EXPLORING GRAPHICAL DISPLAY EFFECTS IN THE CONTEXT OF PROCESSING AND DECISION-MAKING STYLES

BY

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ABSTRACT

Graphical displays have been shown to be effective tools in risk communication, especially for low-probability risks. Graphs depicting only the number of people affected by a risk ("foreground-only" graphs) can increase risk aversion, as compared to graphs that also depict the number of people at risk of harm ("foreground-background" graphs). However, there is little research looking into the cognitive mechanisms behind this "foreground-only effect". The current work seeks to inform our knowledge of the ways in which these graphs influence behavior by determining both how they are processed and how people make decisions based on the information they are presented with. Cognitive load manipulations were used to interfere with people's processing and decision making in order to determine whether the different displays are processed consciously versus automatically, as well as the degree to which they promote rational versus intuitive decisions. Individual differences in thinking style were also measured. An interaction between display type (foreground-only vs. foreground-background) and processing-stage cognitive load on risk aversion indicated support for a model which explains the foreground-only effect by stating that the two types of displays produce automatic processing of two distinct graphical elements. Subsequently, an element of conscious processing mitigates the influence of this effect for foreground-only graphs.

INTRODUCTION

Risk is an inevitable aspect of daily life, and people are constantly faced with decisions involving public safety, health, and environmental risks. It is essential that the general public have an accurate understanding of these risks, so that they can weigh them against the potential benefits. Experts who are well-versed in their respective fields thus help to inform the public and promote good decision making. In turn, these experts look to risk communication research to assist them in determining optimal ways of presenting information to the public. There are several goals of risk communication, including increasing people's awareness and understanding of risks, and promoting risk-avoidant behavior (Ancker, Senathirajah, Kukafka, & Starren, 2006; Lipkus, 2007). The latter objective will be the main focus of the current work; for example, experts may wish to convince people of the dangers involved in a particular behavior (e.g., tobacco use) by increasing the perceived size of the risk and ultimately increasing risk-avoidant behavior.

One particularly troublesome issue in risk communication is the presentation of low-probability risks. People have difficulty interpreting these risks and often dismiss them as negligible (Camerer & Kunreuther, 1989; Kahneman & Tversky, 1979), yet the consequences can sometimes be serious or fatal (e.g., automobile accidents). Furthermore, although low probability risks may be very unlikely to occur for any particular individual, they can have a strong overall impact on society when multiplied at national or worldwide levels (Shepperd et al., 2013). Research has found that the method of presentation of low-probability risks can have a significant impact on how they are interpreted (Halpern, Blackman, & Salzman, 1989; Stone, Yates, & Parker, 1994). Stone et al. (1994) suggest that these differences in interpretation are due to people's tendency to dismiss extremely low-probability risks as essentially nil. This assertion is consistent with prospect theory, which holds that low-probabilities are either overestimated or else "edited" to zero (Kahneman & Tversky, 1979).

One approach to dealing with these low probability risks is the use of visual aids. In attempting to determine the most effective ways to communicate risk, much research has examined the use of graphical displays as a way of improving understanding, drawing and maintaining people's attention, and reducing the cognitive effort required by other formats, such as numerical displays (Ancker et al., 2006; Lipkus & Hollands, 1999). Graphs have also been shown to aid in the risk communication goals mentioned above, including that of increasing risk avoidant behavior (Stone, Yates, & Parker, 1997; Stone et al., 2003). For example, Stone et al. (1997) found that people were generally more risk averse when viewing icon displays as opposed to purely numerical ones. Some studies have looked into how and why graphical displays assist in the communication of risk (Lipkus & Hollands, 1999; Okan, Garcia-Retamero, Cokely, & Maldonado, 2015; Stone, Bruin de Bruine, Wilkins, Boker, & MacDonald Gibson, 2016; Stone, Reeder, Mills, Miller, & Parillo, 2017). However, it is still not very well understood why they provide a benefit, nor have the cognitive mechanisms behind graphical display effects been fully explained. The current work aims to investigate the manner in which certain graphs are processed differently than other presentations of risk, as well as how decisions are made based on these displays.

Numerical and Graphical Display Effects on Risk Aversion and Perception

Stone and colleagues (1997) created scenarios that involved the number of people at risk of serious injury due to tire blowouts using "standard tires," and compared the reduction in risk as a result of using safer "improved tires." On average, participants were willing to pay a higher price for the safer tires when the information was presented graphically. This effect held for both bar graphs and graphical icons used to represent a person or individual case, including asterisks, stick figures and faces. However, in subsequent research, Stone et al. (2003) found that these differences no longer held for displays that depicted both the numerator and denominator of the risk ratio graphically. This finding led to an important distinction. The type of graph that originally produced the display effects mentioned above (Stone et al., 1997) graphically depict only the numerator of a risk ratio (the number of people affected) and are referred to as *foreground-only* displays. Figure 1a, taken from Stone et al. (2003), demonstrates this type of display: we can see the difference in the number of people suffering from gum disease using Standard versus Improved Toothpaste are 30 and 15, respectively. Here, the total number of people at risk of gum disease, or "background," are not depicted graphically, and only appear in the description as a number (5,000). *Foreground-background* displays, on the other hand, graphically show both the numerator and denominator of a particular risk. This feature allows individuals to see the part-to-whole relationship in one continuous display (Ancker et al., 2006). Figure 1b thus shows the 30 people affected by gum disease using Standard Toothpaste *and* the 5,000 people at risk, compared to 15 out of 5,000 who use Improved Toothpaste. Stone et al. (2003) found that when viewing foreground-background displays (in this case pie charts and stacked bar graphs), people were no longer more inclined to pay for a safer product than those who viewed only numbers. Thus foreground-only displays produce more risk aversion than numbers, but this effect does not hold for foreground-background displays.

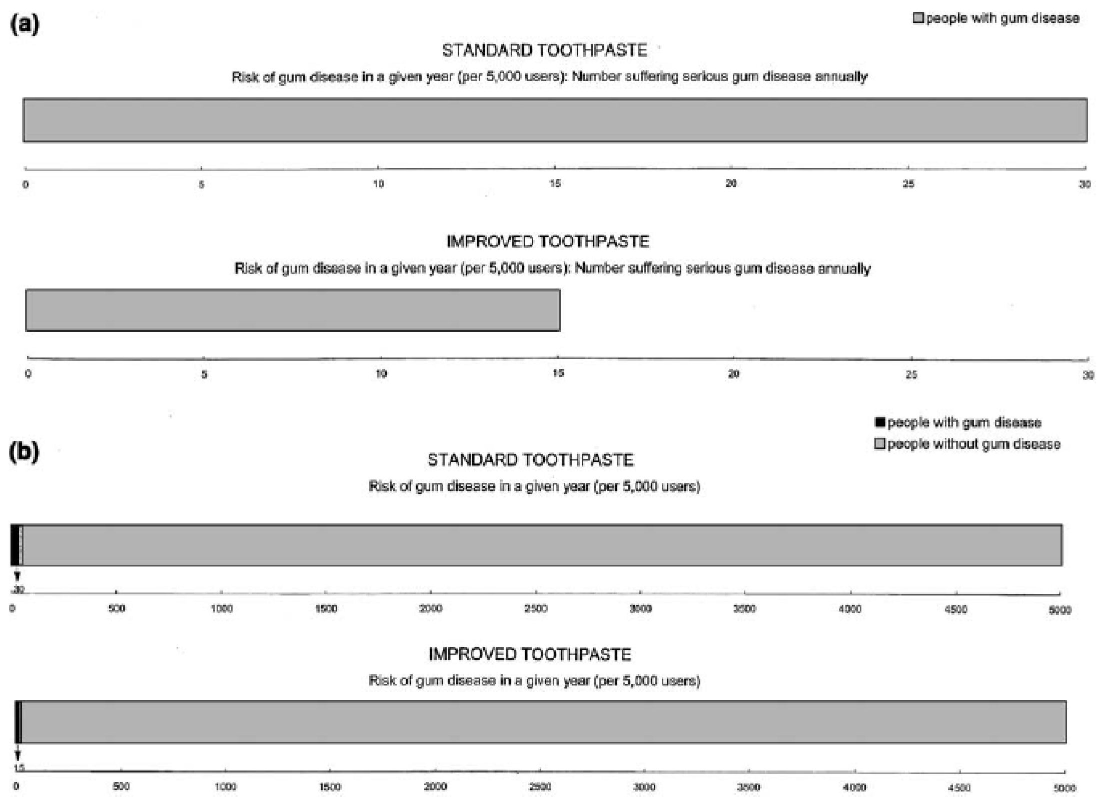

Figure 1. (a) Foreground-only graph (b) Foreground-background graph. Adapted from "Foreground:background salience: Explaining the effects of graphical displays on risk avoidance," by Stone, E. R., Sieck, W. R., Bull, B. E., Yates, J. F., Parks, S. C., & Rush, C. J. (2003). *Organizational Behavior and Human Decision Processes*, *90*(1), 19-36. Copyright 2003 by Elsevier Ltd.

Following Stone et al. (2003), other work directly comparing these two types of graphical displays has provided additional evidence that foreground-only displays produce more risk aversion than foreground-background displays. This "foreground-only effect" has been found with bar graphs versus stacked bar graphs (Bruine de Bruin, Stone, MacDonald Gibson, Fischbeck, & Shoraka, 2013; Stone et al., 2003; Stone, Bruine de Bruin, Wilkins, Boker, & MacDonald Gibson, 2016), pie "slices" versus pie charts (Hu, Jiang, Xie, Ma, & Xu, 2014), and foreground-only versus foreground-background icon arrays (Stone, Okan, Bonapart, Parker, & Bruine de Bruin, 2015). Interestingly, Bruine de Bruin et al. (2013) also found that text without emphasis on the denominator produced more risk aversion than text with the denominator emphasized.

Foreground-only displays have thus been shown to produce more risk aversion than foreground-background and numerical displays. Studies comparing the latter types of displays, however, have shown no such effect. Some have found no differences in risk-avoidant behavior between foreground-background and numerical displays (MacDonald Gibson, Rowe, Stone, & Bruine de Bruin, 2013; Waters, Weinstein, Colditz, & Emmons, 2007; Zikmund-Fisher et al., 2008), while others suggest that foreground-background displays produce even less risk aversion than purely numerical displays (Galesic, Garcia-Retamero, & Gigerenzer, 2009; Stone et al., 2003). It appears that the basic mechanism at work here is that foreground-only displays lead people to believe that the risk is larger than it actually is, whereas foreground-background displays, which allow viewers to see the part-to-whole relationship, give people a clearer idea of the true risk magnitude (Ancker et al., 2006; Stone et al., 2003).

Theoretical Accounts of Graphical Effects

Taken together, the findings outlined above provide a large amount of evidence for the greater effectiveness of foreground-only displays than foreground-background displays at inducing risk aversion. However, they do not address the question of why these graphical display effects occur, which is critical to advancing the field (Lipkus & Hollands, 1999; Stone, Bruine de Bruin, et al., 2016). Although our knowledge of what is behind these effects is still somewhat limited, recent research has begun to look into this issue.

Existing Explanations for Graphical Display Effects

One approach to investigating how graphical displays influence risk averse behavior has been to determine the pathways through which this effect occurs. Building upon the work of Jarvenpaa (1990), Chua, Yates, and Shah (2006) proposed an "attention priority model," whereby (foreground-only) graphs draw attention to the visually salient reduction in risk. This initial focus has downstream effects on people's behavior later in the process and results in higher perceived risk and an increase in negative emotions, which ultimately influences risk avoidant behavior. Similarly, Stone, Bruine de Bruin et al. (2016) found that the way in which graphical display effects influence decision making is twofold: by influencing their perception of the risk and the fear they experience as a result of the graphs (and the accompanying text). More specifically, their model indicates that graph format (foreground-only vs. foreground-background) affects people's perception of the risks, their experienced fear, and their understanding of the risk magnitudes, all of which eventually influence their decision making.[1] Thus emotion, along with risk perception, mediates the link between graph format and risk aversion.

Although the previous work established that foreground-only graphs affect people's risk perception and emotions, it does not address the question of why this occurs. Stone et al. (2003) proposed that the increased risk aversion found in foreground-

[1] The full structural equation model in Stone, Bruine de Bruin et al. (2016) includes an additional step, feelings of worry, between risk perception/fear and risk aversion. As Stone et al. note, worry has both affective and cognitive elements. In addition, the way in which worry is assessed can determine which of these elements are activated. Thus, for the sake of clarity and simplicity, we chose to leave out this link for the purposes of this paper.

only displays depicting low-probability risks was due to a salience effect, whereby these displays made the risk appear larger due to their emphasis on the number of people affected (i.e., the numerator) while simultaneously drawing attention away from the total number of people at risk (i.e., the denominator). Subsequently, Stone, Reeder et al. (2017) tested this theory along with an alternative account—that the mechanism behind the effect depends on the display's ability to draw attention to the proportion. According to this *proportional reasoning* account, graphs that show only the foreground graphically inhibit people's ability to form the proportion, thus making it difficult to see that the probability is low, whereas foreground-background displays—where both the numerator *and* denominator of the proportion are shown graphically—encourage viewers to attend to the proportion. Thus foreground-only displays, lacking a visual portrayal of the part-to-whole relationship, cause individuals to view the risk as larger than it actually is, whereas foreground-background displays are seen as appropriately small. A series of three experiments found support for the proportional reasoning account, including the finding that presenting the foreground and background in the same modality (i.e., both graphs or both numbers) produced less risk aversion, presumably because they facilitated proportional thinking.

Processing Types and Their Relationship to Graphs

Much of the work on risk communication has suggested that graphical displays, including foreground-only and foreground-background displays, are to some degree processed automatically (Chua et al., 2006; Jarvenpaa, 1990; Reyna, 2008), whereas numerical displays are generally seen as involving slower, more controlled processes (Ancker, 2006; Lipkus & Hollands, 1999). Lipkus (2007) notes that the lack of automatic responses are a drawback of purely numerical formats: they need to be processed rationally in order to be understood. Graphical displays have been found to provide individuals with a more complete understanding of risk, as they provide visual cues that lead to automatic, rather than cognitive, mathematical operations (Lipkus & Hollands, 1999) and are thus capable of reducing processing load. For this reason, some researchers advocate the use of graphical displays to exploit the immediate, automatic responses that they produce (Ancker et al., 2006). For example, a simple bar graph depicting different levels of risk and consisting of bars of different heights elicits an automatic, intuitive calculation (Lipkus, 2007; Okan, Galesic, & Garcia-Retamero, 2016).

Research specific to graphs and graph comprehension has shown that certain features of graphs elicit immediate, automatic responses. These features draw upon the preconscious ability of the visual system to perceive patterns and determine relative magnitudes (Cleveland & McGill, 1985). Thus, graphs can visually portray information that allow individuals to easily make inferences, such as size, distance, and spatial comparisons, that rely almost exclusively on perception and require little cognitive effort (Casner, 1991). These types of inferences significantly reduce processing load and are also considerably faster. It is important to note, however, that not all graphs produce such responses and indeed some lend themselves to rather slow and labor-intensive cognitive processes (e.g., Carpenter & Shah, 1998). According to Hollands and Spence (1998), graphs can be differentiated by whether they involve simpler perceptual inferences, or more time consuming mental operations. Another related factor may be the complexity of the graph; for example, a simple bar graph showing a comparison of two quantities would involve mostly rapid perceptual judgements, whereas a bar graph displaying information from two independent variables would involve elements of direct (i.e., automatic) visual perception in addition to slower, more involved cognitive processes (Carpenter & Shah, 1998). Thus, it is not the case that certain types of graphs are processed either automatically or consciously, but instead that certain features of graphs are more or less conducive to automatic processing.

Part-to-whole displays vs. foreground-only displays. Ancker et al. (2006) noted that foreground-background displays possess a unique design feature: They display the part-to-whole relationship visually, which helps people's ability to judge proportions. Indeed, Hollands and Spence (1992) found that people were faster and more accurate in gauging the proportion with pie charts and stacked bar graphs—both of which display the part-to-whole visually—than line or standard bar graphs.[2] Hollands and Spence contend that pie charts and stacked bar graphs thus allow people to perceive the proportion "directly," i.e., simply and with less mental effort. The same theoretical principle can be applied to foreground-background icon arrays, where the number of people affected and the total number of people are shaded differently and are easily comparable. Conversely, foreground-only displays, which lack a visual representation of the part-to-whole relationship, do not promote automatic processing of the proportion—people simply judge the relative size of the bars (see Figure 1a) at a glance, thus making the only comparison visually available to them (i.e., that one of the bars is twice as big as the other). Reyna (2008) notes that such graphs encourage the extraction of the gist that the risk is reduced in one treatment as opposed to the other. This type of frequency judgment

[2] Note that these results held only for when the graphs had no graduated scale. Of course, graphs typically have a scale, but they tend to not show the percentage units, which is precisely the information that would make judging the proportion easier.

of relative magnitude is believed to occur automatically, without much conscious effort (Gigerenzer, 1984; Gigerenzer et al., 1991), and is evident even in young children (Reyna & Brainerd, 2008).

Taken together, graph comprehension and risk communication research suggests that certain elements of both foreground-only and foreground-background displays are to some degree processed automatically. However, there are no studies to our knowledge that have empirically tested this within the framework of risk communication. In addition, while it may be true that graphs require less cognitive effort to process than numerical presentations of risk in general, other work suggests that the manner in which each particular graph or element of a graph is processed lies on a continuum, ranging from fast and effortless to slow, effortful, and cognitively taxing (Allen, Edwards, Snyder, Makinson, & Hamby, 2014; Carpenter & Shah, 1998). In addition, as shown in Stone, Bruine de Bruin et al. (2016), the pathway that ultimately leads from a graph format to decision making involves several steps. Edwards, Snyder, Allen, Makinson, and Hamby (2012) make an important distinction between interpreting a graph and making a decision based on that information. Even in cases where graph interpretation involves an automatic process, the decision making stage may involve deliberative thinking. Thus, determining how risk-related displays are processed, the manner in which judgments are made based on these displays, and how these factors might ultimately affect people's behavior could be a valuable contribution to our understanding of the mechanisms behind graphical display effects.

Modeling the Impact of Display Type on Risk Aversion

Building upon findings from two papers by Stone and colleagues (Stone, Bruine de Bruin, et al., 2016; Stone, Reeder et al., 2017), we will introduce some possible models of how people's processing of graphical information, as well as how they make decisions based on that information, might help explain graphical display effects. As shown in Figure 2, each of the models claim that the type of display (foreground-only vs. foreground-background) is processed in one of three ways. This in turn influences people's perception of the risk and their emotional response, which ultimately affects their degree of risk averse behavior. Each of the models is discussed in detail below.

The first model states that since numerical displays are assumed to be processed consciously, and foreground-background graphs produce similar levels of risk aversion as numerical displays, foreground-background displays should be processed similarly. Foreground-only graphs, on the other hand, induce more automatic (as opposed to conscious) processing and thus lead to greater perceived risk and emotion, resulting in higher levels of risk aversion. As shown in Figure 2, Model 1 thus explains the foreground-only effect by proposing that the foreground-only display produces more automatic (vs. conscious) processing than does the foreground-background display, and this increased level of automatic processing produces greater perceived risk, emotions, and risk aversion.

Although this explanation is consistent with the data, one drawback to this model is the claim (cited above) that foreground-background displays, which visually portray the part-to-whole information, are processed automatically. If this is the case, then the reason why foreground-background displays produce less risk aversion is not because the

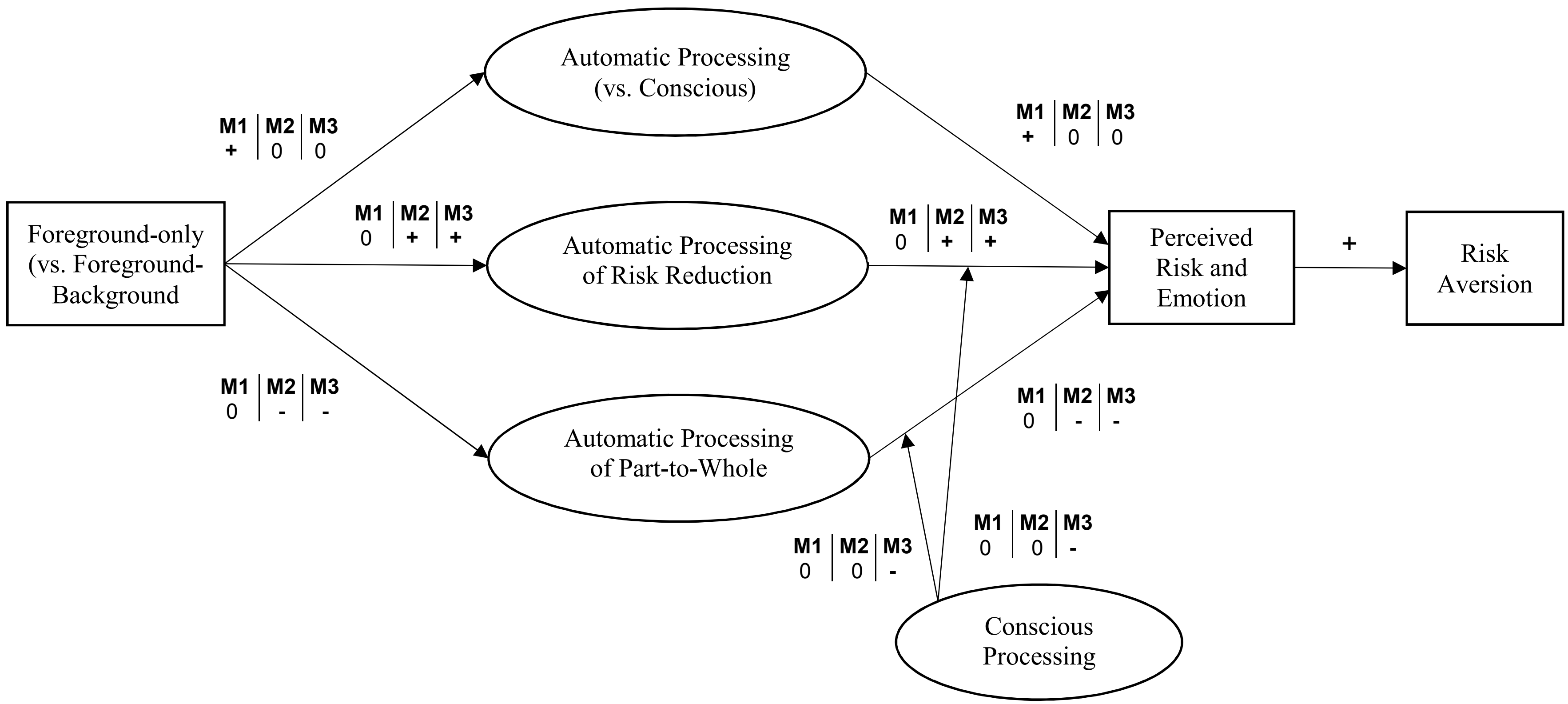

Figure 2. Conceptual models. Foreground-only (and foreground-background) graphs are processed in one of three ways. This processing style then influences people's perception of the risk and their emotional response, which ultimately affects their degree of risk averse behavior.

information is processed more consciously, but rather that the *type* of information being processed automatically is different. Model 2 thus considers not only the manner in which the displays are cognitively processed, but also the nature of the information being processed. This model states that with foreground-only displays, people process the risk reduction automatically, leading to greater risk perception and a stronger emotional response, and ultimately more risk aversion. Conversely, with foreground-background displays, people process the part-to-whole automatically, which visually conveys the information that the risk is small. Model 2 thus proposes that foreground-only displays produce more automatic processing of the risk reduction and less automatic processing of the part-to-whole relationship, which in turn leads to the risk being perceived as larger, stronger emotions, and ultimately more risk aversion.

The third model builds on the assumptions of the first two, and considers the possibility that both types of graphs involve a combination of both automatic *and* conscious processing. Jarvenpaa (1990) argued that sensory features of graphs are initially processed automatically, followed by a conscious appraisal of that information. Thus Model 3 posits that two effects are happening. First, foreground-only displays produce automatic processing of the risk reduction, which leads to greater perceived risk and emotion, and ultimately more risk aversion. However, this effect is then somewhat weakened by the conscious processing that immediately follows the automatic perceptual processing of the graphical elements. Concurrently, foreground-only displays lead to *less* automatic processing of the part-to-whole, which would result in the risk being perceived as smaller, a milder emotional response, and ultimately less risk aversion. Here again, conscious processing weakens the link between automatic processing (of the part-to-whole) and perceived risk and emotion.

The models above assume that during the decision-making stage, people are making rational judgments. However, there is evidence suggesting that different types of displays might affect people's decision making. Allen et al. (2014) found that participants viewing graphs under cognitive load were able to extract probability information from the graphs, but had difficulty making more complex judgments. In addition, Ancker and colleagues (2006) suggested that people may be able to reduce the emotions involved in decision making by viewing part-to-whole displays, since they can effectively decrease the influence of anecdotal reasoning (Fagerlin, Wang, & Ubel, 2005). Given this account, the processes posited in the above models may be supplemented by an additional effect that occurs *after* the emotional reaction.

Specifically, foreground-only graphs also promote intuitive or emotional decision making, in addition to the previously outlined processing effects. Thus the foreground-only effect is proposed to be produced by two different components, which can be conceptualized by extending the first three models with an additional component. As indicated in Figure 3, the extension adds an intuitive (vs. rational) decision making variable between perceived risk & emotion and risk aversion. In the case of foreground-only graphs, the intuitive decision making further increases risk avoidant behavior. First, as indicated in Models 1-3, the degree to which the displays are processed automatically or consciously lead to the foreground-only condition producing greater perceived risk, emotions, and ultimately risk aversion. Second, due to their increased emotional reaction

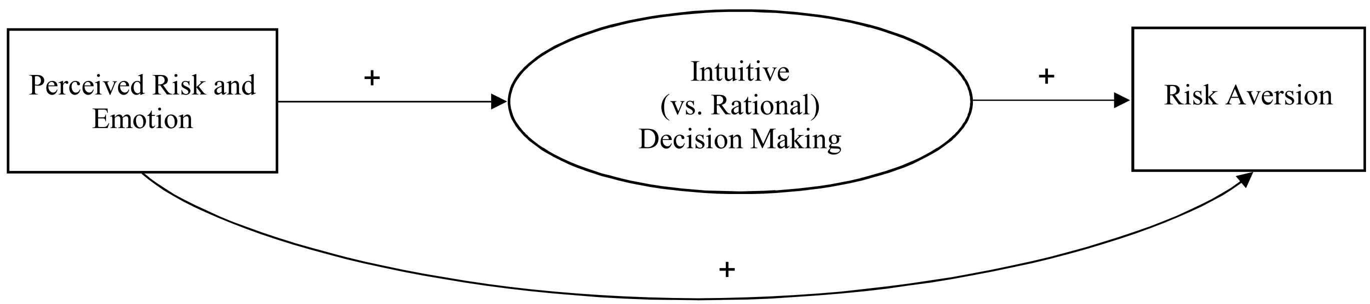

Figure 3. The decision-stage model extension adds an additional component to each of the previous three models. In addition to the direct link between risk perception and risk aversion, perceived risk and emotion also induces intuitive decision making, which leads to increased levels of risk aversion.

and risk perception, people also decide more intuitively in the foreground-only condition, which further increases risk aversion.

Cognitive Load Manipulations

In order to distinguish among our proposed models and thereby determine the manner in which people are processing the graphs and making decisions, we used a cognitive load manipulation in order to interfere with a) people's conscious processing of the graphical displays and b) their ability to decide rationally. Research has shown that people's ability to make rational judgments is compromised when they are *cognitively busy* (Gilbert & Osborne, 1989). In addition, Allen et al. (2014) found that people's decision making behavior was affected while under cognitive load when viewing graphs and responding to related questions, and that this effect varied according to the type of display. The cognitive load manipulations were therefore intended to tax participants' cognitive resources, with the following objectives: For the processing stage, the goal was to interfere with conscious processing, so as to induce automatic processing. Similarly, the goal for the decision stage was to interfere with rational decision making, so that it is more intuitive.

Model Predictions

Processing stage. Each of the models predicted different effects as a result of the processing-stage cognitive load manipulation. Figure 4 thus adds the cognitive load variable to the models, showing the predicted effects. According to Model 1, the cognitive load will presumably cause participants in the foreground-background condition to process the information more automatically, causing them to behave similarly to the way they would in the foreground-only condition: perceiving the risk as

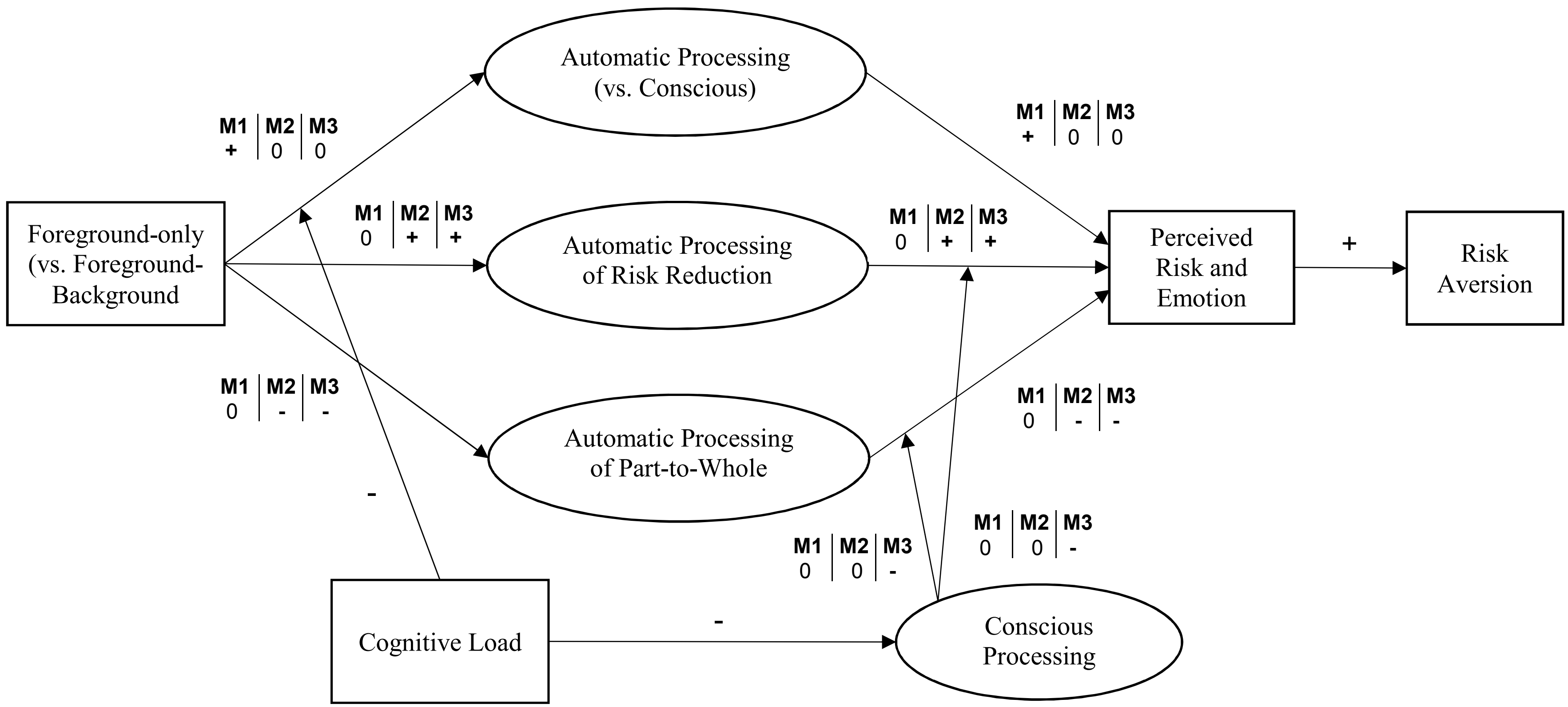

Figure 4. Conceptual models with cognitive load manipulation

larger and becoming more risk averse. In Model 1, the link between display type and processing will be weakened as a result of the cognitive load, resulting in a weaker foreground-only effect (see Table 1). Model 1 therefore predicts an interaction between display type and processing cognitive load, where the effect of display type on risk perceptions, emotions, and risk aversion will be weaker in the high cognitive load condition.

In Model 2, the cognitive load is not expected to have an effect, since both types of graphs are already processed automatically and thus would not be affected by cognitive load. As can be seen in Figure 4, the link between display type and processing will remain unaffected by the cognitive load. Model 2 should therefore produce the typical foreground-only effect, with no interaction between processing cognitive load and display type.

The cognitive load manipulation is predicted to affect the conscious processing element in Model 3, which in turn inhibits the negative effect that conscious processing is assumed to exert on the links between automatic processing and perceived risk and emotion. In other words, since conscious processing is normally expected to weaken the influence of automatic processing on risk perception and emotion, interfering with conscious processing will reduce this effect. As a result, people become even more risk averse in the foreground-only condition, and even less risk averse in the foreground-background condition as a result of the cognitive load. Model 3 thus predicts an interaction between display type and processing-stage cognitive load, such that the foreground-only effect will increase as a result of the cognitive load.

Table 1

Predicted Effects of Cognitive Load Manipulations on the "Foreground-only Effect"

	Mean Risk Aversion	
	Processing stage	Decision stage
Model 1	Reduces	No effect
Model 2	No effect	No effect
Model 3	Increases	No effect
Model 1 with extension	Reduces	Reduces
Model 2 with extension	No effect	Reduces
Model 3 with extension	Increases	Reduces

Note. The "foreground-only effect" refers to the difference in mean risk aversion between the foreground-only and foreground-background conditions.

Decision-stage extension. The decision-stage cognitive load manipulation is expected to have no effect on Models 1-3. However, the extension to the models predicts an increase in risk aversion for the foreground-background condition as a result of the cognitive load, since leading people to decide more intuitively should increase their risk aversion to a level similar to that of the foreground-only condition. Figure 5 shows how the cognitive load is predicted to weaken the connection between perceived risk and emotion and intuitive (as opposed to rational) processing, thus reducing the difference in risk aversion between the two types of displays. As indicated in Table 1, the foreground-only effect would be reduced for all models with the extension.

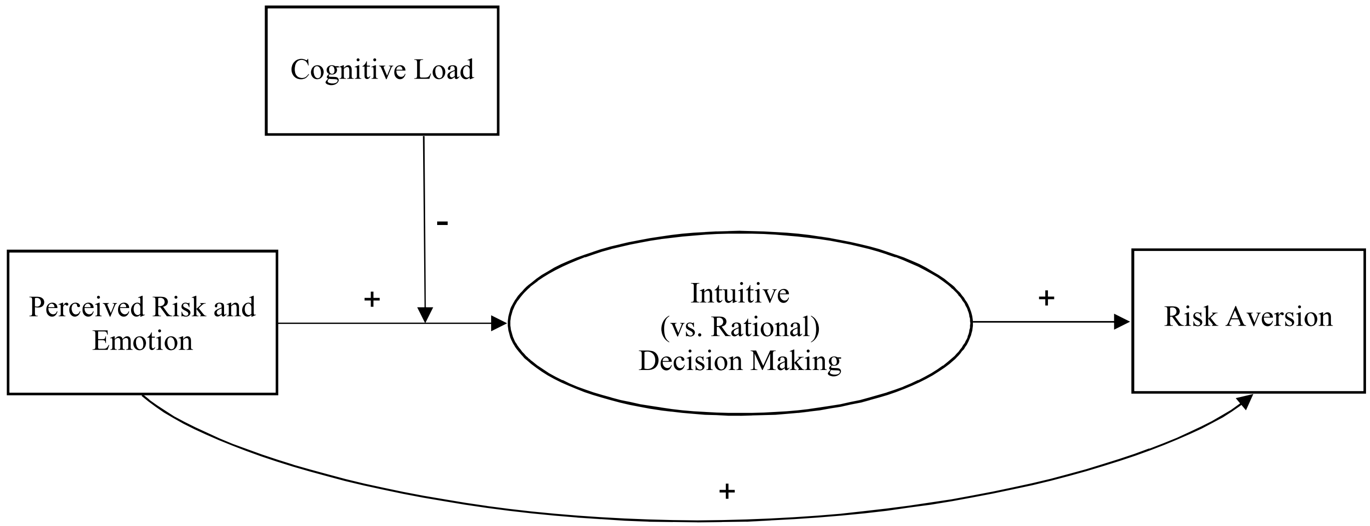

Figure 5. Decision-stage model extension with cognitive load manipulation

Rational and Experiential Thinking Styles

The above models assume that individuals process risk communication formats and make decisions based on that information in the same manner. However, there are undoubtedly individual differences that contribute to the foreground-only effect as well. Epstein's (1994) Cognitive–Experiential Self-Theory (CEST) claims that people differ in their tendency to rely on rational, as opposed to intuitive thinking (Epstein, Pacini, Denes-Raj, & Heier, 1996), and this may help provide explanations as to their risk-avoidant behavior. We were particularly interested in whether rational or experiential thinking styles interacted with display type, and with the display type by cognitive load interactions. To the extent that automatic processing of information produces the foreground-only effect and conscious processing mitigates this effect, as suggested in Model 3, then people who tend to think more experientially or less rationally should exhibit a greater foreground-only effect. In addition, according to Model 3, those that think more rationally should be more affected by the cognitive load manipulation. Including a measure of individual differences in thinking style will also allow us to conduct exploratory analyses on how these differences might moderate the predicted effects of the cognitive load manipulations.

EXPERIMENT 1

Method

Participants. One-thousand five-hundred and ninety-eight participants were recruited on Amazon Mechanical Turk (MTurk) and were compensated $0.30 USD for their participation. Eighty-one participants were excluded for not completing the survey. Due to the cognitively taxing nature of the study, we were particularly concerned with the possibility of participants in the high cognitive load conditions disproportionately withdrawing from the study. Two separate chi-square tests of independence were thus conducted to determine if the percentage of participants who did or did not finish the survey varied according to each of the cognitive load conditions. The proportions did not vary by processing cognitive load condition, $\chi^2(1, N = 1{,}555) = .11$, $p = .740$, or the decision making cognitive load condition, $\chi^2(1, N = 1{,}535) = .89$, $p = .344$.

Materials.

Risk scenario. Participants were presented with a modified version of a risk scenario used in Okan, Stone, Parillo, Bruine de Bruin, and Parker (2017). They were asked to consider the following scenario:

> Imagine that you are living in an area that the Centers for Disease Control and Prevention (CDC) has identified as being at risk for an infectious disease, mylobia, which can be spread from direct or indirect contact. Symptoms include high fever, severe diarrhea, skin rash and lesions. Mylobia usually subsides in 3-4 weeks with aggressive treatment, but can become serious and even fatal if not treated early enough. A vaccine has been developed that reduces the likelihood of contracting the disease.

Cognitive load. Participants were given a number to memorize in order to induce cognitive load for two separate manipulations: a) viewing the graph and answering risk perception and emotion questions (processing stage), and b) responding to outcome measures assessing their risk aversion (decision stage). Participants in the high cognitive load conditions were asked to memorize a string of eight digits (e.g., 85291073), and those in the low load conditions were given two digits (e.g., 17).

Graphical displays. Two graphical displays were created using Microsoft PowerPoint. The foreground-only display (Figure 6) used 20 person icons on the left side of the display to depict the number of people that would contract mylobia without the vaccine, and 10 person icons on the right side that showed the number of people that would contract mylobia with the vaccine. Although the total number of people at risk is not portrayed graphically, this figure (1,000) is presented numerically in the description above each section of the graphs.

The foreground-background display (Figure 7) used 1,000 person icons on each side of the display. On the left, 20 icons were shaded black, representing the number of people that would contract mylobia with the vaccine, and 980 were shaded gray that depicted the number of people that would not contract mylobia. On the right side, 10 icons were shaded black and 990 were shaded gray.

Outcome measures. Participants were presented the following items, modified from Okan et al. (2017). The complete outcome measures can be found in Appendix A.

Risk perception and emotion. For the risk perception items, participants estimated the likelihood of contracting mylobia without the vaccine, with scales ranging from 1 (*not at all likely*) to 7 (*extremely likely*). In addition, they indicated their estimate

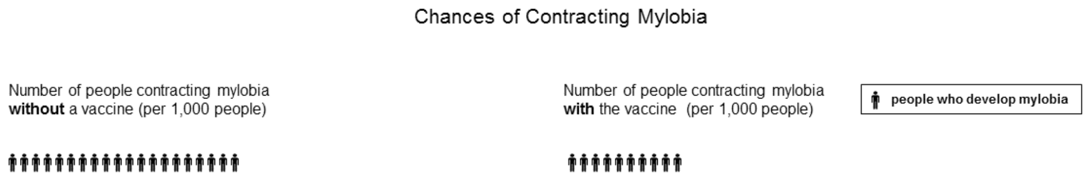

Figure 6. Foreground-only condition.

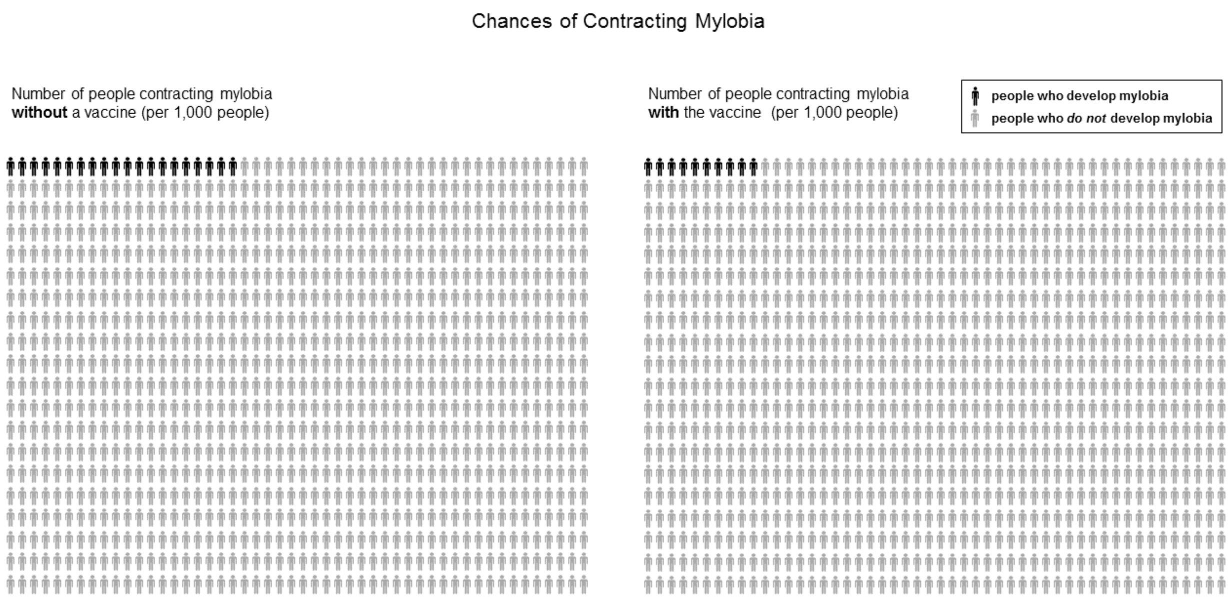

Figure 7. Foreground-background condition.

of the decrease in the likelihood of contracting mylobia if they receive the vaccine on a scale ranging from 1 (*not at all less likely*) to 7 (*much less likely*). In order to measure their emotional response to the displays, participants rated the degree to which they were scared about contracting mylobia assuming they did not receive the vaccine, from 1 (*not at all scared*) to 7 (*extremely scared*). As with risk perception, participants rated how much less scared they would be about contracting mylobia assuming they received the vaccine on a scale ranging from 1 (*not at all less scared*) to 7 (*much less scared*). All four items were combined to form a single risk perception and emotion variable (Cronbach's $\alpha = .67$), despite the relatively low alpha.[3]

Risk aversion. Because participants responded to the risk aversion items while undergoing the decision-stage cognitive load, it was necessary to ensure that their responses to these measures were separate from the first cognitive load manipulation. In other words, these items had to be presented in such a way as to prevent decisions from having been made immediately upon viewing the displays. If participants had made their decisions immediately after viewing the graphs (whether consciously or not), the decision cognitive load manipulation would not be capable of having an effect. Therefore, we designed decision-making items that participants would presumably not make until prompted. Participants were first told to imagine that all manufacturers had run out of their supply of the mylobia vaccine. They were then presented with three items assessing

[3] In order to accurately test the models, it was necessary to have a single risk perception and emotion variable. The low alpha seemed to be due to the relatively weak correlations between the two risk perception ($r = .194$) and two emotion ($r = .248$) items. However, because the risk was framed in terms of a risk reduction (as a result of the vaccine), it is important to measure both people's initial perception of the risk and their perception of the decrease in risk as a result of the vaccine. In addition, previous work (Okan et al., under review; Stone et al., 2003; Stone, Bruin de Bruine et al., 2016; Stone, Reeder et al., 2017) found higher correlations among similar items. It is possible that the grouping of the items or the slightly different wording in the current study may have led to the lower correlations.

risk aversion that would presumably not have been decided upon while viewing the graphical display. Participants were asked how much money they think health organizations should allocate towards emergency production of the mylobia vaccine on a 7-point scale ranging from 1 (*zero*) to 7 (*$1,000,000*). In addition, they were asked what priority health organizations should give to production of the mylobia vaccine on a scale ranging from 1 (*extremely low priority*) to 7 (*extremely high priority*). Finally, participants estimated the percentage of the emergency budget they thought health organizations should allocate towards emergency production of the vaccine, using a scale ranging from 0 to 100 percent. The three items were averaged to provide an overall measure of risk aversion (Cronbach's alpha = .79).

Rational-Experiential Inventory. In order to assess participants thinking style, we administered the 10-item version of the Rational-Experiential Inventory (REI-10; Epstein et al., 1996). The REI-10 consists of two separate subscales: a 5-item *need for cognition* scale and a 5-item *faith in intuition* scale. The need for cognition subscale (α = .79) tests people's propensity for rational thinking (e.g., "I prefer to do something that challenges my thinking abilities rather than something that requires little thought"). Three of the items are reverse scored. The faith in intuition subscale (α = .91) tests people's tendency to think intuitively or experientially (e.g., "I believe in trusting my hunches".) Items for both subscales were rated from 1 (*completely false)* to 5 (*completely true*). The complete list of measures can be found in Appendix B.

Manipulation checks and other additional measures. In order to assess the effectiveness of the cognitive load manipulations, participants will be asked to rate how distracted they felt while viewing the graphs and answering the questions on a scale from

1 (*not at all distracted*) to 7 (*extremely distracted*), in addition to two "filler" items designed to deflect attention away from the manipulation check.

Verification task. One final cognitive load "verification task" was included to allow us to exclude participants on the basis of not being sufficiently under cognitive load, without differentially excluding participants from the high cognitive load conditions. All participants were given an eight-digit number to memorize, followed by a graph and two questions related to that display. After responding to the questions, they were asked to recall the number. Finally, participants were requested to honestly report whether they had written the numbers down, rather than memorize them. Appendix C contains the manipulation check and verification task items and graph.

Procedure. Participants were provided with a link on MTurk that directed them to a survey programmed using Qualtrics' online survey platform. After providing consent, they were given the risk scenario, followed by the first number memorization task. Next, participants were randomly assigned to either a low or high cognitive load and were asked to memorize the corresponding number. They were requested to rehearse the number in their head until asked to recall it. While maintaining the number in their memory, participants were randomly assigned to view either a foreground-only or a foreground-background display that included the risk information, followed by the risk perception and emotion measures. The next screen directed them to recall the number and write it in a text box. At this point, participants were again randomly assigned to a high or low cognitive load condition in which they were asked to memorize another number, followed by a set of outcome measures assessing risk aversion. Once again, they were asked to recall the number and enter it into a text box. Subsequently, the Rational-

Experiential Inventory was administered, followed by the manipulation check assessing their level of distraction and the filler items. Participants were then given the cognitive load verification task, and the question regarding whether they had written the numbers down, rather than memorizing them. Finally, participants created a payment code and were thanked for their participation.

Results and Discussion

Cognitive load manipulation checks. Three-hundred twenty-five participants were excluded for failing either of two predetermined manipulation checks intended to ensure that participants were in fact under cognitive load at the appropriate points in the experiment. First, 46 participants were excluded for admitting to writing the numbers down instead of memorizing them as requested. A chi-square test of independence showed no disproportionate concentration of those that wrote the number down among the cognitive load conditions, $\chi^2(3, N = 1{,}517) = 3.59, p = .309$. In addition, 279 participants were excluded from the final analyses for committing more than two errors when reporting the final cognitive load manipulation number.[4] The final analyses were thus conducted using a sample of 1,192 participants.

In order to determine whether the cognitive load manipulations were effective, participants' responses to the manipulation check item that assessed their self-reported degree of distractedness were analyzed to compare only those who were assigned to the same condition for each of the cognitive load manipulations (i.e. the same cognitive load

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[4] An *a priori* decision was made to exclude participants based on the results of the final cognitive load number memorization, provided that the average correlation between this task and the two other number memorization tasks was above .30. Since the average correlation ($r = .346$) was indeed above this cut off, the participants were excluded. It is important to note, however, that although the analyses conducted without excluding these participants were trending in the direction of the final analyses, some of the key observed effects, including the interaction of display type and processing-stage cognitive load on risk aversion, were not significant.

for both the processing and decision manipulations). Indeed, an independent samples t-test showed that participants in both high load conditions (*M* = 3.54, *SD* = 1.98) reported being more distracted than those who were assigned to both low load conditions (*M* = 2.22, *SD* = 1.47), $t(604) = 9.38$, $p < .001$.

Risk aversion. Because the three risk aversion items were measured differently, each item was z-standardized before averaging the three items. All subsequent analyses were run on this composite z-scored variable, and the reported means are thus also in z-units. A 2 (display type: foreground-only & foreground-background) x 2 (processing-stage cognitive load: high & low) x 2 (decision-stage cognitive load: high & low) analysis of variance (ANOVA) was conducted on the combined risk aversion variable. In line with previous research, there was main effect of display type. Participants presented with foreground-only graphs (*M* = .18, *SD* = .83) were significantly more risk averse than those who were presented with foreground-background graphs (*M* = -.19, *SD* = .84), $F(1, 1184) = 61.46$, $p < .001$, $\eta^2 = .05$. In addition, there was a significant two-way interaction between display type and processing cognitive load, $F(1, 1184) = 4.04$, $p = .045$, $\eta^2 = .003$ (see Figure 8). In support of Model 3, planned contrasts showed that under low cognitive load, participants exhibited the typical foreground-only effect: Those who were presented with foreground-only displays (*M* = .10, *SD* = .81) were more risk averse than those presented with foreground-background displays (*M* = -.18, *SD* = .81), $t(1184) = 4.16$, $p < .001$, $d = .34$. Under high cognitive load, however, this effect was stronger, $t(1184) = 6.91$, $p < .001$, $d = .56$, as there was a larger difference between the foreground-only condition (*M* = .26, *SD* = .84) and the foreground-background condition (*M* = -.20, *SD* = .86). This pattern of data is thus consistent with Model 3, which

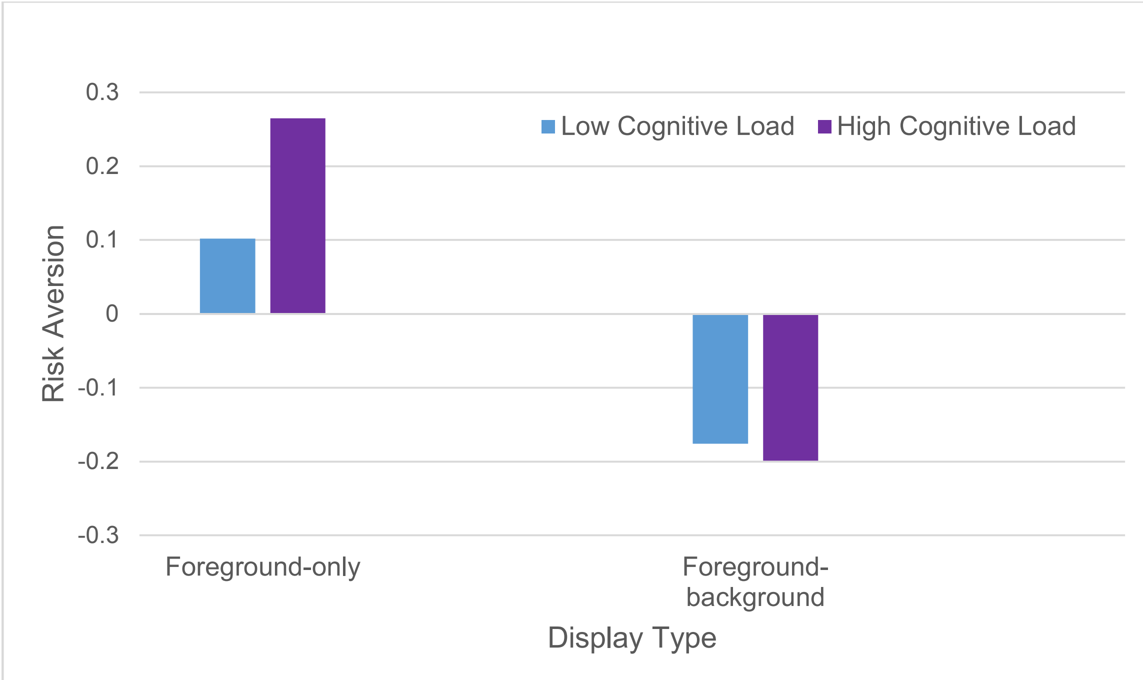


Figure 8. Two-way interaction between display type and processing-stage cognitive load

predicted that the cognitive load manipulation would increase the foreground-only effect.

In order to gain a better understanding of this interaction, we also looked at the simple effects from the perspective of processing cognitive load. For participants in the foreground-only condition, those under high cognitive load (*M* = .26, *SD* = .84) were more risk averse than those under low cognitive load (*M* = .10, *SD* = .81), *t*(1184) = 2.45, *p* = .015, *d* = .20. However, participants in the foreground-background condition were no more risk averse under high cognitive load than low cognitive load, *t*(1184) = .36, *p* = .717, *d* = .03. Furthermore, there was a significant main effect of decision-stage cognitive load, *F*(1, 1184) = 4.54, *p* = .033, η^2 = .004, such that participants under high cognitive load (*M* = .03, *SD* = .84) were more risk averse than participants under low cognitive load (*M* = -.05, *SD* = .86). Contrary to the predictions of the decision-stage model extension, there was no interaction between display type and decision-stage cognitive load, $F(1, 1184) = .79$, $p = .374$. Despite the lack of a significant interaction, however, planned contrasts showed a significant effect of cognitive load at the decision-making stage for participants who viewed foreground-only displays, $t(1184) = 2.10$, $p = .036$, $d = .35$, whereby people under high cognitive load ($M = .26$, $SD = .79$) were more risk averse than those under low cognitive load ($M = .12$, $SD = .85$). However, for foreground-background displays there was no significant difference between people under high cognitive load ($M = -.16$, $SD = .83$) and people under low cognitive load ($M = -.22$, $SD = .84$), $t(1184) = .89$, $p = .036$, $p = .373$. This finding suggests that, despite the presence of a main effect of cognitive load at the decision stage, the effect may only occur when people are viewing foreground-only displays. More importantly, this finding contradicts the predictions of the decision-stage model extension, which predicted an increase in risk aversion for the foreground-background condition.

Risk perception and emotion. Because participants' risk perception and emotion were assessed prior to the second cognitive load manipulation and any interactions with this variable would therefore be due to chance, the following analyses did not include the decision-stage cognitive load variable. A 2 (display type: foreground-only & foreground-background) x 2 (processing-stage cognitive load: high & low) ANOVA was conducted on the combined risk perception and emotion variable and again showed the expected significant main effect of display type, $F(1, 1188) = 110.42$, $p < .001$, $\eta^2 = .09$, such that people who viewed the foreground-only display ($M = 4.44$, $SD = 1.08$) had a stronger emotional response and perceived the risk of contracting the disease as higher than participants who viewed the foreground-background display ($M = 3.76$, $SD = 1.15$). The main effect of display type is thus stronger for risk perception and emotion than it is for risk aversion. This finding is consistent with our models: higher perceived risk and emotion produce high levels of risk aversion, and because this is not a direct link, we would expect the effect to be stronger here. However, these analyses failed to detect an interaction between display type and the processing-stage cognitive load manipulation.

There was also a significant main effect of processing cognitive load, $F(1, 1188) = 5.79$, $p = .016$, $\eta^2 = .005$. People under high cognitive load ($M = 4.17$ $SD = 1.17$) perceived the risk as larger and had higher levels of emotion than those under low cognitive load ($M = 4.01$, $SD = 1.17$). However, despite the lack of an interaction with processing-stage cognitive load, planned contrasts showed that the effect of cognitive load at the processing stage was significant for the foreground-only condition, such that those under high cognitive load ($M = 4.54$, $SD = 1.07$) were more risk averse than those under low cognitive load ($M = 4.34$, $SD = 1.08$), $t(1188) = 2.18$, $p = .029$, $d = .18$. The effect did not hold for foreground-background displays, $t(1188) = 1.20$, $p = .229$, $d = .09$. Thus the effect seen for risk aversion was similar for the foreground-only condition, but seemed to disappear for the foreground-background condition. These results provide limited support Model 3. Despite the lack of an interaction between display type and processing-stage cognitive load, cognitive load may increase people's perception of the risk and their emotions for foreground-only displays but not for foreground-background displays, thus increasing the foreground-only effect.

The impact of risk perception and emotion on risk aversion. The decision-stage extension, which predicted a two-way interaction between decision-stage cognitive load and risk aversion, was tested above in the 2 x 2 x 2 ANOVA on risk aversion.

However, since the extension (Figure 3) claims that any effect would operate via perceived risk and emotion, we tested this prediction directly. Perceived risk and emotion, as well as decision-stage cognitive load and the interaction between the two, were entered into a multiple linear regression as predictors of risk aversion. Perceived risk and emotion was found to significantly predict risk aversion (partial $r = .54$, $p < .001$). However, the main effect of decision-stage cognitive load that was demonstrated earlier was no longer significant with perceived risk and emotion in the model ($p = .12$), nor was there an interaction between cognitive load and perceived risk and emotion (partial $r = .003$, $p = .916$). This analysis thus confirms the ANOVA result with risk aversion that the predictions for the extension were incorrect.

Rational-Experiential Inventory. In order to explore whether individual differences in thinking style moderate the relationships between our main independent variables and their interactions, additional exploratory regression analyses were conducted with the Rational-Experiential Inventory (REI). We ran two separate multiple linear regressions. In the first, we entered the REI rational scale, display type, processing and decision-stage cognitive load variables as predictors of risk aversion. There was no main effect of rational thinking. There was, however, a two-way interaction between processing-stage cognitive load and the REI rational scale, (partial $r = .06$, $p = .039$), such that people high in rational thinking were more affected by cognitive load than those low in rational thinking. In addition, there was a four-way interaction with all variables in the model (partial $r = -.06$, $p = .045$), for which we have no interpretation to offer. It should also be noted that due to the large number of predictors in this model, these effects could be due to chance and therefore we cannot be confident about the results.

In the second regression analysis, the REI experiential was entered along with display type, and processing and decision-stage cognitive load variables as predictors of risk aversion. Here we found a main effect of experiential thinking (partial $r = .10$, $p < .001$), indicating that people who score high on the experiential scale tended to be more risk averse in general. However, no interactions were found as a result of adding the REI experiential scale to our main independent variables.

Conclusion. Experiment 1 found support for Model 3, with an increase in the foreground-only effect under high processing cognitive load for risk aversion. This interaction was not significant for risk perception and emotion, although the results were trending in the same direction. Figure 9 shows the regression weights between display type, perceived risk and emotion, and risk aversion, and how they vary by high or low cognitive load. There was also a main effect of decision-stage cognitive load on risk aversion, although simple effects analyses indicated that this effect held only for the foreground-only condition.

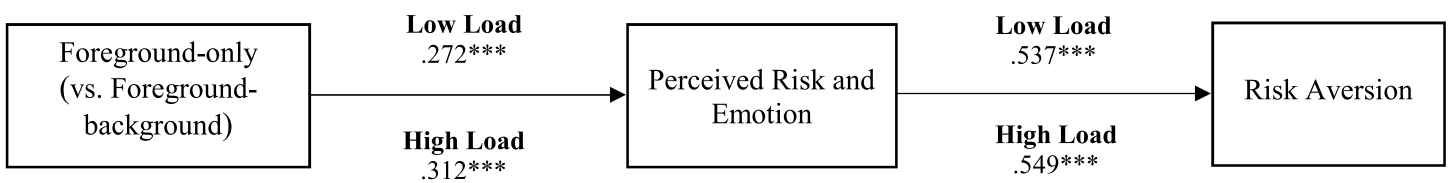


Figure 9. Model showing the relationship between display type, perceived risk and emotion, and risk aversion, and how they vary according to cognitive load. Standardized beta weights are shown. *** $p < .001$

EXPERIMENT 2

Experiment 1 attempted to explain the foreground-only effect by looking at the manner in which foreground-only and foreground-background displays are processed, and how these displays might subsequently influence the degree to which people's decisions are made more intuitively or rationally. We found no support of the moderating role of the decision-stage cognitive load, providing evidence against the extension model. However, perceived risk and emotions were only manipulated indirectly, providing a relatively weak test of this effect. Therefore, to provide a stronger test of the impact of the decision-stage cognitive load manipulation on the influence of risk perceptions on risk aversion, we conducted a second experiment in which we directly manipulated people's perception of the risk.

Contrary to Experiment 1, which dealt with both the processing and decision stages, Experiment 2 began with people's perception of the risk, and therefore involved only the decision stage. Cognitive load was again manipulated in order to interfere with people's ability to make decisions. If it is the case that perceiving the risk as high produces an emotional response, which leads people to make more intuitive and emotional decisions, then the cognitive load will presumably cause people in the low risk condition to be more risk averse.

Method

Participants. Seven-hundred twenty-two participants were recruited on MTurk and were compensated $0.30 USD. All participants completed the study.

Materials.

Risk scenario and stimuli. The risk scenario was identical to Experiment 1. However, in place of an icon array, participants were presented with a display in which they were instructed their level of risk of contracting the disease. In the high risk condition (Figure 10), participants were told that the CDC had determined that their chance of contracting mylobia was high. They were also told that the vaccine would reduce their chances of contracting mylobia by 50 percent. The low risk condition was identical, except that participants were told their chance of contracting the disease without the vaccine was low.

Cognitive load. As in Experiment 1, participants were given a two or eight-digit string of numbers to memorize, for the low and high cognitive load conditions, respectively. However, the cognitive load manipulation was only used for the decision

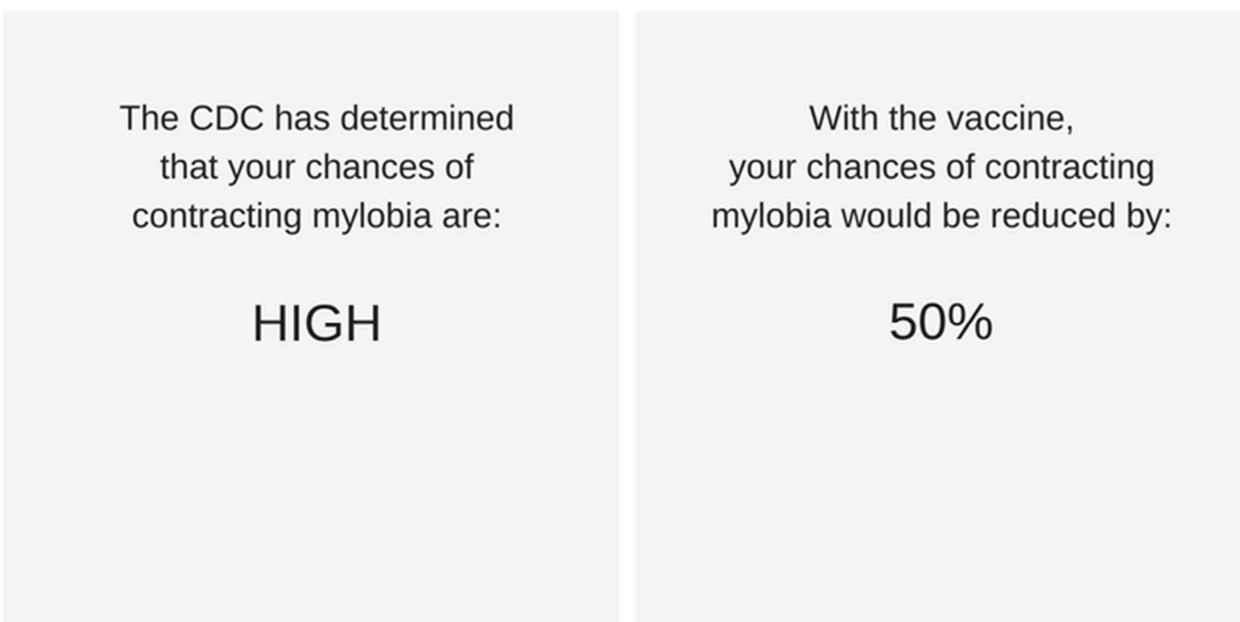


Figure 10. Risk display for Experiment 2 (high risk condition)

stage. Thus, participants were not under cognitive load while viewing the stimulus or answering the risk perception or emotion measures. The numbers were identical to those used at the corresponding stage in Experiment 1.

Outcome measures. All outcome measures were identical to those in Experiment 1, except for minor adjustments due to the use of different types of displays. Again, the four risk perception and emotion items were combined to into a single variable (Cronbach's $\alpha = .52$), despite the relatively low alpha. The three risk aversion items were also combined as in Experiment 1 (Cronbach's alpha = .80). The REI rational scale ($\alpha = .84$) and experiential scale ($\alpha = .91$) were again shown to have high reliability.

Procedure. The procedure was identical to Experiment 1 with the following exceptions. After the risk scenario, participants were immediately presented with the risk displays, with no number memorization task at this stage. They responded to the risk perception and emotion measures and were subsequently given the number memorization task, followed by the risk aversion questions. From this point on, the study proceeded just as in Experiment 1.

Results and Discussion

Cognitive load manipulation checks. Eighteen participants were excluded for writing the cognitive load numbers down instead of memorizing them as requested. A chi-square test of independence showed no disproportionate concentration of those that wrote the number down among the conditions, $\chi^2(1, N = 722) = 0.00, p = .991$. Additionally, 109 participants were excluded from the final analyses for committing more than two errors when reporting the final cognitive load manipulation number, using the same criteria outlined in Experiment 1. The final sample thus included 595 participants.

As in Experiment 1, participant's responses to the item assessing distraction as a result of the cognitive load manipulation were analyzed to determine if the manipulation was successful. An independent samples t-test showed that participants in the high load condition ($M = 3.65$, $SD = 2.01$) reported being more distracted than those in the low load condition ($M = 2.03$, $SD = 1.45$), $t(593) = 11.35$, $p < .001$.

Risk perception and emotion manipulation check. A 2 (risk condition: high or low) x 2 (decision-stage cognitive load: high or low) ANOVA conducted on the combined risk perception and emotion variable indicated that, as expected, those presented with a high risk ($M = 5.01$, $SD = .71$) perceived the risk as larger and had a stronger emotional response than those presented with a low risk ($M = 3.97$, $SD = 1.05$), $F(1, 591) = 205.05$, $p < .001$, $\eta^2 = .26$. There was no main effect of cognitive load or an interaction (both p values > .68).

Risk aversion. As in Experiment 1, the three risk aversion items were z-standardized before averaging the three items and the reported means are thus also in z-units. A 2 (risk condition: high or low) x 2 (decision-stage cognitive load: high or low) ANOVA conducted on the combined behavior variable found the expected main effect of risk condition, $F(1, 591) = 89.75$, $p < .001$, $\eta^2 = .13$, whereby those who were told that the risk was high ($M = .32$, $SD = .73$) were more risk averse than those who were told the risk was low ($M = -.28$, $SD = .82$). Thus directly manipulating risk perception resulted in a stronger effect on risk aversion than through manipulating display type, as in Experiment 1. Contrary to the results from Experiment 1, there was no main effect of decision-stage cognitive load, nor an interaction (both ps > .78). These results confirm those of Experiment 1, which indicated that the decision-stage extension model was incorrect.

Rational-Experiential Inventory. Regression analyses were conducted to determine whether either of the REI scales interacted with the risk condition and decision-stage cognitive load variables. For the rational scale, there was no main effect and no two-way interactions (all *p*s > .20). However, the three-way interaction between risk condition, cognitive load, and rational thinking significantly predicted risk aversion (partial $r = .12$, $p = .003$). However, we do not have an interpretation of this effect.

As with Experiment 1, the REI experiential scale showed a significant main effect of experiential thinking (partial $r = .15$, $p < .001$), indicating that high experiential thinkers tended to be more risk averse regardless of condition. However, no interactions were found as a result of adding the REI experiential scale to our main independent variables (all *p*s > .19).

Conclusion. Beyond demonstrating that people's perception of risk does indeed increase risk avoidant behavior, Experiment 2 confirmed the lack of support for the decision-stage model extension of Experiment 1. Even when directly manipulating risk perception, people's decision-making style had no impact on their risk aversion level, and did not vary according to their risk perception and emotions. In addition, unlike Experiment 1, there was no overall effect of increased risk aversion due to the decision-stage cognitive load.

GENERAL DISCUSSION

The main objective of the current work was to determine whether differences in processing or decision making produced between foreground-only and foreground-background displays are responsible for the foreground-only effect, whereby foreground-only displays increase risk avoidant behavior. Several models were presented, each with specific predictions, and the data were evaluated to determine their degree of support for each of these models. Although the results were not conclusive, our findings indicated some support for Model 3, which held that different aspects of the graphs are processed automatically, in addition to an element of conscious processing. Under high cognitive load at the processing stage, people exhibited an increased foreground-only effect.

Although we found no evidence of an interaction between any of our variables and the decision-stage cognitive load, there was an overall increase in risk aversion as a result of this manipulation. However, analyses of the simple effects revealed that this effect may only hold for foreground-only displays. Furthermore, Experiment 2 found no evidence for any effect of the decision-stage cognitive load. Finally, people high in experiential thinking were found to be more risk averse overall in both experiments, perhaps suggesting that intuitive decision making increases risk aversion.

Support for Models

The key prediction of Model 1 was that, under high cognitive load, foreground-background displays would produce levels of risk aversion equivalent to those of foreground-only displays. No support was found for this model, and it seems that its claims may have been oversimplified despite findings that they produce similar levels of risk aversion as numerical displays, which are thought to be processed rationally

(MacDonald Gibson et al., 2013; Waters et al., 2007; Zikmund-Fisher et al., 2008). Model 2, which predicted no effect of the cognitive load manipulations, was also not supported.

Contrary to the predictions of the decision-stage extension, there was no interaction effect between the decision-stage cognitive load manipulation and display type across the two experiments. Furthermore, it seems there may have been an overall increase in risk aversion as a result of the cognitive load at this stage, although perhaps only for the foreground-only condition, which is the opposite of what the extension predicted. However, this effect was not seen in Experiment 2. One possible explanation for this discrepancy is that explicitly stating participants' risk level, as in Experiment 2, requires less cognitive effort than viewing and interpreting graphs. Interfering with their ability to interpret a graph might therefore cause people to decide more intuitively, especially for foreground-only displays, which might require more conscious reflection. Interestingly, this finding seems to correspond with our results involving the REI experiential, which suggest that intuitive decision making results in higher overall levels of risk aversion.

Model 3 predicted an increase in the foreground-only effect as a result of the processing-stage cognitive load. Experiment 1 indicated that the difference in risk aversion between the foreground-only and foreground-background conditions was indeed exacerbated when people were under cognitive load. This finding is in line with those of Jarvenpaa (1990), who argued that graphical processing occurs in a purely perceptual stage, followed by focused attention. In addition, Allen et al. (2014) contend that "behavioral" judgments involving graphs require a series of conscious reappraisals of information that is gleaned automatically from people's initial perceptions of the displays. In the case of foreground-only displays, the lack of a visual depiction of the denominator limits the information that people have to go on, and may provide an unstable foundation for subsequent conscious judgments.

Experiment 1 found some support for an effect of cognitive load at the decision stage, whereby an increase in risk aversion was found only for those viewing foreground-only displays. However, this result was not found when risk perception and emotion was added into a regression model predicting risk aversion, nor with risk perception and emotion as the dependent variable. Furthermore, Experiment 2 failed to replicate any effect of decision-stage cognitive load. We are thus hesitant to offer an explanation of this effect.

Although we expected the results for risk perception and emotion to mirror those of risk aversion (or perhaps be even stronger), they were slightly less clear. A parallel interaction between display type and cognitive load was not found. However, people presented with foreground-only displays saw the risk as greater and had a stronger emotional response under high cognitive load, and no such effect was found for those presented with foreground-background displays. It is interesting to note that this trend of effects being stronger in the foreground-only condition was found throughout Experiment 1, and suggests a possible revision to Model 3.

Revised Model

As shown in Figure 2, Model 3 claims that conscious processing will moderate the two links of automatic processing on perceived risk and emotion: that of the risk reduction, as well as the part-to-whole. Thus, the model assumes that cognitive load will have a similar effect for both the foreground-only and foreground-background conditions. However, our data show evidence for this effect only in the foreground-only condition. Here it seems that people's conscious effort helps mitigate their automatic processing of the risk reduction of foreground-only graphs. In light of this finding, it is interesting to note that Hu et al. (2014) found that having participants carefully consider and reflect upon risk information nullified the foreground-only effect. With foreground-background displays, however, the conscious processing of the part-to-whole relationship has less impact: They see the risk as small and no further conscious input is required. Figure 11 shows a modified model which reflects a slight adjustment to Model 3, such that the conscious processing exerts its influence only on the link between automatic processing of the risk reduction and perceived risk and emotion.

Limitations and Future Research

Whether our cognitive load manipulations succeeded in their goal of interfering with conscious processing and rational decision making are key to the current work. Based on our rigorous manipulation checks and the large sample size, it seems that the manipulations were indeed successful, although it is possible that they failed to capture what we intended. Also of concern are the differential results without excluding participants who failed the manipulation checks (i.e., those who committed multiple errors in reporting cognitive load verification task and those who wrote down the numbers). According to analyses run on data without the exclusions, some of these results were trending towards significance, but were not quite detectable. Our findings should therefore be interpreted with caution; however, we felt it was necessary to commit to our *a priori* decision to exclude those who were not sufficiently cognitively taxed

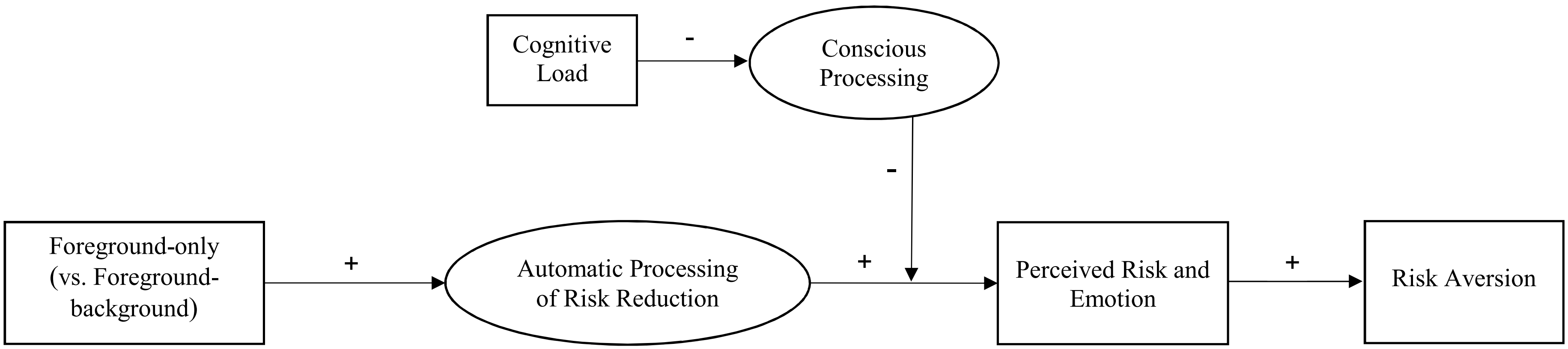


Figure 11. Revised model. Foreground-only graphs produce automatic processing of the risk reduction, which result in increased risk perception and emotion, and ultimately higher levels of risk aversion. However, the automatic processing is directly followed by a conscious processing element that mitigates the effect.

during the experiments, as including those who were not truly under cognitive load would make it difficult to detect any effect.

Furthermore, the low correlations we observed with our risk perception and emotion items may also have been problematic, although it is difficult to discern whether more closely related items would have hampered or bolstered our results. As noted above, it is not certain what contributed to these low correlations. However, it is possible that these items, which assessed participants' overall risk perception and emotion, as well as the reduction in risk, may have been affected differently depending on how people process the graphs (i.e., the different types of measures might have covaried with processing types).

Although our data were only capable of answering this question indirectly (i.e., by testing the effects of the cognitive load manipulation separately for each item), we did not find evidence in support this claim. We conducted 2 (display type) by 2 (processing-stage cognitive load) ANOVAs on each of the separate risk perception and emotion items to see if the cognitive load manipulation had different effects for the different types of items (e.g., if the cognitive load had more of an effect on the items that asked about the risk reduction for the foreground-only condition than the foreground-background condition). Results showed no such interactions. Nonetheless, we must acknowledge the possibility of covariability between our risk perception & emotion items and processing types.

The current work is also somewhat limited by the fact that our cognitive load manipulations only get at processing types indirectly, given that we were not able to measure the extent to which people process automatically or consciously. Future work could perhaps find a way to reliably test processing types directly, perhaps by collecting self-report data, if nothing else. In addition, some of our key results relating to the models had relatively weak effect sizes. Perhaps more accurate risk perception and emotion items and a more focused design could have produced stronger results. Future research might also directly test the modified version of Model 3 with a simpler design that does not include the additional decision-stage cognitive load. Perhaps such a study could also confirm the exploratory results we found with the REI scales.

Finally, there exists the possibility of another, perhaps simpler, explanation for our results. Foreground-background graphs give people a complete visual picture of the likelihood of contracting the disease, including the number of people affected and the total number of people at risk. Foreground-only graphs, on the other hand, visually depict only the number of people affected: The total number of people at risk is included numerically (in this case 1,000; see Figure 6), but requires that people mentally simulate the 980 people unaffected by the disease. This simulation is effortful, and people are thus likely to stop short of creating a full mental image of the probability. Since our results show that cognitive load affects the foreground-only condition, it is possible that this difference is due instead to this mental simulation. Perhaps future research can test this account directly.

Conclusion

As Nelson, Reyna, Fagerlin, Lipkus, and Peters (2008) note, "future work should focus on developing theory-based models of the perceptual and cognitive processes involved in understanding graphic displays of health risk” (p. 271). Although the results are not conclusive, we believe the current work marks an important contribution to achieving this goal. Moreover, isolating the mechanisms behind graphical display effects can help experts determine where and when to utilize certain graphs, and predict how different people will respond to them. Explaining these cognitive mechanisms and having a deeper understanding of what produces them can thus help advance the field of risk communication.

REFERENCES

Allen, P. M., Edwards, J. A., Snyder, F. J., Makinson, K. A., & Hamby, D. M. (2014). The effect of cognitive load on decision making with graphically displayed uncertainty information. *Risk Analysis, 34*(8), 1495-1505.

Ancker, J. S., Senathirajah, Y., Kukafka, R., & Starren, J. B. (2006). Design features of graphs in health risk communication: A systematic review. *Journal of the American Medical Informatics Association*, *13*, 608-618.

Bruine de Bruin, W., Stone, E. R., MacDonald, J., Fischbeck, P., & Shoraka, M. B. (2013). The effect of communication design and recipients' numeracy on responses to UXO risk. *Journal of Risk Research*. *16*, 981-1004.

Camerer, C. F., & Kunreuther, H. (1989). Decision processes for low probability events: Policy implications. *Journal of Policy Analysis and Management*, *8*(4), 565-592.

Carpenter, P. A., & Shah, P. (1998). A model of the perceptual and conceptual processes in graph comprehension. *Journal of Experimental Psychology: Applied*, *4*(2), 75.

Casner, S. M. (1991). Task-analytic approach to the automated design of graphic presentations. *ACM Transactions on Graphics (ToG)*, *10*(2), 111-151.

Chua, H. F., Yates, J. F., & Shah, P. (2006). Risk avoidance: Graphs versus numbers. *Memory & Cognition*, *34*, 399-410.

Cleveland, W. S., & McGill, R. (1985). Graphical perception and graphical methods for analyzing scientific data. *Science*, *229*(4716), 828-833.

Edwards, J. A., Snyder, F. J., Allen, P. M., Makinson, K. A., & Hamby, D. M. (2012). Decision making for risk management: A comparison of graphical methods for presenting quantitative uncertainty. *Risk Analysis*, *32*(12), 2055-2070.

Epstein, S. (1994). Integration of the cognitive and the psychodynamic unconscious. *American Psychologist*, *49*(8), 709.

Epstein, S. (2003). Cognitive-experiential self-theory of personality. In T. Millon, M. Lerner, & B. Weiner (Eds.), *Handbook of psychology: Personality and social psychology* (Vol. 5) (pp.159-184). Hoboken, NJ: John Wiley & Sons.

Epstein, S., Pacini, R., Denes-Raj, V., & Heier, H. (1996). Individual differences in intuitive–experiential and analytical–rational thinking styles. *Journal of Personality and Social Psychology*, *71*(2), 390.

Fagerlin, A., Wang, C., & Ubel, P. A. (2005). Reducing the influence of anecdotal reasoning on people's health care decisions: Is a picture worth a thousand statistics? *Medical Decision Making*, *25*, 398-405.

Galesic, M., Garcia-Retamero, R., & Gigerenzer, G. (2009). Using icon arrays to communicate medical risks: Overcoming low numeracy. *Health Psychology*, *28*, 210-216.

Gigerenzer, G. (1984). External validity of laboratory experiments: The frequency-validity relationship. *The American Journal of Psychology*, *97*(2), 185-195.

Gigerenzer, G., Hoffrage, U., & Kleinbölting, H. (1991). Probabilistic mental models: A Brunswikian theory of confidence. *Psychological Review*, *98*(4), 506.

Gilbert, D. T., & Osborne, R. E. (1989). Thinking backward: Some curable and incurable consequences of cognitive busyness. *Journal of Personality and Social Psychology*, *57*(6), 940.

Halpern, D. F., Blackman, S., & Salzman, B. (1989). Using statistical risk information to assess oral contraceptive safety. *Applied Cognitive Psychology*, *3*, 251-260.

Hollands, J. G., & Spence, I. (1992). Judgments of change and proportion in graphical perception. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *34*(3), 313-334.

Hollands, J. G., & Spence, I. (1998). Judging proportion with graphs: The summation model. *Applied Cognitive Psychology*, *12*(2), 173-190.

Hu, T-Y., Jiang, X-W., Xie, X., Ma, X-Q., & Xu, C. (2014). Foreground:background salience effect in traffic risk communication. *Judgment and Decision Making*, *9*, 83-89.

Jarvenpaa, S. L. (1990). Graphic displays in decision making—the visual salience effect. *Journal of Behavioral Decision Making*, *3*, 247-262.

Kahneman, D., & Tversky, A. (1979). Prospect theory: An analysis of decision under risk. *Econometrica: Journal of the Econometric Society, 47*(2), 263-291.

Lipkus, I. M. (2007). Numerical, verbal and visuals formats of conveying health risks: Suggested best practices and future recommendations. *Medical Decision Making*, *27*, 696-713.

Lipkus, I. M., & Hollands, J. (1999). The visual communication of risk. *Journal of the National Cancer Institute Monographs*, *25*, 149-163

MacDonald Gibson, J., Rowe, A., Stone, E. R., & Bruine de Bruin, W. (2013). Communicating quantitative information about unexploded ordnance risks to the public. *Environmental Science & Technology*, *47*, 4004-4013.

Nelson, W., Reyna, V. F., Fagerlin, A., Lipkus, I., & Peters, E. (2008). Clinical implications of numeracy: theory and practice. *Annals of Behavioral Medicine*, *35*(3), 261-274.

Okan, Y., Galesic, M., & Garcia-Retamero, R. (2016). How people with low and high graph literacy process health graphs: Evidence from eye-tracking. *Journal of Behavioral Decision Making*, *29*, 271-294.

Okan, Y., Garcia-Retamero, R., Cokely, E. T., & Maldonado, A. (2015). Improving risk understanding across ability levels: Encouraging active processing with dynamic icon arrays. *Journal of Experimental Psychology: Applied*, *21*(2), 178.

Okan, Y., Stone, E. R., Parillo, J. M., Bruine de Bruin, W., & Parker, A. (2017). *When context matters: The impact of different probability sizes and risk reductions on graphical display effects.* Manuscript in preparation.

Reyna, V. F. (2008). A theory of medical decision making and health: Fuzzy trace theory. *Medical Decision Making*, *28*, 850-865.

Reyna, V. F., & Brainerd, C. J. (2008). Numeracy, ratio bias, and denominator neglect in judgments of risk and probability. *Learning and Individual Differences*, *18*(1), 89-107

Shepperd, J. A., Lipkus, I. M., Sanderson, S. C., McBride, C. M., O'Neill, S. C., & Docherty, S. (2013). Testing different communication formats on responses to imagined risk of having versus missing the GSTM1 gene. *Journal of Health Communication*, *18*, 124-137.

Stone, E. R., Bruine de Bruin, W., Wilkins, A. M., Boker, E. M., & MacDonald Gibson, J. (2016). Designing graphs to communicate risks: Understanding how the choice of graphical format influences decision making. *Risk Analysis*. doi:10.1111/risa.12660

Stone, E. R., Okan, Y., Bonapart, J., Parker, A. M., & Bruine de Bruin, W. (2015, November.) *Examining graphical display effects at different probability levels: Do effects only hold for low-probability risks?* Poster presented at the annual meeting of the Society for Judgment and Decision Making, Chicago, Illinois.

Stone, E.R., Reeder, E.C., Mills, C., Miller, L., & Parillo, J. (2017). *Foreground:background salience or proportional reasoning? Rethinking the mechanisms behind graphical display effects*. Manuscript submitted for publication.

Stone, E. R., Sieck, W. R., Bull, B. E., Yates, J. F., Parks, S. C., & Rush, C. J. (2003). Foreground:background salience: Explaining the effects of graphical displays on risk avoidance. *Organizational Behavior and Human Decision Processes*, *90*, 19-36.

Stone, E. R., Yates, J. F., & Parker, A. M. (1997). Effects of numerical and graphical displays on professed risk-taking behavior. *Journal of Experimental Psychology: Applied*, *3*, 243-256.

Stone, E. R., Yates, J. F., & Parker, A. M. (1994). Risk communication: Absolute versus relative expressions of low-probability risks. *Organizational Behavior and Human Decision Processes*, *60*(3), 387-408.

Waters, E. A., Weinstein, N. D., Colditz, G. A., & Emmons, K. (2007). Formats for improving risk communication in medical tradeoff decisions. *Journal of Health Communication*, *11*(2), 167-182.Waters 2007

Zikmund-Fisher, B. J., Ubel, P. A., Smith, D. M., Derry, H. A., McClure, J. B., Stark, A., Pitsch, R. K., & Fagerlin, A. (2008). Communicating side effect risks in a tamoxifen prophylaxis decision aid: The debiasing influence of pictographs. *Patient Education and Counseling*, *73*, 209-214.

APPENDIX A

Outcome Measures

Risk perception and emotion

Assuming you do not get the vaccine:

1. How scared would you be about contracting mylobia? 1 (*not at all scared*) to 7 (*extremely scared*)

2. How likely is it that you would contract mylobia? 1 (*not at all likely*) to 7 (*extremely likely*)

Assuming you do get the vaccine:

3. How much less scared would you be about contracting mylobia if you got the vaccine? 1 (*not at all less scared*) to 7 (*much less scared*)

4. How much less likely is it that you would contract mylobia if you got the vaccine? 1 (*not at all less likely*) to 7 (*much less likely*)

Risk aversion

1. How much do you think health organizations should allocate towards emergency production of the vaccine? 1 (*zero*) 2 (*under $10,00*0) 3 (*$10,000 - $20,000*) 4 (*$20,000 - $50,000*) 5 (*$50,000 - $100,000*) 6 (*$100,000 - $500,000*) 7 (*$500,000 - $1,000,000*)

2. Compared to other health concerns, what priority should health organizations give to production of the mylobia vaccine? 1 (*extremely low priority*) to 7 (*extremely high priority*)

3. What percentage of their emergency budget do you think health organizations should allocate towards emergency production of the vaccine? (Slider scale ranging from 0 to 100 percent)

APPENDIX B

Rational Experiential Inventory

Rational (Need for Cognition) Scale

1. I don't like to have to do a lot of thinking.*

2. I try to avoid situations that require thinking in depth about something.*

3. I prefer to do something that challenges my thinking abilities rather than something that requires little thought.

4. I prefer complex to simple problems.

5. Thinking hard and for a long time about something gives me little satisfaction.*

Experiential (Faith in Intuition) Scale

1. I trust my initial feelings about people.

2. I believe in trusting my hunches.

3. My initial impressions of people are almost always right.

4. When it comes to trusting people, I can usually rely on my "gut feelings."

5. I can usually feel when a person is right or wrong even if I can't explain how I know.

Note. * = indicates item is reverse scored

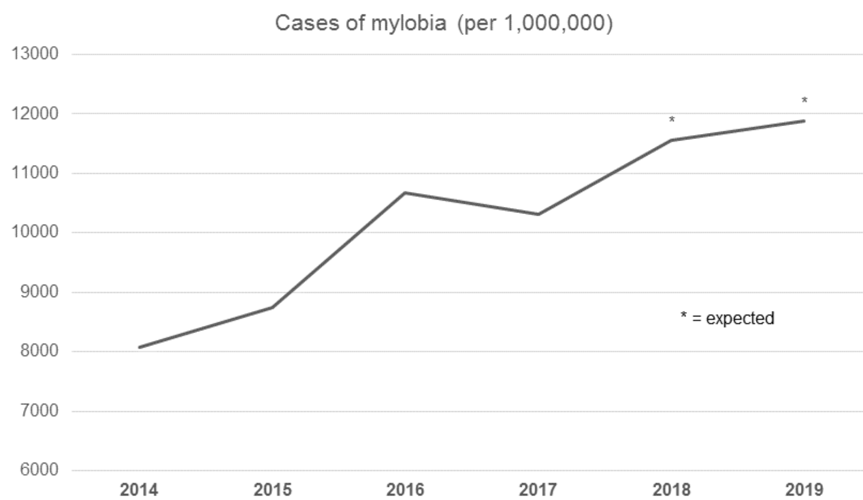
APPENDIX C

Manipulation Checks

1. How distracted did you feel while viewing the graphs and answering the questions? 1 (*not at all distracted*) to 7 (*extremely distracted*)

2. Did you write down the numbers or use any other method (e.g. the paste function) to remember the numbers that were assigned to you? Please be honest—your answer to this question will not affect your payment. (*yes* or *no*)

Verification task



1. Would you be concerned about the increase in cases of mylobia? 1 (*not at all concerned*) to 7 (*extremely concerned*)

2. Given this information, what priority should health organizations give to combating mylobia? 1 (*extremely low*) to 7 (*extremely high*)

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Wake Forest University, Winston-Salem, NC
M.A., Psychology, Expected May 2017
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- Currently under revision at the *Journal of Behavioral Decision Making*.

Okan, Y., Stone, E. R., **Parillo, J.,** Bruine de Bruin, W. & Parker, A. M. (2017). *Determining boundary conditions for graphical display effects: The role of probability sizes and risk reductions.* Manuscript in preparation.

PRESENTATIONS

Parillo, J., Stone, E.R., Okan, Y., Bruine de Bruin, W. & Parker, A. M. (2016, November). *When context matters: The impact of different probability sizes and risk reductions on graphical display effects.* Poster presented at the annual meeting of the Society for Judgment and Decision Making, Boston, MA.

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TEACHING EXPERIENCE

Graduate Instructor, Research Methods II **Aug 2015 – Present**
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- Teaches undergraduate students in research methodology, course content and relevant SPSS procedures, two labs per week
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Private Violin Instruction **2007 – 2013**
Xalapa, Mexico
- Created teaching methods that emphasized efficient technical execution while inspiring expressive musicianship

English as a Second Language Teacher **2002 – 2004**
Apple English School, Mibu-machi, Japan
- Taught conversational English to students of all ages

PROFESSIONAL EXPERIENCE

Xalapa Symphony Orchestra **2008 – 2015**
Xalapa, Mexico
- Tenured violinist in one of the leading professional orchestras of Latin America
- In addition to regular performing duties, organized and produced several multi-media concerts which raised considerable funds
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Orquesta Sinfónica Juvenil del Estado de Veracruz **2005 – 2008**
Xalapa, Mexico
- Violinist in a full-time semi-professional orchestra for musicians aged 30 and under
- Assumed a leading role in helping younger and less-experienced members learn orchestral performance techniques

Spoleto Festival Orchestra **1999-2001 (summers)**
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- Violinist in the renowned opera orchestra of the "Festival dei Due Mondi"
- Performed on three critically acclaimed recordings under the British label *Chandos*

HONORS & FUNDING

- Graduate Assistantship full tuition scholarship and stipend, *Wake Forest University,* 2015 – 2017
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