To risk or not to risk: Anxiety and the calibration between risk perception and danger mitigation.

RUNNING HEAD: CALIBRATING RISK PERCEPTION AND DANGER MITIGATION

Lies Notebaert (lies.notebaert@uwa.edu.au)

Stijn Masschelein (stijn.masschelein@uwa.edu.au)

Bridget Wright (bridget.wright@student.uwa.edu.au)

Colin MacLeod (colin.macleod@uwa.edu.au)

University of Western Australia, 35 Stirling Highway, Crawley 6009, WA, Australia

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Corresponding Author: Lies Notebaert, School of Psychology, University of Western Australia, 35 Stirling Highway, Crawley 6009, Australia. Tel: +61 8 6488 8080, e-mail: lies.notebaert@uwa.edu.au

Abstract

Anxiety prepares an organism for dealing with threats by recruiting cognitive resources to process information about the threat, and by engaging physiological systems to prepare a response. Heightened trait anxiety is associated with biases in both these processes: high trait-anxious individuals tend to report heightened risk perceptions, and inappropriate engagement in danger mitigation behaviour. However, no research has addressed whether the calibration between risk perception and danger mitigation behaviour is affected by anxiety, though it is well recognised that this calibration is crucial for adaptive functioning. The current study aimed to examine whether anxiety is characterised by better or worse calibration of danger mitigation behaviour to variations in risk magnitude. Low- and high-trait anxious participants were presented with information about the likelihood and severity of a danger (loud noise burst) on each trial. Participants could decide to mitigate this danger by investing a virtual coin, at the cost of losing danger mitigation ability on subsequent trials. Importantly, level of risk likelihood and severity were varied independently, and the multiplicative relationship between the two defined total danger. Multilevel modelling showed that the magnitude of total danger predicted the probability of coin investments, over and above the effects of risk likelihood and severity, suggesting that participants calibrated their danger mitigation behaviour to integrated risk information. Crucially, this calibration was affected by trait anxiety, indicating better calibration in high-trait anxious individuals. These results are discussed in light of existing knowledge and models of the effect of anxiety on risk perception and decision-making.

Key words: risk perception; danger mitigation; anxiety; decision-making; individual differences

To risk or not to risk: Anxiety and the calibration between risk perception and danger mitigation.

Anxiety is generally thought to have evolved to help organisms deal with dangerous environments, by acting on a number of physiological and cognitive systems to enhance an individual's ability and motivation to deal with potential threats (Barlow, 2002; Beck, Emery, & Greenberg, 1985; Marks & Nesse, 1994). Heightened dispositional anxiety is indeed associated with biases in both cognitive and behavioural responding to risks. At the cognitive level, research has shown that individuals with high levels of trait anxiety have heightened perceptions of the severity of potential negative events and heightened perceptions of the likelihood of negative events happening (e.g. Butler & Mathews, 1987; Maner & Schmidt, 2006; Stober, 1997). At the behavioural level, studies investigating risk-taking using the Iowa gambling task (Miu, Heilman, & Houser, 2008) and the balloon analogue risk task (BART, Lejuez et al., 2002; Lorian & Grisham, 2010) have shown that high anxious participants have a reduced tendency to take risks. These findings have been linked to a pervasive behavioural safety bias in high trait anxious and clinically anxious individuals, which refers to a persistent tendency to avoid all perceived risks (Lorian & Grisham, 2010). The safety bias can manifest itself as an active engagement in perceived risk reduction behaviour, but it can also be expressed as a more passive avoidance of possible risks and a reduction in risk-taking behaviour (Cicolini & Rees, 2003; Lorian & Grisham, 2010).

These cognitive and behavioural patterns suggest trait anxiety may affect the calibration between perceptions of risk and danger mitigation behaviour. While it is well recognised that such calibration between risk perception and danger mitigation is important (Blanchard, Griebel, Pobbe, & Blanchard, 2011; Dolan, 2002; O'Donovan, Slavich, Epel, & Neylan, 2013), there is a paucity of research investigating the factors that improve or impair this calibration. In order to better understand the precise influence of trait anxiety on perceiving and responding to risks, it is crucial to investigate how anxiety affects the calibration between these two processes. This paper therefore presents the results of an experimental study to investigate whether high trait anxious individuals show better or worse calibration of danger mitigation behaviour to variation in risk magnitude than low anxious individuals.

As engagement in danger mitigation behaviour is costly, requiring the investment of time, energy, and/or resources, it is important for organisms to closely calibrate their investment in danger mitigation to the magnitude of the risk encountered (O'Donovan et al., 2013). The magnitude of a risk is not a one-dimensional construct, but consists of different components. The two components that have been studied most extensively are the likelihood and the severity of the risk. Risk likelihood refers to how likely it is a negative event will occur if no mitigating behaviour is performed. Risk severity conceptualises how 'bad' the outcome of a negative event will be, if no preventative or mitigating behaviour is undertaken (Weinstein, 2000). Both increases in the perception of risk likelihood and risk severity have been found to contribute to people’s engagement in danger mitigation behaviour (Floyd, Prentice-Dunn, & Rogers, 2000). However, research on risk perception has typically investigated how individual risk components contribute to risk perception, without taking into account how the integration of different components affects the perception of risk and the consequent engagement in danger mitigation behaviour. Nevertheless, this integration is crucially important (Blanchard et al., 2011; Weinstein, 2000). If an event is very likely to happen but has low severity (e.g. getting the sniffles in winter), the overall risk is rather low. Likewise, if an event has very high severity but is very unlikely to happen (e.g. a nuclear bomb being dropped on one’s country), the overall risk of this event is again rather low. It would be maladaptive to align danger mitigation behaviour with only one component of risk while ignoring others. Thus, optimal functioning should involve calibrating one's investment in danger mitigation to the magnitude of risk, computed by integrating the two dimensions of risk information.

A few studies have touched upon the relation between anxiety, risk perception, and danger mitigation. However, upon closer investigation, these studies are not well suited to provide insight into the calibration of danger mitigation to the magnitude of risk. Maner and Schmidt (2006) presented undergraduate students with a list of positive and negative scenarios (such as "I won some money while gambling" and ""I tripped and broke a bone"), and asked them to rate the likelihood and severity of each of these. Danger mitigation behaviour was assessed on a questionnaire in which participants reported their willingness to engage in risky decision-making across a range of domains. The results showed that trait anxiety was associated with risk-avoidant decision making, which was moderated by subjective ratings of the severity of negative events. Mitte (2007) presented participants with scenarios describing an event (e.g. an infectious disease is spreading in the country of your holiday destination) and asked them to choose between a risky alternative (e.g. travelling to the destination) and a safe alternative (e.g. cancelling the vacation). Participants were also asked to rate the severity of both outcomes (in terms of how bad it would be), and the probability of the threatening event (e.g. the probability of getting sick). Consistent with the results from Maner & Schmidt (2006), findings showed that high trait anxious participants more often chose the safe alternative, and this was mediated by the rating of the severity of the negative outcome.

These studies suggest that high trait anxious individuals might calibrate their danger mitigation behaviour more closely to the perceived severity of risky events. However, several aspects of these studies warrant further investigation. The first is that these studies do not allow drawing conclusions on whether appropriate engagement in danger mitigation was observed, as choosing a safe over a dangerous alternative in risky situations is not necessary a sign of excessive risk avoidance. It is important to assess danger mitigation behaviour in response to risks that objectively vary in magnitude such that it is clear to participants that the likelihood and/or severity of some dangers is greater than the likelihood and/or severity of other dangers. In this way, engagement in danger mitigation in response to low risks versus high risks can be properly compared. Second, these previous studies did not manipulate risk magnitude, but relied on subjective perceptions of a variety of risks. Given the lack of manipulation, it remains unknown whether the inflated perceptions of risk constituted a cause or a symptom of risk-avoidant decision-making. To remedy this, the relationship between perception and behaviour should be measured using a paradigm where the magnitude of the risk (both likelihood and severity) is explicitly manipulated. In the current study, we included conditions where the magnitude of the risk is manipulated and participants are presented with information about the magnitude of the risk, as well as conditions in which the magnitude of the risk is unknown. This allows simultaneous assessment of the calibration of danger mitigation behaviour to objective variation in risk magnitude, and the subjective perception of information about risks with an unknown magnitude. Third, many studies examining the relationship between risk perception and danger mitigation rely on self-report measurements of either or both of these constructs. As the responses on these self-report measures can be biased in the absence of biases in the cognitive or behaviour constructs assessed (Eysenck, 2014), objective measures constitute a better way to examine the relationship between risk perception and danger mitigation. The last important issue is that previous studies did not model the multiplicative relationship between risk likelihood and risk severity. Therefore, they do not allow investigating the possibility that investment in danger mitigation might be calibrated to integrated information about different components of risk.

The aim of the current study was to examine the relationship between variation in different risk components and danger mitigation behaviour, and investigate whether anxiety is characterised by an enhanced or compromised calibration of danger mitigation behaviour to variation in risk magnitude. To this end, a task was developed in which the magnitude of two components (likelihood and severity) of risk was varied, and the probability to engage in danger mitigation behaviour as a function of this variation in risk magnitude was assessed. High and low trait anxious participants were exposed to a risk of receiving a loud noise burst (the danger), which could differ in likelihood or severity on every trial. The likelihood of the risk referred to the chance the noise burst would be delivered, while the severity of the risk referred to the volume with which the noise burst would be delivered. On every trial, information about the likelihood of this risk and information about its severity was communicated through two differently coloured squares. Five shades of each colour represented five levels in each risk component. Thus, as the colour intensity of the rectangle increased, the level of risk likelihood or severity increased. In this manner, participants were presented with objective information about the magnitude of the risk. The level of risk likelihood and risk severity were manipulated independently, and the multiplicative relationship between the likelihood and severity of the risk defined the risk magnitude (Robinson-Riegler, 1994; Weinstein, 2000). To assess the calibration of danger mitigation behaviour to the variation in risk magnitude, participants were given the opportunity to mitigate the danger on some trials. To this end, participants were given a virtual coin which, when invested, would mitigate the danger, i.e. annul the delivery of the noise burst. However when the coin was invested, two trials with no coin and hence no opportunity for danger mitigation would follow before a new coin was made available. Therefore, participants had to be selective in choosing when best to invest the coin. Changes in the probability of investing a coin for different combinations of level of risk likelihood and level of risk severity, served as a measure of the calibration of danger mitigation behaviour to variation in risk magnitude.

Method

Participants

Seventy-six undergraduate psychology students from the University of Western Australia participated in this study for partial course credit. In order to recruit both high and low anxious participants, students (n = 1134) completed the Spielberger State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983) and were invited to participate if they obtained scores in the top or bottom third of this sample. The final sample consisted of those students who responded to the invitation first. This sample consisted of 37 low trait anxious participants (24 male, mean age 20.7, SD = 6.1) and 39 high trait anxious participants (16 male, mean age 19.6, SD = 5.7). High trait anxious participants had significantly higher trait anxiety scores (M = 53.56, SD = 6.26) and state anxiety scores (M = 44.51, SD = 7.60) than low trait anxious participants (trait: M = 30.62, SD = 5.04; state: M = 27.24, SD = 7.56), $t_{trait}(74) = 17.55$, $p < .001$ and $t_{state}(74) = 9.93$, $p < .001$. The average trait anxiety score in the high anxious group corresponds to the 93rd percentile rank in college students, while the average trait anxiety score in the low anxious group corresponds to the 25th percentile rank in college students, averaged across male and female students (Spielberger et al., 1983). The STAI does not suggest clinical cut-offs, however studies have reported average trait anxiety scores ranging from 51.8 to 56.4 in clinically diagnosed anxious samples (Borkovec & Costello, 1993; Mathews & MacLeod, 1985). There were no significant differences between groups in age, $p > .1$. There were more women in the high trait anxious group than in the low trait anxious group, Mann-Whitney U = 549.50, $p = .039$, which is consistent with the higher prevalence rates of heightened anxiety in women than in men (McLean, Asnaani, Litz, & Hofmann, 2011). No participants reported hearing problems. All participants provided their informed consent, and were informed that they could terminate the experiment at any time. The study was approved by the ethical committee of the University of Western Australia.

Tasks and Materials

Anxiety questionnaires. The Spielberger State Trait Anxiety Inventory (STAI; Spielberger et al., 1983) was used to screen candidate participants for trait anxiety, and to confirm state and trait anxiety levels at the time of testing. The trait scale of the STAI consists of 20 items assessing the frequency with which anxiety symptoms occur. The state scale consists of 20 items assessing the intensity of current anxiety symptoms. This questionnaire instrument yields a reliable and valid measure of dispositional anxiety (Barnes, Harp, & Jung, 2002; Spielberger et al., 1983). Participants completed a paper version of the trait anxiety subscale prior to the test session. These scores were used to guide study invitations. During the test session, participants completed an electronic version of both the state and trait subscales. The latter scores were used in the analysis.

Calibration task. The calibration task served to assess individual differences in the calibration between danger mitigation behaviour and risk magnitude. Participants were presented with a risk of receiving a loud noise burst (=danger). Information about the likelihood of the risk (probability of the noise burst being presented) and its severity (loudness of the noise burst) was conveyed on screen via two coloured rectangles. On each trial, participants could choose to mitigate the danger (i.e. avoid the noise burst) by investing a coin that was made available to them. However, investing the coin came at the cost of losing the danger mitigation opportunity on the next two trials. This way, participants were encouraged to be selective in choosing when to mitigate the danger.

Two 3.8cm by 2.2cm coloured rectangles (blue and orange) represented information about the likelihood and severity of the danger (colours counterbalanced across participants), with a darker hue indicative of a higher likelihood or severity (see Figure 1). There were five levels of the likelihood a noise burst would be delivered: 20%, 40%, 60%, 80% and 100%, and five levels of severity: 60db, 70db, 80db, 90db, or 100db. The hue intensity for each level was matched for both colours. By presenting information about the magnitude of the likelihood and severity of risks through different hues and not using specific numbers, we aimed to present objective information about the variation in risk magnitude, without encouraging participants to respond in an artificial manner by simply multiplying numbers. Additionally, for each of the two colours a scrambled rectangle consisting of all five hues was created (see Figure 1), indicating that the level of severity and likelihood was to be determined at random. This allowed us to compare danger mitigation behaviour on trials with unknown risk information to danger mitigation on trial with objective information (van Ravenzwaaij, Dutilh, & Wagenmakers, 2011).

To allow variability in the information participants could attend to, a neutral grey square, shaded darker to either the left of right, was also presented, indicating whether the noise burst would be delivered through the left or right earpiece of the headphones. An image of a coin, 2cm in diameter, signalled the opportunity for danger mitigation. The noise burst was a 500ms burst of white noise, presented to participants through headphones. Participants received their first coin in one of the first three trials. The coin remained available until it was invested, after which two trials followed in which no coin was available. On the third trial following a coin investment, participants received a new coin.

A more detailed overview of the trial sequence is presented in Figure 1. At the start of each trial, the statement “New Trial” was presented for 1000ms. Next, participants were shown whether or not they had a coin available on the current trial (A). On trials in which a new coin was gained, the caption “You have gained” and an image of the coin was displayed. On the remainder of the trials, the caption “You currently have:” was presented with a coin image if a coin was available, or no coin image if no coin was available. Next, participants were encouraged to focus on the centre of the screen in order not to bias initial allocation of attention. This was done by presenting a central fixation cross (B) (Notebaert, Crombez, Van Damme, Durnez, & Theeuwes, 2012). Next, the three rectangles were presented (C). The grey rectangle was presented at fixation, and the other two rectangles were presented to its left and right (with the centres of the distal and central rectangles 6cm apart). To ensure participants remained attentive to the information presented, this was followed by a task requiring the discrimination of a visual target presented on screen (D) (MacLeod, Mathews, & Tata, 1986). Participants were instructed to click the left mouse button if the target consisted of two horizontally aligned dots and the right mouse button if the target consisted of two vertically aligned dots. Following this response, feedback on the target discrimination response (“Correct” or “Incorrect”) was presented on screen for 1000ms. On trials in which a coin was available, participants were next asked if they wanted to invest the coin (E). The image of the coin was displayed with the caption “Invest coin? Y/N” until a response had been made. Following this response and a 500ms delay, a noise burst (500ms) could be delivered. The delivery and dB value of the noise burst was dependent on the likelihood and severity in that trial, and whether or not a participant had used the coin to mitigate the danger. There was a 500ms interval before the next trial commenced.

The severity and likelihood of the danger were manipulated independently, such that each level of severity was crossed with each level of likelihood. This was crossed with the location of the dot probe, which could be presented at each of the three locations, for a total of 108 trials. To be able to assess how likely a participant was to mitigate the danger (i.e. invest the coin) on each of these 108 trials, trials in which no coin was available were repeated until each of these 108 trials had been presented with the opportunity for danger mitigation (i.e. the participant had the opportunity to invest a coin on that trial).

Procedure

After obtaining informed consent, participants were seated approximately 60cm from the screen. The experiment was programmed using the E-Prime software package (Psychology Software Tools, Sharpsburg, PA, USA). The study consisted of assessing demographic information (age and gender), followed by the anxiety questionnaires and the calibration task. The entire study lasted 25 to 50 minutes, depending on the speed of responding and the number of trials that had to be repeated.

Data Analysis

For each participant, responses on the 108 trials in which a coin was available were analysed using a multilevel model. The multilevel approach allows modelling the observable differences in the calibration of danger mitigation behaviour to variation in risk magnitude due to trait anxiety, while accounting for other unmeasured individual differences (Langford, et al. 1999), such as participants' aversion to noise bursts.

Calibration of danger mitigation behaviour to known risk magnitude

Danger mitigation behaviour. The probability, p_{ij}, that participant j invested the coin on trial i follows a multilevel logit model (Kruschke 2010a, Gelman and Hill 2007), as presented in equation (1).

$$\log\left(\frac{p}{1-p}\right) = \beta_{ij}^{0} + \beta_{ij}^{L} L_{ij} + \beta_{ij}^{S} S_{ij} + \beta_{ij}^{LS} L_{ij} S_{ij} \tag{1}$$

The log odds of the probability of investing versus not investing were defined as a function of the likelihood, L_{ij}, the severity, S_{ij} , and their interaction. The 5 levels of risk likelihood and risk severity were coded from -2 to 2. β_{0ij} represents the average log odds for participant j while the other coefficients represent to what extent participants calibrated their coin investments to the likelihood and severity of the noise.

The logit link function was used as it is one of the standard methods to transform a linear model to a probability scale between 0 and 1, and ensures that the model cannot predict negative probabilities or probabilities larger than 1 (Gelman & Hill, 2006). Furthermore, mathematical models often use the logit function to model an individual's probability of taking one of two possible actions based on an underlying latent variable (see van Ravenzwaaij et al., 2011 for an example with the BART task). The probability that a participant will invest the coin was thus modelled according to equation (2), which re-expresses the logit link function with the probability on the right-hand side.

$$p_{ij} = \frac{1}{1 + exp(-(\beta_{ij}^{0} + \beta_{ij}^{L} L_{ij} + \beta_{ij}^{S} S_{ij} + \beta_{ij}^{LS} L_{ij} S_{ij}))} \tag{2}$$

One interpretation of this formulation is that the linear function of the likelihood, severity and the interaction, $\beta_{ij}^{0} + \beta_{ij}^{L} L_{ij} + \beta_{ij}^{S} S_{ij} + \beta_{ij}^{LS} L_{ij} S_{ij}$, is a model of participant j's unobserved willingness to mitigate the danger. The willingness to mitigate includes not only the total danger (i.e the interaction) but also the individual components likelihood and severity. This allows controlling for individual variation in the weighting of information about likelihood and severity, such as the tendency of high anxious individuals to overweigh the severity of the danger (Maner & Schmidt, 2006; Mitte, 2007).

The interaction coefficient β^{LS}_{j} is of critical interest because it indicates how well the willingness to mitigate the danger was calibrated to the combined information about the likelihood and severity. Because L_{ij} and S_{ij} can take on positive as well as negative values and all conditions have an equal number of observations, a positive interaction effect, β^{LS}_{ij}, cannot be explained by a main effect, such as participants' higher willingness to mitigate danger with either higher likelihood or higher severity. For instance, with a positive interaction coefficient β^{LS}_{ij} and likelihood $L_{ij} = -1$ (40% likelihood), the contribution of the total danger to the log odds, $\beta^{LS}_{ij}L_{ij}S_{ij}$, decreases as the level of severity increases. However, with the same β^{LS}_{ij} and a $L_{ij} = 1$ (80% likelihood), $\beta^{LS}_{ij}\, L_{ij}\, S_{ij}$, increases as the level of severity increases.

Because of the non-linearity in the logit function, this interaction effect on the willingness to mitigate danger cannot necessarily be translated to the probability of danger mitigation[1]. In order to interpret the interaction effect on the probability of the coin investment directly, Gelman and Pardoe's (2007) average predictive comparison (APC) methodology was adapted. Based on the results of the estimation procedure and equation, the probability, p_{njls}, of danger mitigation was simulated for every participant and every combination of severity and likelihood. For every simulation, n, and participant, j, the interaction effect, γ_{njls}, was calculated according to equation (3).

$$\gamma_{njls} = (p_{njls} - p_{njl(s-1)}) - (p_{nj(l-1)s} - p_{nj(l-1)(s-1)}) \ for\ l,s\ in\ \{1,0,1,2\} \tag{3}$$

Similar to a linear interaction effect, the γ's represent the increase in predicted probability of the coin investment from a combined increase in likelihood and severity that is not accounted for by the main effects of increasing likelihood or severity. The reported APC was calculated as the average difference in γ between two participants from the same gender and age who differ one

[1] We thank the editor for this suggestion.

standard deviation in trait anxiety (see the technical appendix for more details). As such, APC provides a direct estimate of the effect of trait anxiety on calibration of the coin investment to the magnitude of the total danger.

Individual differences and time trends. The model further decomposed each of the β's into several components. Specifically, for a given participant, calibration of behaviour to information about risk likelihood (β^L_j), was decomposed into the average sample calibration, μ^L, a participant specific deviation, μ^L_j, a time trend δ^L_T trial, and the effect of measured individual differences in trait anxiety (δ^L_{TA} TA_j), gender (δ^L_G G_j), and age (δ^L_A A_j). Similarly, calibration to severity and calibration to the total danger were decomposed into a sample average, an unobserved individual component, and the effect of trait anxiety, time, gender, and age according to equation (4).

$$\beta^{\cdot}_{ij} = \mu^{\cdot} + \mu^{\cdot}_{j} + \delta^{\cdot}_{T} trial + \delta^{\cdot}_{TA} TA_{j} + \delta^{\cdot}_{A} A_{j} + \delta^{\cdot}_{G} G_{j} \tag{4}$$

An overview of all parameters in this model is provided in Table 1. The estimates for the δ_{TA}'s are of critical interest, because they measure the difference in calibration explained by trait anxiety, i.e they represent the interaction between trait anxiety and likelihood, severity, and the total dangermagnitude. The unobserved individual components take into account if some participants perceived noise bursts as more aversive (μ^0_j), or if some participants calibrated their investment more to the likelihood and severity than others (μ^L_j, μ^S_j, μ^{LS}_j).

Calibration of danger mitigation behaviour to unknown risk magnitude

The model also allowed estimating participants' interpretation of unknown likelihood and severity information on trials where scrambled squares were presented. For these trials, the unobserved value participants attach to the scrambled likelihood (severity) square is modelled as L_j (S_j) which is assumed to lie between -2 and 2[2]. The estimated L_j and S_j is plugged into equation equation (1) and (2) for the trials with scrambled squares. As before, those parameters depend on

[2] In other words, participants interpret a scrambled likelihood (severity) square as a likelihood (severity) between 20% and 100% (60dB and 100dB)

the sample average, a participant specific deviation, a time effect, and observable individual differences and a logit link function is used to constrain L_j and S_j to the interval between -2 an 2 in equation (5) (see also Table 1). The result of this formulation is that a participant who mitigates danger more often with scrambled likelihood (severity) squares than with the average likelihood (severity) of 60% (80dB) will have a positive L_j (S_j).

$$
\begin{aligned}
L_j &= -2 + \frac{4}{1+exp(-(\lambda_0^L + \lambda_j^L + \lambda_T^L Trial + \lambda_{TA}^L TA_j + \lambda_A^L Age_j + \lambda_G^L Gender_j))} \\
S_j &= -2 + \frac{4}{1+exp(-(\lambda_0^S + \lambda_j^S + \lambda_T^S Trial + \lambda_{TA}^S TA_j + \lambda_A^S Age_j + \lambda_G^S Gender_j))}
\end{aligned} \tag{5}
$$

Results

Calibration of danger mitigation behaviour to known risk magnitude

Danger mitigation behaviour. The average and the 95% credibility interval for each parameter are presented in Figure 2. Bayesian credibility intervals can be directly interpreted as the interval that includes the value of the underlying parameter with 95% probability. Because of the Bayesian estimation procedure for the model, it is not possible to report traditional p-values. As an alternative, the probability that a given parameter is larger than 0 is reported. The advantage of the technique is that 1 minus this probability can be interpreted as the probability that the parameter is negative.

The results showed that a 20% increase in the likelihood of a noise burst, increased the willingness to mitigate danger with μ_L = 0.63. A 10dB increase in severity increased the willingness to mitigate danger with μ_L = 1.06. Thus, these estimates show that participants calibrated their danger mitigation behaviour to the individual components of risk magnitude, as they were more likely to invest the coin as the likelihood and severity increased. The non-overlapping credibility intervals for μ_L (95% CrI = [0.51, 0.76]) and μ_S (95% CrI = [0.92, 1.22]) show that participants calibrated their behaviour more to information about severity than to information about likelihood. Furthermore, a joint increase of one level in the level of likelihood and severity increased the log odds ratio with an additional factor of μ_{LS} = 1.18 over and above the main effects. This interaction effect indicates that participants were calibrating their danger mitigation behaviour to integrated information about the likelihood and severity of the risk.

Trait anxiety. The effect of trait anxiety on calibration was estimated by the δ's in Figure 3. The results show that high anxious participants were significantly more likely to invest the coin when risk severity increased (δ^{S}_{TA} = 0.18, Pr(δ^{S}_{TA} > 0) > 0.999). Thus, anxiety was associated with an increased calibration of danger mitigation behaviour to risk severity. In contrast, higher anxiety was not associated with an increased calibration to risk likelihood (δ^{L}_{TA} = 0.00). Importantly, the results show that the coin investments of higher anxious participants were more sensitive to the combination of likelihood and severity than lower anxious participants (δ^{LS}_{TA}= 0.06, Pr(δ^{LS}_{TA} > 0) = 0.977). This indicates that anxiety was associated with enhanced calibration of danger mitigation behaviour to integrated information about risk likelihood and severity. To illustrate the magnitude of the contribution of trait anxiety to calibration, the interaction effect for a low anxious and high anxious individual was calculated. A participant with a trait anxiety score of one standard deviation below the sample average, showed an estimated calibration to the combined risk magnitude of μ^{LS} - δ^{LS}_{TA}= 0.09 (95% CrI = [0.01, 0.19]), while a participant with a trait anxiety score of one standard deviation above the average, showed an estimated calibration of μ^{LS} + δ^{LS}_{TA} = 0.21 (95% CrI = [0.12, 0.33]).

The effect of trait anxiety, likelihood, and severity on the probability of danger mitigation is illustrated in Figure 3. The figure graphs the actual and the estimated probability (in the curves) of the coin investment across the different levels of severity and likelihood for low anxious (triangles) and high anxious participants (circles). The sample-wide calibration to the total danger can be seen in the steeper curves in the last panel compared to the first panel which means that the effect of an increase in severity on danger mitigation increased with the likelihood. Furthermore, the increase in steepness from the first to the last panel is stronger for the curves of the high anxious participants (circles) than the low anxious participants (triangles). A vivid illustration of this effect is the lack of a crossover point between the curves in the first panel, and a crossover point at ever lower severity levels in the panels with higher likelihood.

To test the effect of total risk magnitude on the probability of investment directly, the simulated γ's were analysed. The simulations quantify the additional probability of engaging in danger mitigation over and above the main effects for a 10dB increase in severity and 20% increase in likelihood, i.e. the interaction effect of likelihood and severity on the probability of danger mitigation. The average γ was higher for high anxious participants than for low anxious participants (γ_H = 3.5%, 95%, CrI_H = [3.1%, 4.0%], γ_L = 2.5%, 95% CrI_L = [2.0%, 3.0%]). To control for the possible confounding effects of age and gender, the Average Predictive Comparison (APC) was calculated. The APC quantifies the increase in γ between participants of equal age and gender who differ two standard deviations in trait anxiety[3]. The APC indicated that an increase of two standard deviations in trait anxiety was associated with an increase in calibration of danger mitigation to the interaction of likelihood and severity (APC = 0.89%, 95% CrI = [-0.12%, 1.89%], Pr(APC > 0) = 0.958).

Demographic variables and time trends. The demographic characteristics, age and gender, only explain some of the variation in calibration to the likelihood and severity interaction. The willingness to mitigate the danger tended to be less calibrated to the interaction for younger participants (δ^{LS}_A = -0.05, 95% CrI = [-0.12, 0.01]) and female participants (δ^{LS}_G = -0.07, 95% CrI = [-0.19, 0.05]). The results in Figure 2 also show that the calibration to likelihood (δ^{L}_T = 0.12, 95% CrI = [0.05, 0.18]), severity (δ^{S}_T = 0.14, 95% CrI = [0.08, 0.19]), and the interaction (δ^{L}_T = 0.05, 95% CrI = [0.00, 0.09]) increased over time.

Calibration of danger mitigation behaviour to unknown risk magnitude

[3] The average high anxious participant differed about two standard deviations from the average low anxious participant.

The estimates for the effects of the danger mitigation behaviour to unknown risk magnitude are depicted in Figure 4. The results show that participants acted as if the unknown severity was lower than the average severity of 80dB (λ^{S}_{0} = -1.91, 95% CrI = [-3.70, -0.82]) and to lesser extent as if the unknown likelihood was lower than the average likelihood of 60% (λ^{L}_{0} = -0.73, 95% CrI = [-1.86, 0.04]. The individual characteristics of trait anxiety, age, and gender or the time trend did not explain more of the variation in participants' danger mitigation behaviour in response to risks of unknown magnitude.

Discussion

The aim of the current study was to investigate whether anxiety is characterised by better or worse calibration of danger mitigation behaviour to variations in risk magnitude. Importantly, the magnitude of the total danger was defined as the multiplicative relationship between the level of risk likelihood and risk severity. The results suggest that anxiety is characterised by better calibration, as high trait anxious participants were less likely than low trait anxious participants to engage in danger mitigation behaviour when the total magnitude of the danger was small, and more likely to engage in danger mitigation when the danger magnitude was largest. Consistent with previous research, our results indicated that high anxious' risk taking behaviour was more sensitive to the severity of the risk (Maner & Schmidt, 2006; Mitte, 2007). However, the current findings show that the interaction of risk likelihood and severity served to additionally predict danger mitigation behaviour, and more so in high anxious participants. To our knowledge, this is the first study to show that individuals calibrate their danger mitigation behaviour to integrated information about different components of risk, and that this calibration is more pronounced in individuals with higher levels of trait anxiety.

The calibration between risk perception and danger mitigation is paramount for adaptive functioning (Blanchard et al., 2011). Neuroimaging research has shown that the same brain regions are involved in the perception of threats and in behavioural and biological responding to such threats (Bishop, 2007; Shin, Rauch, & Pitman, 2006). Therefore, this calibration between perception and behaviour is supported by shared activation in an integrated network consisting of the amygdala, the hippocampus, and the medial prefrontal cortex (O'Donovan et al., 2013). The involvement of this network might contribute to our understanding of the current findings. In describing a neurobiological model for anxiety-linked sensitivity to threat, O'Donovan et al. (2013) review evidence that activity in this neural network is potentiated for individuals with anxiety disorders, as well as for individuals exhibiting high levels of trait anxiety. Thus, when confronted with information about a risk or potential threat, high anxious individuals may show enhanced processing of this information, enhanced engagement in behaviour aimed at minimising harm, but crucially also increased calibration between these two.

This finding opens up several new avenues for research is this area. One important avenue is to investigate the nature of this calibration in clinical populations as compared to non-clinical populations. Whereas heightened trait anxiety might be associated with more adaptive cognitive and behavioural responding to threat, the patterns of cognitive and behavioural processes in clinical anxiety are thought to contribute to the maintenance or exacerbation of dysfunctional anxiety (Lorian & Grisham, 2010; MacLeod & Mathews, 2012; Van Bockstaele et al., 2014; Weinstein, 1980). Therefore, it is possible that heightened anxiety is a driver for adaptive responding to threat, whereas clinical levels of anxiety only serve to impair performance. As such, the relative advantage shown in the current study by high trait anxious individuals could disappear or even be reversed in a clinically anxious group. In addition, individual differences in the manifestation of anxiety symptomatology may be characterised by differences in the calibration of behaviour to varying risks. For example, some people suffering from social phobia might over-estimate the severity of risks encountered in certain social situations (e.g. public speaking), whereas other people might over-estimate the probability of negative social evaluations across many social situations, causing pervasive avoidance behaviour. Such differential weighting of risk information and its influence on behaviour might therefore contribute to the distinction between subtypes of a particular emotional disorder (for example the generalised versus specific subtype of Social Anxiety Disorder (Turner, Beidel, & Townsley, 1992), or even between different disorders.

In addition to investigating how anxiety influences the calibration between risk perception and danger mitigation, future research could also investigate anxiety-linked differences in the *degree* of investment in danger mitigation behaviour. In the current study, the task offered limited behavioural flexibility as the main goal was to examine *when* participants chose to engage in danger mitigation. By allowing more flexibility, it would be possible to investigate whether or not anxiety contributes to excessive investment of danger mitigation resources, as compared to the type and magnitude of risk that is encountered. For example, anxiety could be associated with excessive attempts to mitigate minor risks (such as in the case of Obsessive Compulsive Behaviour), leading to a maladaptive balance between the effort invested in danger mitigation and the pay-off in terms of risk reduction. The current paradigm could be adapted to investigate this relationship between the degree of risk encountered, and the amount of effort invested in danger mitigation. For example, participants could be given a large number of coins at the start of the task, and instructed to invest as many coins as they want on each trial to mitigate the danger. The more coins would be invested, the greater reduction of risk. Critically, participants would not have enough coins to eliminate the risk on every trial. Therefore, selectivity is needed when deciding to invest coins. This would allow investigating whether high anxious participants “over-invest” coins as compared to low anxious participants when confronted with minor risks, which would be suggestive of maladaptive excessive danger mitigation behaviour in anxiety.

Of course, the current study is not without its limitations. One limitation concerns the use of undergraduate psychology students. While there is sufficient variation in trait anxiety in this population to address the main aim of the study, it is possible that individuals in this population may exhibit different risk management behaviour as compared to other groups. In addition, the danger participants were exposed to was an aversive auditory stimulus, which some populations or some individuals within the current sample may have been more eager to avoid than others. Although some of this variation is captured in the regression model, future research could usefully examine whether similar effects are obtained across a variety of populations and in response to different types of risk (such as a monetary loss). For example, while the “two-trial wait” after investment of the coin in the current design can be interpreted as a cost (the loss of danger mitigation opportunity), this was not intended to represent the typical costs that can be incurred by engaging in danger mitigation behaviour. Rather, the two-trial wait was introduced to encourage participants to be selective in when they chose to invest their coin, thereby revealing which aspects of risk this choice is calibrated against. The main aim of this two-trial wait was thus not to simulate costly danger mitigation behaviour, but to encourage selectivity, similar to how costly danger mitigation behaviour encourages selectivity. Future research however could usefully implement and manipulate externally valid danger mitigation costs, to examine how variation in such costs may impact on investment choices. For example, participants could be incentivized at the start of the study and required to invest part of the money they have been allocated every time they choose to mitigate the danger.

Second, it is possible that high and low anxious participants experienced the aversiveness of the noise burst differently, with high trait anxious individuals assigning a higher threat value to this noise burst than low trait anxious individuals (Mogg & Bradley, 1998). However, such subjective differences in the perception of the noise burst do not necessarily present a problem, and may even be a necessary condition for anxiety-linked biases in cognitive processes to manifest. When presented with extremely high risks or extremely aversive stimuli, it is likely that there will be no room for individual differences in trait anxiety to play a role. Evidence for such ceiling effects comes from research examining anxiety-linked attentional vigilance for threat (Notebaert, Crombez, Van Damme, De Houwer, & Theeuwes, 2011; Wilson & MacLeod, 2003). These studies show that when stimuli are highly threatening, both high and low anxious individuals show equivalent attentional vigilance for these stimuli. However, when stimuli are mildly or moderately threatening (as is more common in everyday life), this vigilance is moderated by individual differences in trait anxiety. Specifically, in this case high trait anxious individual show more attentional vigilance to threat than low trait anxious individuals (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van Ijzendoorn, 2007). Thus, in the current study we aimed to present a threat of moderate intensity, allowing variation in responding with individual differences in anxiety.

A third potential limitation concerns the lack of self-report measures. Although the aim of this study was to measure risk perception and danger mitigation behaviour in a manner that reduces reliance on self-report, we do acknowledge that, in line with previous research, self-report measures of risk level and strategy use may have been informative, for example to compare objective and subjective measures of the same construct.

Lastly, while the gender distribution in the current study is representative of the gender distribution in high and low anxious populations, the lack of a balanced gender design prohibits any strong conclusions about gender differences in risk perception, danger mitigation, and the calibration between the two in the current study. Previous research has shown that that women generally take fewer risks than men (except in social domains), which appears to be mediated by greater perceived likelihood of negative outcomes and less perceived enjoyment for some risks (gambling, recreation, health), or by increased perception of the severity of potential negative outcomes (for gambling and health) (Byrnes, Miller, & Schafer, 1999; Harris, Jenkins, & Glaser, 2006). In the current study, accounting for gender in the model did not reveal any meaningful effects.

In conclusion, the current study developed a novel flexible paradigm to investigate the calibration of danger mitigation behaviour to variation in different components of risk. The results suggested that high trait anxious individuals calibrated their behaviour more to the integration of risk likelihood and severity information than low anxious individuals. These findings and this paradigm open up a range of new avenues for future research to investigate the nature of this calibration, and the person and event moderators that may impact on it. This line of research holds the promise to shed new light on the influence of anxiety on cognitive processing and behaviour in risky environments.

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For participant j	Sample Average	Participant specific	Time trend	Trait anxiety	Age	Gender
Log odds for average likelihood and severity (β_{0j})	μ^0	$\mu^0{}_j$	$\delta^0{}_T$	$\delta^0{}_{TA}$	$\delta^0{}_A$	$\delta^0{}_G$
Calibration to risk likelihood (β_{Lj})	μ^L	$\mu^L{}_j$	$\delta^L{}_T$	$\delta^L{}_{TA}$	$\delta^L{}_A$	$\delta^L{}_G$
Calibration to risk severity (β_{Sj})	μ^S	$\mu^S{}_j$	$\delta^S{}_T$	$\delta^S{}_{TA}$	$\delta^S{}_A$	$\delta^S{}_G$
Calibration to likelihood x severity interaction (β_{LSj})	μ^{LS}	$\mu^{LS}{}_j$	$\delta^{LS}{}_T$	$\delta^{LS}{}_{TA}$	$\delta^{LS}{}_A$	$\delta^{LS}{}_G$
Latent likelihood (L_j)	γ^L	$\gamma^L{}_j$	$\gamma^L{}_T$	$\gamma^L{}_{TA}$	$\gamma^L{}_A$	$\gamma^L{}_G$
Latent Severity (S_j)	γ^S	$\gamma^S{}_j$	$\gamma^S{}_T$	$\gamma^S{}_{TA}$	$\gamma^S{}_A$	$\gamma^S{}_G$

Table 1. An overview of the parameters estimated in the known risk magnitude model.

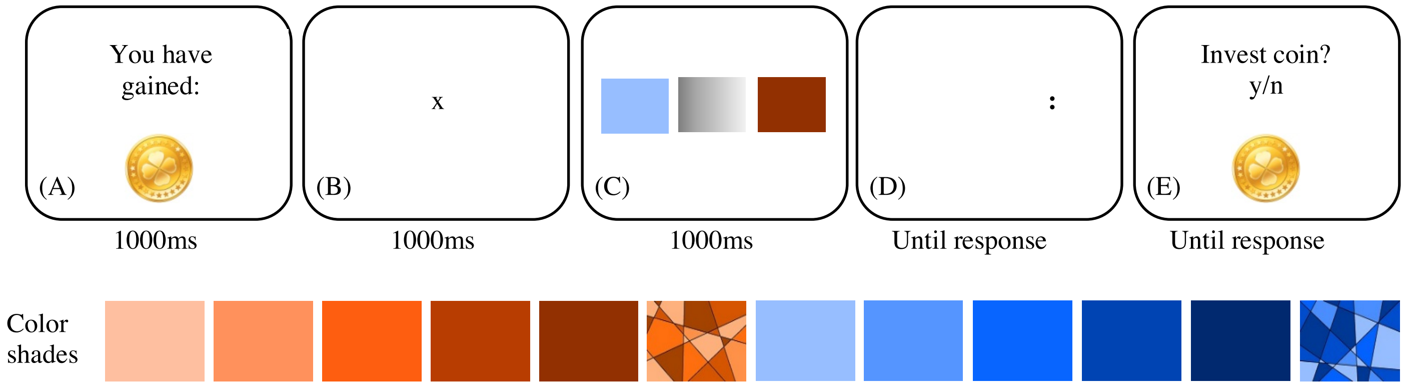

Figure 1. Calibration task stimuli and trial overview.

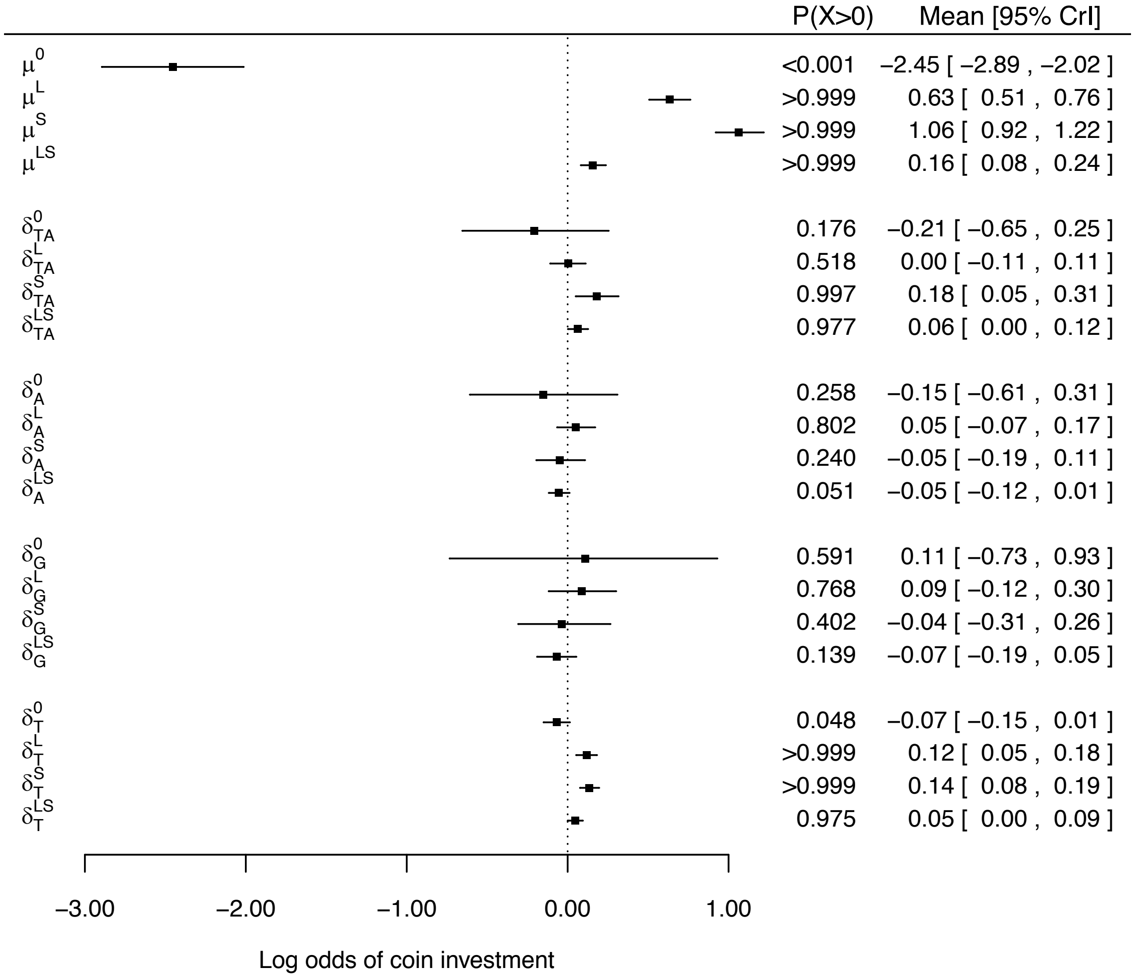

Figure 2. Parameter estimates for the log odds of coin investment and the calibration to the level of risk likelihood, to the level of risk severity, and to total danger. All effects are allowed to vary over time (T), and with participants' level of trait anxiety (TA), age (A), and gender (G).

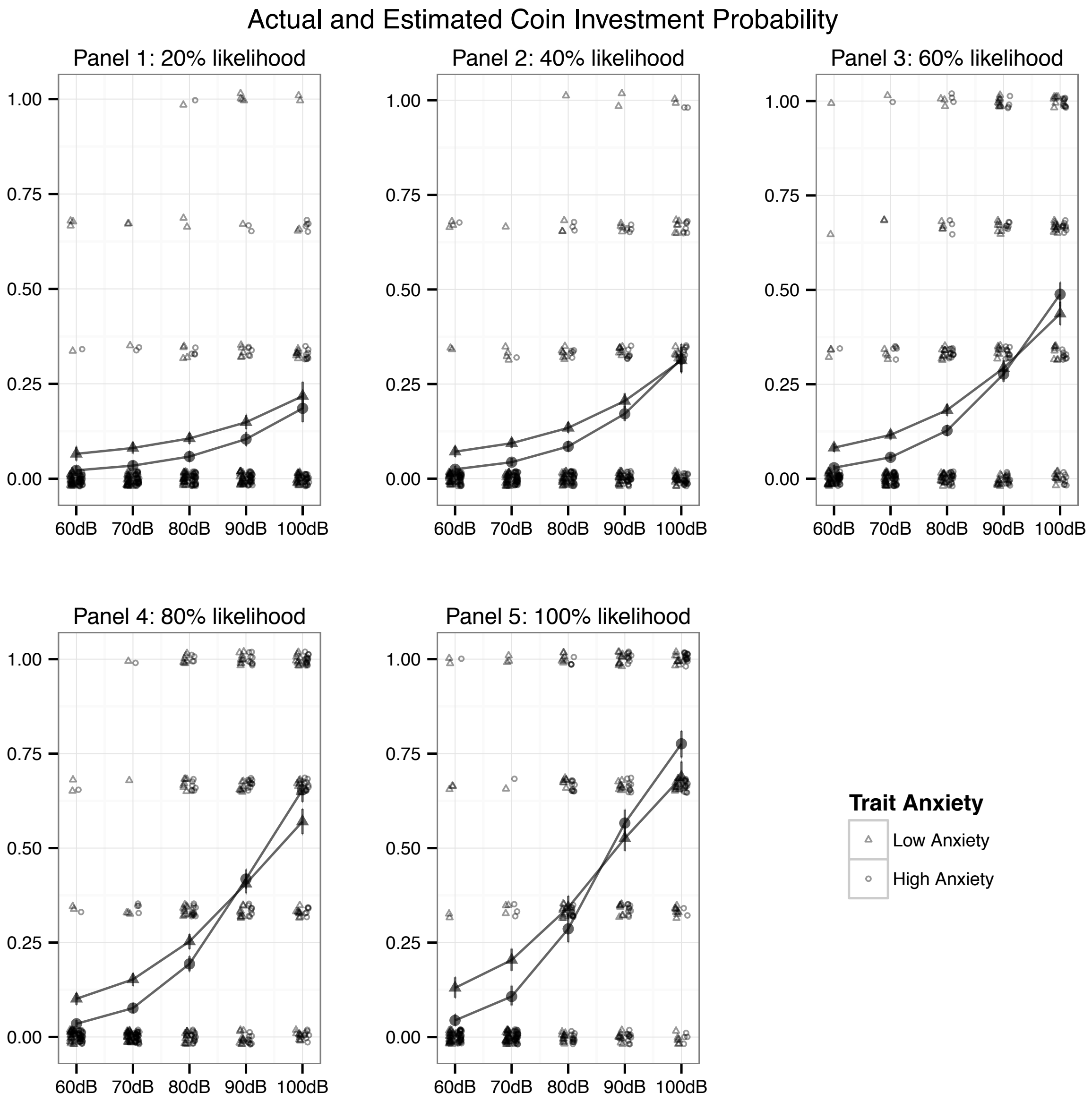

Figure 3: The actual probability of danger mitigation for all participants for every combination of likelihood (over 5 panels) and severity (on the x-axis) is depicted as a hollow triangle for low anxious and a hollow circle for high anxious participants. The curves represent the average predicted probability and 95% credibility intervals of the low anxious and high anxious group.

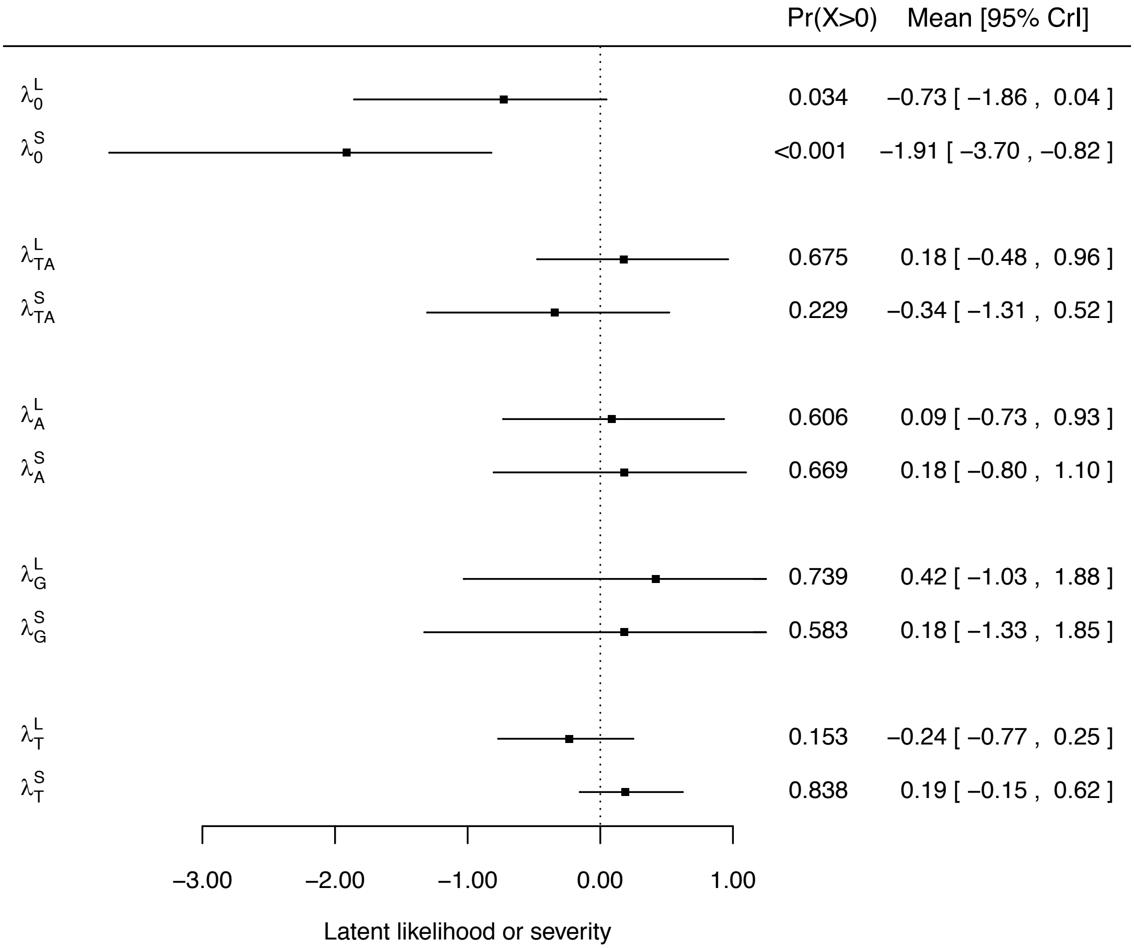

Figure 4. Parameter estimates for the participants' unobserved interpretation of unknown severity and likelihood. The effects are allowed to vary over time (T), and with participants' level of trait anxiety (TA), age (A), and gender (G).

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