* level of participants into each of our analyses done previously (**RQ.2**). As a consequence of most of our sample presenting a *high* neuroticism level (41 out of the total 91 participants), the bulk of individuals opting for each existing option within the two framing conditions - *positive* and *negative* - presented that same neuroticism level (see Table 4) - 25, 16, 27, and 14 for the options *B*, *A*, *D* and *C*, respectively. Following our framing strategy, we consider that 35 participants (38.5%) within our research were primed as these changed their choice between the *positive* and *negative* framing conditions. Albeit not finding a significant association between the changing of choice (i.e., being primed) and the *neuroticism* level of participants (*H2.3*), we were able to check that considering each neuroticism level group - *low*, *average* and *high* - individually, the greater part in all of them did not alter their decision between the two conditions. Nonetheless, the majority of primed participants presented a *high* neuroticism level group. The obtained results for our analysis under **RQ.2** suggest that perhaps **neuroticism does not affect being primed by the different framings**. Even so, such may be a consequence of the possibility that visualizations help reduce the *framing effect* of individuals. Such may be so that it aids in contradicting the general tendency of more neurotic individuals to be more risk-averse.

The curious and experimental basis approach to our research led us to design a third supplementary condition for our work - the *neutral* framing condition (**RQ.3**). We aimed to delve into the choices of participants and investigate whether these would hold between getting the frames - *positive* and *negative* - isolated and seeing them simultaneously. From our study sample ($N = 91$) we assessed that the bulk of participants did hold their answer (87), whereas merely 4 did not. Moreover, only 45 individuals of those 87 assigned an equal perceived risk of choice when taking the same one between getting the frame isolated versus seeing them simultaneously. Lastly, for this condition, participants tended to

Table 4: Number of participants and their choices, according to the neuroticism level.

<i>Framing</i>	<i>Possible Choices</i>	<i>Neuroticism Level</i>	<i>Number of Participants</i>	<i>Total</i>
<i>Positive</i>	<i>Risky (B)</i>	<i>High</i>	25	57
		<i>Average</i>	18	
		<i>Low</i>	14	
	<i>Not Risky (A)</i>	<i>High</i>	16	34
		<i>Average</i>	8	
		<i>Low</i>	10	
<i>Negative</i>	<i>Risky (D)</i>	<i>High</i>	27	62
		<i>Average</i>	19	
		<i>Low</i>	16	
	<i>Not Risky (C)</i>	<i>High</i>	14	29
		<i>Average</i>	7	
		<i>Low</i>	8	

pick a program presented with a *positive* frame (*A* or *B*, 54) and the majority of our sample (61) decided to take a risk in their choice - options *B* or *D* - upon our *neutral* framing condition, regardless of the option's frame. These findings allowed us to explore our third and last research question **RQ.3**, supporting that **decisions taken in individual contexts do hold when contexts are seen simultaneously**.

All this evidences the importance of further exploration of the framing bias within InfoVis systems; namely to better support the decision-making process and avoid biased choices. Moreover, due to the peculiar findings when exploring the incorporation of participants' personalities, it also attests to possibly interesting research of such interaction of fields. Namely, with the facets of neuroticism or even other personality traits and/or dimensions.

3.5 Experimental Implications

To the best of our knowledge, there is no measure to assess the *framing effect* of individuals. Considering the definition of this cognitive bias, we considered the priming of individuals to be the changing of behaviour - *risk-taking* or *risk-averse* - between the two main conditions of our work - *positive* and *negative* framings. Attending to the applied framing strategy, the obtained results suggest that **visualizations may help individuals be less susceptible to the framing effect**.

As aforementioned, there is a sharp gap in research regarding how humankind's cognitive limitations can affect visualization-supported decision-making. In particular, a lack of investigation into how the *framing effect* may affect such a process. Ergo, there is no consensus on what constitutes a good visualization to support decision-making, notably when investigating the possible inherent *framing bias* present. Considering this current lacuna, we began our research with the initial problem that led to the discovery of this bias. Attempting to build on it and bring it into the InfoVis community, we plucked inspiration from the small body of research found within our literature review phase. Namely, studies intersecting the decision-making process and visualization such as the one by Bancelhon et al. [2].

There are, likewise, very few studies approaching the influence of personality traits - including *neuroticism* - upon risk-taking behaviour [29]. Unfortunately, such extends to studies evaluating the impact of personality traits in *framing bias*. Despite our findings on this front being mostly non-significant, their singularity attests to the interest in further investigation of the subject. For instance, how far do visualizations help mitigate the *framing effect* and counter the expected behaviours of certain personality traits and dimensions.

Thus, our research offers some implications for future studies. These shall take into consideration the ample implications different

problem contexts may have within the decision-making process itself alongside the disparity between online and in-person studies may bring. Additionally, these should consider the impact of different personality traits and dimensions can introduce to the equation. Likewise, it should be noted that factors such as decision situation setup, experience, effort, and demographics can influence the effects of framing in experiments [5]. Moreover, that the *framing effect* on highly involved subjects - according to their personality, for instance - may be context-dependent [17]. We believe the gathered results provide further understanding for future research that aims to leverage cognitive bias-aware mechanisms to promote more rational decision-making. Additionally, our research reinforces the formerly need to further explore the *framing bias* within this context. Namely, with other visualizations alongside distinct problem contexts and other psychological constructs such as distinct personality dimensions and/or traits and respective facets.

4 CONCLUSIONS

Throughout the years, improvements made within the InfoVis field have brought a wider acknowledgement of the shortage of one-size-fits-all visualization systems. Increasingly, researchers have become to recognize the influence individual differences - namely, cognitive abilities and personality - can have on the interaction with the mentioned human-machine systems [24]. Albeit designing a visualization one shall take into account three kinds of limitations: computers, displays, and humans [27]. Hence, it becomes imperative to consider the limitations present within human judgement and decision making in such a process [13] alongside individual differences. This was precisely what our exploratory study focused on, with a particular aim to delve into the influence *framing bias* may have within the visualization community. Moreover, the potential effect of personality alongside it, specifically the *neuroticism* personality trait.

A rational choice implies that changes in the frame - identical alternatives under different frames, *positive* and *negative* - should not affect preferences or behaviour - *risk-averse* or *risk-seeking* - since both the alternatives as well as consequences of each choice are exactly the same [1]. Yet, ample evidence has risen establishing the existence of the *framing effect*, i.e., the systematic deviation from rational judgment as a consequence of different framings of the same decision-making problem. This particular cognitive bias has shown plausible evidence to transfer its priming effect onto the InfoVis context. However, upon our literature review, we verified an acute research gap between this intersection of fields and found that, despite its recognition, the *framing bias* is yet to be further investigated within the visualization field [13]. Moreover, within the domain of personality, *neuroticism* has proven to be a trait that interacts with the use of visualization systems and with the potential to play a role in shaping interaction with said systems. In particular, some works have found that *neuroticism* is correlated with both mouse activity and task completion time.

To achieve the objective of our work mentioned in Section 1, we began our research by investigating the *framing bias* alone. That is, to assess the potential effect different framings - *positive* and *negative* - could have within the established visualizations. The bulk of our results was non-significant, hinting that visualizations might be a helpful tool to reduce this bias upon interaction with visualization-supported systems. Especially, when the basis of a system is to aid in a decision-making process. Afterwards, we incorporated participants' personality data into our analysis, particularly their *neuroticism* scores. Such data were collected according to the European Portuguese version of the NEO PI-R by Lima and Simões [23]. Our findings with such interaction - *framing effect* and *neuroticism* - were, as well, mostly not statistically significant, likely reflecting the previously mentioned *framing effect* results. Nonetheless, we did encounter some singular findings involving

the *neuroticism* trait, which reflects the potential to further novelty research. Lastly, we discovered that, within our study sample, the decision taken in individual contexts - *positive* and *negative* framings - did hold when the same contexts were seen simultaneously.

Altogether, our results shed new light on the understanding of the *framing bias* within the InfoVis field suggesting that **visualization helps mitigate the framing effect**. Furthermore, lifting the possibility of it being so that it additionally lightens the generally expected behaviour of certain personality traits. In particular, how *neurotic* individuals tend to be risk-averse. We believe that we can leverage this knowledge to explore which visualization techniques prime individuals based on utility theory and devise a set of design guidelines to improve the design of visualization-based decision support systems. Namely, when likewise considering the personality of users.

4.1 Limitations and Future Work

Existing gaps in research together with the usage of Zoom meetings for the user tests posed some limitations to this research and offer some implications for future studies. The biggest limitation of our work stemmed from the research gap evidenced which is particularly noticeable concerning the *framing bias*. Namely, the lack of a validated apparatus to assess the framing effect, i.e., whether individuals were affected by it and/or the quality of the decisions taken.

Our research was merely able to encompass the one chart type - bar charts with error bars. Such leaves ample room for further research to explore not only other encodings - being those simple or complex - but also other types of framing. Future research would benefit from adding at least a control group to the experiment - i.e., where the information is merely presented through text - enabling the comparison between the two groups, with and without the visualization. Another feasible approach would be to conduct an investigation consisting of multiple trials - not only with a control group but also with other encodings - and/or scenarios. Such experiments could perhaps help uncover whether individuals would be consistent with their choices and behaviours or not.

Moreover, there is the possibility that the usage of confidence intervals (CI) indicating two values rather than a fixed (not risky) one can affect the number of hovers events of each option. Thus, future work may also profit from exploring other ways to convey the uncertainty inherent to the different options presented to the users. Comparison experiments with alternative uncertainty visualization techniques could, likewise, be informative. The hover events metric of our study may also have suffered some skewness due to the collection method used. Further research would benefit from not considering random/accidental mouse movements by applying a time threshold for this measurement, for instance. Especially if executed in an online setting like ours. Another suggestion would be instead to collect user interaction through clicks, avoiding accounting for unplanned and/or involuntary mouse movements.

Familiarity levels with the established visualizations alongside the self-reported overall risk attitude of the participants in our sample may both have influenced the interpretation, interaction and decisions taken with the visualizations of the study. As such, introducing both these as well as other individual characteristics (e.g., gender, education, and others) in the analytic models could also be explored in future work. Additionally, future works shall take into account the ample implications different problem contexts may have within the decision-making process itself.

Considering the scope of our work, we deemed our sample size ($N = 91$) to be satisfactory. Nevertheless, future research would benefit to aim for as large a sample size as possible to better corroborate the respective findings. While doing so, it must also be taken into account the desirable balance between personality groups to avoid potential skewness of data.

The usage of Zoom meetings conference brought a higher number

of individuals willing to participate together with a higher versatility in schedule and location for the participants. However, for some, it also meant occasional weak and/or unstable Wi-Fi connection. This contributed to some inaccuracies in the initially done counters for the hover events and affected some decision completion times, could have led to some inevitable data skewing. Considering these implications, the disparity between online and in-person and inherent limitations should be considered by subsequent studies.

We believe the gathered results provide further understanding for forthcoming research that aims to leverage cognitive bias-aware mechanisms to promote more rational decision-making. Furthermore, our research reinforces the aforementioned need to further explore the framing bias within this context. Namely, with other visualizations as well as distinct problem contexts. Finally, complex thinking through visualization becomes more susceptible to individual characteristics [39]. We argue that it is possible to enrich the user profile of the decision-maker with synergies from psychological constructs. Therefore, it is important to likewise investigate the interaction of the *framing effect* with the personality field. Namely, other traits and/or dimensions. In particular, InfoVis systems with access to personality data can detect if the decision-maker will be more susceptible to making an irrational decision. In that case, the system can adapt its content or provide further assistance to counter the priming effect and, consequently, allow the user to make a (more) rational decision.

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