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Research Articles: Behavioral/Cognitive

Updating Beliefs Under Perceived Threat

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Updating Beliefs Under Perceived Threat

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31 **Abstract**

32 Humans are better at integrating desirable information into their beliefs than undesirable. This
33 asymmetry poses an evolutionary puzzle, as it can lead to an underestimation of risk and thus
34 failure to take precautionary action. Here, we suggest a mechanism that can speak to this
35 conundrum. In particular, we show that the bias vanishes in response to perceived threat in
36 the environment. We report that an improvement in participants' tendency to incorporate bad
37 news into their beliefs is associated with physiological arousal in response to threat indexed
38 by galvanic skin response and self-reported anxiety. This pattern of results was observed in a
39 controlled laboratory setting (Experiment I), where perceived threat was manipulated, and in
40 firefighters on duty (Experiment II), where it naturally varied. Such flexibility in how
41 individuals integrate information may enhance the likelihood of responding to warnings with
42 caution in environments rife with threat, while maintaining a positivity bias otherwise, a
43 strategy that can increase well-being.

44

45 **Significance Statement**

46 The human tendency to be overly optimistic has mystified scholars and lay people for
47 decades: how could biased beliefs have been selected for over unbiased beliefs? Scholars
48 have suggested that while the optimism bias can lead to negative outcomes, including
49 financial collapse and war, it can also facilitate health and productivity. Here, we demonstrate
50 that a mechanism generating the optimism bias, namely asymmetric information integration,
51 evaporates under threat. Such flexibility could result in enhanced caution in dangerous
52 environments while supporting an optimism bias otherwise, potentially increasing well-being.

53

54 **Introduction**

55 Whether a piece of news is good or bad is critical in determining whether it will alter our
56 beliefs. In particular, people readily incorporate favorable news into their existing beliefs, yet
57 tend to underweight the strength of unfavorable information (Eil and Rao, 2011; Kuzmanovic
58 and Rigoux, 2017; Kuzmanovic et al., 2015, 2016; Lefebvre et al., 2017; Mobius et al., 2012;
59 Sharot et al., 2011; Wiswall and Zafar, 2015). For example, when learning that their risk of
60 experiencing future aversive events, such as robbery, is higher than they had expected, people
61 are less likely to integrate these data into prior beliefs relative to a situation in which they
62 learn that their risk is lower than expected (Sharot et al., 2011). The same pattern emerges
63 when people receive desirable and undesirable information about their financial prospects
64 (Wiswall and Zafar, 2015), or feedback about their intellectual abilities (Eil and Rao, 2011;
65 Mobius et al., 2012), personality (Korn et al., 2012) and physical traits (Eil and Rao, 2011).
66 This is known as a **valence-dependent learning asymmetry** (Sharot and Garrett, 2016).

67
68 Incorporating desirable information about the self at a higher rate than undesirable (Korn et
69 al., 2012) will subsequently lead to overconfidence and optimistically biased predictions
70 (Sharot et al., 2011). On the upside an optimistic outlook, even when biased, can improve
71 physical and mental health (Taylor and Brown, 1988), boost motivation (Bandura, 1989),
72 exploration (Tiger, 1979) and persistence (Sherman, 1980), thus enhancing success and well-
73 being (for a review, see (Chang, 2001). However, ignoring negative information can result in
74 faulty assessment and lack of precautionary action leading to, for example, ill preparedness in
75 the face of natural disasters, and financial market bubbles (Shefrin, 2009) .

76
77 These apparent costs present a conundrum; why have humans evolved a bias in learning that
78 leads to systematic errors in judgement? The common answer is that people make errors that
79 are costly in certain situations, because those errors are advantageous in other situations, and
80 on balance the benefits outweigh the costs (McKay and Dennett, 2010). There is another
81 possibility though - that the asymmetry fluctuates in response to environmental demands. For
82 example, in relatively safe surroundings, where potential harm is low, an asymmetry in
83 information integration may be prominent leading to biased expectations. Yet in
84 environments rife with threats, a physiological/psychological response may trigger changes to
85 how information is integrated leading to more balanced information integration which may be
86 adaptive in environments where potential costs are high (see Johnson and Fowler, 2011).

87
88 Because affect provides an internal signal about the external context, it could potentially be
89 used to adaptively modulate cognitive biases. Specifically, we suggest that the key is a
90 learning mechanism that is modulated by the two core aspects of affect: valence and arousal.

91 A valence-dependent learning mechanism biases judgements and an arousal-dependent switch
92 controls the degree and perhaps sign of the bias.

93

94 To test this prediction, we exposed participants to an acute threat manipulation in the lab
95 (Experiment I) or tested participants in a real-life environment (firefighters tested on call,
96 Experiment II). After measuring indicators of arousal, stress and anxiety, participants
97 completed the belief update task (Chowdhury et al., 2014; Garrett and Sharot, 2014; Garrett et
98 al., 2014; Kappes et al., 2018; Korn et al., 2013; Kuzmanovic et al., 2015, 2016; Moutsiana et
99 al., 2013, 2015; Sharot et al., 2011, 2012a, 2012b) (**Fig. 1**). Past studies have shown that
100 participants put more weight on good news (i.e. that a negative life event is less likely to
101 occur than expected, **Fig. 1a**) compared to bad news (i.e. that a negative event is more likely
102 to occur than expected, **Fig. 1b**) in altering beliefs in this task. Here we test whether
103 heightened response to threat abolishes this bias.

104

105 **Materials & Methods**

106

107 **Experimental Design and Statistical Analysis: Experiment I**

108 **Participants.** Thirty-six participants recruited via the UCL participant pool participated in the
109 study. Participants gave informed consent and were paid for their participation. The study was
110 approved by the Research Ethics Committee of the University College London. One
111 participant's responses resulted in only two good news trials (out of a possible 40), which
112 prevented us from calculating a meaningful information integration parameter (we define how
113 we calculate information integration parameters below), thus this participant's data had to be
114 excluded. Two participant's cortisol samples were insufficient for analysis, and samples of six
115 participants who were suspected to have depression (BDI score greater than 10) were never
116 sent to be analyzed. Thus, analysis that includes cortisol scores is given for $n = 27$. Note,
117 however, that either excluding those participants all together from all analysis or including
118 them as done here generated similar results. Each participant was randomly assigned to either
119 the threat manipulation condition (13 females, 6 males, mean age = 26.37 years, $SD = 6.58$)
120 or the control condition (10 females, 6 males, mean age = 24.94 years, $SD = 3.82$).

121

122 **Manipulation Procedure.** We designed the experiment such that the perceived threat was
123 unrelated to the information presented in the task. Thus, we could test whether the effect of
124 perceived threat on information integration was general rather than specific to the source of
125 the threat itself.

126

127 Participants assigned to the threat manipulation group were told that they would be exposed
128 to an uncomfortable, stressful, event at the end of the study. Specifically, they were informed
129 that at the end of the experiment they would be required to deliver a speech on a surprise
130 topic, which would be recorded on video and judged live by a panel of staff members. They
131 were shown an adjacent room across a double mirror window where chairs and tables were
132 already organized for the panel. In addition, participants were presented with six difficult
133 mathematical problems which they were asked to try and solve in 30 seconds. This
134 manipulation is a variation of the Trier Social Stress Test (TSST) (Birkett, 2011) with the
135 main difference between the typical TSST procedure and the one used here being that
136 participants were threatened by the possibility of a stressful social event, and completed the
137 main task under threat, but the threat was never executed. Having the participants believe the
138 stressful event will take place at the end of the task, rather than before, increased the
139 likelihood that participants' arousal levels remained high throughout the task. Participants
140 assigned to the control condition were informed that at the end of the experiment they would
141 be required to write a short essay on a surprise topic, which would not be judged. They were
142 then presented with six elementary mathematical problems to solve in 30 seconds.

143

144 **Manipulation Check.** We examine if the threat manipulation resulted in the following
145 psychological and physiological changes, which are typically observed in studies using
146 variations of TSST (Birkett, 2011).

147

148 1. *Self-Report.* Before and after the induction procedure participants filled out a short-
149 form of the State scale of the Spielberger State Trait Anxiety Inventory developed by
150 Marteau and Bekker (Marteau and Bekker, 1992). Participants reported their current
151 anxiety state according to 6 statements (e.g. I am worried) on a 4-point Likert scale (1
152 = *not at all* to 4 = *very much*). Possible scores range from 6 to 24 with high scores
153 indicating high levels of state anxiety.

154 2. *Skin Conductance Level (SCL).* SCL is an index of sympathetic tone which reflects
155 changes in autonomic arousal. Skin conductance was recorded for 2 minutes pre- and
156 post-induction whilst participants stared at a fixation cross using disposable
157 electrodermal gel electrodes (Biopac, EL507) attached to the distal phalanx of the
158 pointer and middle fingers of the participants' non-dominant hand. Skin conductance
159 responses were monitored using a MP36R system (BIOPAC Systems, Inc., Goleta,
160 CA) and analyzed with BIOPAC software *AcqKnowledge*. The difference in mean
161 SCL in each period were taken as a change in participants' autonomic arousal levels.

162 3. *Cortisol Level.* To measure changes in participants' cortisol levels, saliva samples
163 were collected using Salivette collection devices, (Salimetrics, UK). Four samples

164 were taken at different time points: before the induction procedure (baseline: t0);
165 immediately after the induction procedure but prior to undertaking the task (10 min
166 after the threat/control manipulation: t1); halfway through the task (30min after the
167 threat/control manipulation: t2); after the task and completion of post experiment
168 questionnaires (+1hr after the threat/control manipulation: t3). The experiment was
169 conducted between 2pm and 4pm, restricted to these times to control for the diurnal
170 cycle of cortisol. Samples were stored at -80°C before being assayed. Analysis of
171 salivary cortisol was completed by Salimetrics. Intra-assay and inter-assay
172 coefficients of variation were all below 6.1% ($M = 1.5\%$, $SD = 1.2$). Cortisol values
173 were measured in $\mu\text{g/dL}$. Shapiro-Wilk (SW) tests on cortisol levels at each sample
174 period revealed that these were not normally distributed (one sample SW $< .01$ for all
175 four sample intervals). As a result, cortisol values were log transformed. Since
176 cortisol stress response has a temporal delay (mediated by the slower time scale HPA
177 axis), it is difficult to precisely align the time of the cortisol response to perceived
178 levels of threat at different points in the task. Because of this, the main cortisol
179 measure we use in the manuscript was calculate as the mean difference between
180 cortisol levels at time periods t1, t2 and t3 from baseline cortisol levels at t0, as done
181 previously (Lenow et al., 2017; Lighthall et al., 2013; Otto et al., 2013). This measure
182 represents the average cortisol response throughout the duration of task performance.
183 Below is the formula we used to derive this index where log cort is the natural log-
184 transformed cortisol concentrations:

185

$$\log \text{cort } \Delta = \frac{\log \text{cort}_{t1} + \log \text{cort}_{t2} + \log \text{cort}_{t3}}{3} - \log \text{cort}_{t0}$$

186

187 **Behavioral Task.** The task was adopted from past studies (Chowdhury et al., 2014; Garrett
188 and Sharot, 2014; Garrett et al., 2014; Korn et al., 2013; Moutsiana et al., 2013, 2015; Sharot
189 et al., 2011, 2012a, 2012b).

190

191 **Stimuli.** Stimuli (80 short descriptions of different negative life events, for example: domestic
192 burglary, card fraud) were separated into two lists, each containing 40 events. Participants
193 were randomly assigned one of the two lists of 40 events at the start of the experiment. For
194 each event the average probability of that event occurring at least once to someone from the
195 UK within the same age range as the participants was calculated from data compiled from
196 online resources (including the Office for National Statistics and PubMed). Very rare or very
197 common events were not included; all event probabilities lay between 10% and 70%. To
198 ensure that the range of possible overestimation was equal to the range of possible

199 underestimation, participants were told that the range of probabilities lay between 3% and
200 77% and they were only permitted to enter estimates within this range. Note that differences
201 between the average probabilities provided to participants and the actual probabilities for the
202 sample of participants tested cannot explain differences between the two groups, as we
203 randomly assign participants to either the threat manipulation condition of the control
204 condition.

205

206 **Behavioral Task (Fig. 1).** Participants completed a practice session comprising 3 trials
207 before beginning the main experiment. The main experiment comprised 40 trials. On each
208 trial one of 40 adverse life events were presented for 3s, and participants were asked to
209 estimate how likely the event was to happen to them in the future. Participants had up to 5s to
210 respond. If participants had already experienced an event in their lifetime they were instructed
211 to estimate the likelihood of that event happening to them again in the future. If the
212 participant failed to respond, that trial was excluded from all subsequent analyses ($M = 1.31$,
213 $SD = 1.39$). Following presentation of a fixation cross (5-10s jittered) participants were then
214 presented with the base rate of the event in a demographically similar population for 2s
215 followed by a fixation cross (5-10s jittered). In a second session, immediately after the first,
216 participants were asked again to provide estimates of their likelihood of encountering the
217 same events so that we could assess how they updated their estimate in response to the
218 information presented.

219

220 Note, that studies have shown that the update bias exists both when classifying trials
221 according to participants' estimates of self-risk and when trials are classified according to
222 estimates of base rates (Garrett and Sharot, 2014; Kuzmanovic et al., 2015). Thus, we used
223 the traditional design and analysis here (Sharot et al., 2011). Moreover, multiple past studies
224 have shown that the amount of update bias does not alter whether participants are asked to
225 estimate the likelihood of the event happening in the future or the likelihood of the event not
226 happening in the future (Garrett and Sharot, 2014; Garrett et al., 2014; Sharot et al., 2011).
227 Thus, scores are not driven by response to high and low numbers, but rather by valence per
228 se. As this has been established in the past we used the standard version of the task here (i.e.
229 eliciting estimation of an event happening).

230

231 **Memory control.** To test for memory effects participants were asked at the end of the
232 experiment to provide the actual probability previously presented of each event. Memory
233 errors were calculated as the absolute difference between the probability previously presented
234 and the participants' recollection of that statistic:

235

236 **Memory Error** = | *Probability Presented* – *Recollection of Probability Presented* |

237

238 **Other controls.** At the end of experiment, participants also rated stimuli on 6-point scales for
 239 vividness [for the question “How vividly could you imagine this event?” (1 = *not at all vivid*
 240 to 6 = *very vividly*)], familiarity [for the question “Regardless if this event has happened to
 241 you before, how familiar do you feel it is to you from TV, friends, movies, and so on?” (1 =
 242 *not at all familiar* to 6 = *very familiar*)], prior experience [for the question “Has this event
 243 happened to you before?” (1 = *never* to 6 = *very often*)], emotional arousal [for the question
 244 “When you imagine this event, how emotionally arousing do you find the image in your
 245 mind?” (1 = *not at all arousing* to 6 = *very arousing*)] and negativity [for the question “How
 246 negative would this event be/is this event for you?” 1 = *not negative at all* to 6 = *very*
 247 *negative*].

248

249 **Statistical analysis.** Trials were partitioned according to participants’ first estimates into ones
 250 in which participants received good news [i.e., the probability presented was lower than the
 251 first estimate of their own probability (**Fig. 1a**)] or bad news [i.e., the probability presented
 252 was higher (**Fig. 1b**)]. While information can be better or worse than expected, all stimuli are
 253 negative (i.e. robbery, card fraud), thus comparison is never between positive and negative
 254 stimuli, but between information that is better or worse than expected.

255

256 Trials for which the estimation error was zero were excluded from subsequent analyses as
 257 these could not be categorized into either condition ($M = 0.89$ trials, $SD = 0.92$).

258

259 For each trial an estimation error term was calculated as the difference between the
 260 probability presented and participants’ first estimate on that trial:

261

262 **Estimation Error** = *Probability Presented* - *First Estimate*

263

264 Update was calculated for each trial such that positive updates indicate a change toward the
 265 probability presented and negative updates a change away from the probability presented:

266

267 **Update (Good News)** = *First Estimate* – *Second Estimate*

268 **Update (Bad News)** = *Second Estimate* – *First Estimate*

269

270 Formal models suggest that learning from information that disconfirms one’s expectations is
 271 mediated by a prediction error signal that quantifies a difference between expectation and
 272 outcome (Sutton and Barto, 1998). We have previously shown that an analogous mechanism

273 underpins belief updating in this task (Sharot et al., 2011). Specifically, the difference
274 between participants' initial estimations and the information provided (that is, estimation
275 error = probability presented – first estimate) predicts subsequent updates, as would be
276 expected from learning models (Sutton and Barto, 1998). Hence, similar to our previous
277 papers (Garrett et al., 2014; Moutsiana et al., 2013; Sharot et al., 2011), we estimated the
278 extent to which participants integrated new information into their beliefs by correlating
279 estimation errors and update scores with one another separately for good and bad news trials
280 for each participant. This resulted in two Pearson correlation values for each participant: one
281 for good news trials and one for bad news trials. We denote these Pearson correlation scores
282 as good news (α_G) and bad news (α_B) information integration parameters. Shapiro-Wilk tests
283 were applied to check the values of α_G and α_B were normally distributed. To check the values
284 of α_G and α_B were not at floor or ceiling, we conducted one sample t-tests (separately α_G and
285 α_B) against values of 0 (to test for floor effects) and 1 (to test for ceiling effects).

286
287 To determine whether information integration from good and/or bad news was altered by the
288 threat manipulation, the resulting information integration parameters were submitted to a 2 by
289 2 ANOVA with valence (good/bad news) as a repeated-measure and group (threat
290 manipulation/control) as a between-subjects factor.

291
292 We identified possible confounds to add as covariates to our analysis as follows; first, for
293 factors that were not task related and therefore did not have a valence component
294 (specifically: initial self-reported anxiety, initial SCL, initial cortisol and BDI) we conducted
295 independent sample t-tests (control vs threat manipulation group) for each factor separately to
296 determine if a group difference existed (**Table 1**). For task related variables that could be
297 divided by valence (specifically; number of trials, memory scores, ratings on familiarity,
298 vividness, past experience, negativity, emotional arousal and mean first estimates) we
299 calculated the difference between mean good news and mean bad news for each participant
300 for each of these factors. This gives a bias score for each factor for each subject whereby
301 positive scores indicate a bias towards good news and negative scores indicate a bias towards
302 bad news. We then conducted a one sample t-test (versus 0) on each of these scores for each
303 group separately to isolate those factors which had valence effects in either set of participants.
304 Next we conducted a series of independent sample t-tests to compare the control groups
305 difference scores to the threat manipulation groups scores for each factor (this is equivalent to
306 testing for an interaction between valence and group). For all of these tests we applied a
307 threshold of $p < 0.05$ and deliberately did not correct for multiple comparisons. This is because
308 the purpose was to identify all potential confounds; by not correcting we are being more
309 stringent. Any factor which showed a group effect or a valence effect was added as a

310 covariate. These were: mean first estimates, ratings of vividness, familiarity, past experience
311 and emotional arousal (**Table 1**).

312

313 To explore whether differences in information integration related to any of the specific
314 physiological and psychological changes, we constructed a general linear model (GLM) with
315 α entered as the dependent variable and changes in SCL, self-report anxiety and cortisol as
316 independent variables. This was done separately for information integration parameters for
317 good (α_G) and bad (α_B) news. To control for general changes in information integration and
318 allow us to detect valence-specific effects, we entered information integration parameters for
319 good news (α_G) as a covariate when estimating information integration parameters for bad
320 news (α_B) and vice versa (Moutsiana et al., 2013). In addition, following the same selection
321 procedure outlined above we controlled for any variable where there was a significant
322 ($p < 0.05$) difference between groups, between types of information (i.e. valence) or a
323 group*valence interaction, by including these in the GLM as covariates.

324

325 For α_B the formula for the regression in full therefore is as follows:

326

327 $\alpha_B = \beta_0 + \beta_1 * \text{Change in SCL} + \beta_2 * \text{Change in Self-report} + \beta_3 * \text{Change in Cortisol} +$
328 $\beta_4 * \text{Mean Initial Estimate} + \beta_5 * \text{Initial Self-report anxiety} + \beta_6 * \text{Mean Bad News Vividness}$
329 $\text{Rating} + \beta_7 * \text{Mean Bad News Familiarity Rating} + \beta_8 * \text{Mean Prior Experience Bad News}$
330 $\text{Rating} + \beta_9 * \text{Mean Emotional Arousal Bad News Rating} + \beta_{10} * \alpha_G$

331

332 For (α_G) the formula for this was as follows:

333

334 $\alpha_G = \beta_0 + \beta_1 * \text{Change in SCL} + \beta_2 * \text{Change in Self-report} + \beta_3 * \text{Change in Cortisol} +$
335 $\beta_4 * \text{Mean Initial Estimate} + \beta_5 * \text{Initial Self-report anxiety} + \beta_6 * \text{Mean Good News Vividness}$
336 $\text{Rating} + \beta_7 * \text{Mean Good News Familiarity Rating} + \beta_8 * \text{Mean Prior Experience Good News}$
337 $\text{Rating} + \beta_9 * \text{Mean Emotional Arousal Good News Rating} + \beta_{10} * \alpha_B$

338

339 Finally, we reran the analysis above this time controlling for within-subject covariates at the
340 within-subject level and between-subject factors at the between-subject level. Specifically, for
341 each participant we computed an alternative set of information integration parameters – one
342 for good news ($\alpha_{G_partial}$) and one for bad news ($\alpha_{B_partial}$) - by carrying out a series of partial
343 correlations in which absolute estimation error and update were the two variables of interest.
344 Within-subject covariates - identified as above (first estimate, vividness, familiarity, past
345 experience and emotional arousal) - were controlled for on a trial by trial basis. We examined
346 whether these alternative information integration parameters for bad news ($\alpha_{B_partial}$) related to

347 change in self report and/or change in SCL controlling for any additional between subject
 348 confounds as above (initial self-report anxiety ratings and information integration for good
 349 news). This was done by entering alternative information integration parameters for bad news
 350 ($\alpha_{B_partial}$) as the dependent variable into 2 GLMs as follows:

351

$$352 \quad \alpha_{B_partial} = \beta_0 + \beta_1 * \text{Change in Self-report} + \beta_2 * \text{Initial Self-report anxiety} + \beta_3 * \alpha_{G_partial}$$

$$353 \quad \alpha_{B_partial} = \beta_0 + \beta_1 * \text{Change in SCL} + \beta_2 * \text{Initial Self-report} + \beta_3 * \alpha_{G_partial}$$

354

355 We then examined the significance of the regression weights in each GLM for change in Self
 356 Report and change in SCL. To visualize the effect of each of these (Fig. 4) we generated two
 357 partial regression plots. These are scatterplots of the residuals of the dependent variable
 358 ($\alpha_{B_partial}$) and the independent variable (either Change in Self-report or Change in SCL) when
 359 these are regressed on the rest of the independent variables (Initial Self report and $\alpha_{G_partial}$).

360

361 We ran the equivalent analysis for good news ($\alpha_{G_partial}$) as follows:

362

$$363 \quad \alpha_{G_partial} = \beta_0 + \beta_1 * \text{Change in Self-report} + \beta_2 * \text{Initial Self-report} + \beta_3 * \alpha_{B_partial}$$

$$364 \quad \alpha_{G_partial} = \beta_0 + \beta_1 * \text{Change in SCL} + \beta_2 * \text{Initial Self-report} + \beta_3 * \alpha_{B_partial}$$

365

366 **Experimental Design and Statistical Analysis: Experiment II**

367

368 **Participants.** Thirty-three operational staff stationed across seventeen fire stations within the
 369 South Metro Fire and Rescue Authority of the State of Colorado in the United States
 370 participated in the study. Five of these participants failed to complete the study leaving 28
 371 participants (1 female, 27 males, mean age = 43.15 years, $SD = 9.87$). A link to an online
 372 version of the experiment was sent by email to operational staff inviting them to participate in
 373 the study whilst on duty. Employees were given 18 days to attempt the experiment. They
 374 were permitted to take the experiment once in this time period and were explicitly requested
 375 to do so whilst on shift (i.e. in the station between calls). Participation in the experiment was
 376 anonymous, voluntary and unpaid.

377

378 **Task, stimuli and control variables.** An online version of the task used in Experiment I was
 379 designed using Qualtrics Survey Software (Qualtrics, Provo, UT). The task began by asking
 380 basic demographic questions (age, gender, marital status, level of education and number of
 381 children) and some questions pertaining to their work (including how long they had worked in
 382 the service, how many people they supervised, number of emergency they went on, what their

383 rank in the service was) and social environment (social support at work and outside, and
384 stress experienced at home).

385

386 After providing this information, participants read task instructions on screen at their own
387 pace and then undertook a practice session comprising 3 practice trials. As in Experiment I,
388 stimuli (80 short descriptions of different negative life events; the majority of these were the
389 same as those used in Experiment I but 18 events were exchanged with alternative negative
390 life events) were separated into two lists, each containing 40 negative life events. Participants
391 were randomly assigned one of the two lists of 40 events at the start of the experiment. The
392 task was the same as in Experiment I, except that there was only one fixation cross displayed
393 in each session (for 1s) after participants submitted estimates (i.e. in the first session, unlike in
394 Experiment I, a second fixation cross was not displayed after base rate presentation).
395 Furthermore, mindful of the firefighters' unpredictable time constraints, memory for the
396 information given and subjective ratings (past experience with the event and negativity) were
397 elicited for half the stimuli and participants completed a short version of the state scale of the
398 self-report at the beginning of the study (Chlan et al., 2003), without providing physiological
399 measures of autonomic arousal.

400

401 Statistical analysis: Linear regressions were performed using ordinary least squares
402 implemented using SPSS version 25 for bad news and good news separately, with α entered
403 as the dependent variable and self-reported state anxiety as the independent variable. To rule
404 out potential confounds we followed a similar procedure as in Experiment I. Specifically, we
405 separately tested whether a range of potential confounding factors had valence effects. These
406 factors were: mean first estimates, memory scores, ratings of negativity, ratings of past
407 experience and number of trials. We did this by calculating the difference between mean good
408 news and mean bad news for each participant for each of these factors. This gives a bias score
409 for each factor for each subject whereby positive scores indicate a bias towards good news
410 and negative scores indicate a bias towards bad news. We then conducted a one sample t-test
411 (versus 0) on each of these scores to identify factors which had valence effects. We used a
412 threshold of $p < 0.05$ and deliberately did not correct for multiple comparisons. This is because
413 the purpose was to identify all potential confounds; by not correcting we are being more
414 stringent. Any factor which showed a valence effect was then added as a covariate. These
415 were mean first estimates, ratings of past experience and number of trials (**Table 3**).

416

417 To test for a relationship between anxiety and the asymmetry within the firefighters (i.e.
418 preferential updating for bad news over good) we calculated an information integration bias
419 score for each participant. This is simply the difference between α_G and α_B . A score of 0

420 indicates no bias in information integration in either direction whilst positive scores indicate
 421 greater information integration for good news relative to bad news and negative scores the
 422 opposite. We then examined whether the information integration bias related to self-reported
 423 anxiety as follows:

424
 425 Information Integration Bias Score ($\alpha_G - \alpha_B$) = $\beta_0 + \beta_1 * \text{Self-Reported Anxiety} + \beta_2 * \text{Mean}$
 426 $\text{Initial Estimate} + \beta_3 * \text{Mean Prior Experience Bias Score (Mean Prior Experience Bad News}$
 427 $\text{Rating} - \text{Mean Prior Experience Good News Rating}) + \beta_4 * \text{Number of Trials Bias Score}$
 428 $(\text{Number of Good News Trials} - \text{Number of Bad News Trials})$

429
 430 Next we ran a GLM for each of the two sets of information integration parameters (α_G and α_B)
 431 separately. To ensure effects were valence specific rather than reflecting general changes in
 432 information integration, good news (α_G) was also added as a covariate when examining
 433 information integration parameters for bad news (α_B) and vice versa when examining
 434 information integration for good news.

435
 436 For bad news information integration parameter (α_B), the formula for the regression in full
 437 therefore is as follows:

438
 439 $\alpha_B = \beta_0 + \beta_1 * \text{Self-Reported Anxiety} + \beta_2 * \text{Mean Initial Estimate} + \beta_3 * \text{Mean Prior}$
 440 $\text{Experience Bad News Rating} + \beta_4 * \text{Number of Bad News Trials} + \beta_5 * \alpha_G$

441
 442 For good news information integration parameter (α_G), the formula for the regression in full
 443 therefore is as follows:

444
 445 $\alpha_G = \beta_0 + \beta_1 * \text{Self-Reported Anxiety} + \beta_2 * \text{Mean Initial Estimate} + \beta_3 * \text{Mean Prior}$
 446 $\text{Experience Good News Rating} + \beta_4 * \text{Number of Good News Trials} + \beta_5 * \alpha_B$

447
 448 Finally, we reran the analysis above this time controlling for within-subject covariates at the
 449 within-subject level and between-subject factors at the between-subject level. Specifically, for
 450 each participant we computed an alternative set of information integration parameters – one
 451 for good news ($\alpha_{G_partial}$) and one for bad news ($\alpha_{B_partial}$) - by carrying out a series of partial
 452 correlations in which absolute estimation error and update were the two variables of interest.
 453 Within-subject covariates (first estimates), were controlled for on a trial by trial basis (note it
 454 was not possible to control for past experience on a trial by trial basis here because
 455 participants in this study completed ratings only for a subset of events). We then examined
 456 whether these alternative information integration parameters for bad news ($\alpha_{B_partial}$) related to
 457 self-reported anxiety, controlling for additional between subject covariates (number of bad

458 news trials and information integration for good news) at the between subject level. This was
459 done by entering alternative information integration parameters for bad news ($\alpha_{B_partial}$) as the
460 dependent variable into a GLM as follows:

461

$$462 \alpha_{B_partial} = \beta_0 + \beta_1 * \text{Self-Reported Anxiety} + \beta_2 * \text{Number of Bad News Trials} + \beta_3 * \alpha_{G_partial}$$

463

464 We then examined the significance of the regression weight for Self-Reported Anxiety.

465

466 We ran the same analysis for information integration parameters for good news ($\alpha_{G_partial}$) as
467 follows:

468

$$469 \alpha_{G_partial} = \beta_0 + \beta_1 * \text{Self-Reported Anxiety} + \beta_2 * \text{Number of Good News Trials} + \beta_3 * \alpha_{B_partial}$$

470

471 To visualize the effect of each of these (Fig. 5) we generated two partial regression plots.
472 These are scatterplots of the residuals of the dependent variable ($\alpha_{B_partial}$ or $\alpha_{G_partial}$) and the
473 independent variable of interest (Self-Reported Anxiety) when these are regressed on the rest
474 of the independent variables (Number of Bad News Trials and $\alpha_{G_partial}$ when examining
475 $\alpha_{B_partial}$, Number of Good News Trials and $\alpha_{B_partial}$ when examining $\alpha_{G_partial}$).

476

477 **Results**

478

479 **Experiment I**

480 **Threat manipulation was successful.** Subjective self-reports of anxiety and physiological
481 measures of skin conductance level (SCL) and cortisol showed that the manipulation was
482 effective. Specifically, following the manipulation, self-report anxiety (**Fig. 2a**) and SCL
483 (**Fig. 2b**) showed an increase relative to before (baseline), which was greater in the threat
484 manipulation group relative to controls (self-reported anxiety: $t(33) = 4.16, p < .001$; SCL:
485 $t(33) = 3.32, p = .002$, independent sample t-test). There were no baseline (t_0) differences in
486 cortisol levels between the two groups ($t(25) = -.89, p = 0.38$). Mean cortisol levels (averaged
487 across t_1, t_2 and t_3) relative to baseline (t_0) showed a trend towards being higher in the threat
488 manipulation group relative to controls ($t(25) = 1.90, p = .07$). This effect was driven by a
489 reduction in cortisol levels over time in the control group (main effect of time at t_1, t_2 and t_3
490 relative to baseline: $F(2,26) = 17.19, p < .001$, repeated measures ANOVA) - an effect
491 previously observed when participants become familiar with a novel experiment context
492 (Stones et al., 1999) - but an absence of this common reduction in the threat manipulation
493 group (main effect of time: $F(2,22) = 1.00, p > .25$; **Fig. 2c**). Across participants, these
494 measures were correlated with each other (self-report & SCL: $r(33) = .39, p = .02$; SCL &

495 cortisol: $r(25) = .47, p = .01$; trend for cortisol & self-report: $r(25) = .33, p = .09$). To control
496 for the diurnal cycle of cortisol, each participant undertook the experiment between 2pm and
497 4pm.

498

499 **Threat eliminates asymmetric information integration.** Our results show that the acute
500 threat manipulation eliminated the well-established asymmetry in information integration
501 (Garrett et al., 2014; Moutsiana et al., 2013; Sharot et al., 2011). Specifically, the two sets of
502 information integration parameters (α_G, α_B) were entered into a group (control/threat) by
503 valence (good news/bad news) ANOVA controlling for possible confounds (see **Methods**).
504 The analysis revealed a group by valence interaction ($F(1,27) = 7.56, p = .01, \eta_p^2 = .22$),
505 which also remained if estimation errors were controlled for ($F(1,26) = 7.88, p = .01$) (Garrett
506 and Sharot, 2017) and if the difference between number of good and bad news trials are
507 controlled for ($F(1,26) = 6.97, p = .01$).

508

509 Post hoc tests revealed that the group by valence interaction was the result of asymmetric
510 information integration in the control group, such that the information integration parameter
511 was larger for good news than bad ($t(15) = 3.34, p = .004$, paired sample t-test), but absent in
512 the threat manipulation group ($t(18) = .92, p > .25$, paired sample t-test; **Fig. 3**). Participants
513 in the threat manipulation group were more likely to effectively integrate bad news into their
514 beliefs relative to those in the control group (significant difference in bad news information
515 integration parameters α_B : $t(33) = 2.44, p = .02$, independent sample t-test), whilst
516 information integration parameters for good news (α_G) did not differ between groups ($t(33) =$
517 $.611, p > .250$, independent sample t-test). There were no floor or ceiling effects for α_G and α_B
518 in the threat manipulation or control group (all at $p < .001$, one sample t-tests versus 0 and 1
519 respectively) and participants first estimates were not significantly different from the
520 information provided ($t(34) = -0.45, p = .65$, one sample t-test versus 0 on the difference
521 between participants' first estimates and the information provided).

522

523 Past studies show that asymmetric information integration in this task is not associated with
524 an asymmetry in memory (Moutsiana et al., 2013; Sharot et al., 2011, 2012a, 2012b). In fact,
525 asymmetry in information integration is observed even when the second estimate is elicited
526 immediately after information is on screen (Kuzmanovic et al., 2015, 2016; Kuzmanovic and
527 Rigoux, 2017). Here, we submitted memory scores to a group (threat manipulation/control)
528 by valence (good news/bad news) ANOVA (see **Methods** for details). This did not reveal a
529 main effect of valence ($F(1,33) = 1.24, p > .25$), or a main effect of group ($F(1,33) = 1.03, p >$
530 $.25$) or an interaction ($F(1,33) = .62, p > .25$). This suggests that valence dependent changes

531 in information integration across groups cannot be attributed to memory or
532 encoding/attention.

533

534 Conducting an ANOVA on participants' first estimates with valence (good/bad news) as a
535 repeated factor and group (threat/control) as a between participant factor revealed no main
536 effect of group ($F(1,33) = 1.18, p > .25$), the obvious main effect of valence (as trials are
537 binned into good and bad according to first estimates, $F(1,33) = 278.08, p < .001$) and a group
538 by valence interaction ($F(1,33) = 6.71, p = .014$). The interaction was characterized by the
539 threat group providing lower first estimates than controls for stimuli which will subsequently
540 be categorized as good news ($t(33) = -2.30, p = .028$) but no significant difference for trials
541 that will be subsequently categorized as bad news ($t(33) = 1.59, p = .123$). Controlling for the
542 difference between first estimates on good and bad news trials in the main ANOVA looking
543 at information integration parameters did not alter the results ($F(1,26) = 5.43, p = .028$).

544

545 **What therefore could account for the selective fluctuations in information integration of**

546 **bad news?** To examine which of the changes to the psychological and physiological
547 measures (SCL, cortisol level, self-report) could *independently* explain alterations in
548 information integration of bad news, we ran a General Linear Model (GLM) in which
549 information integration parameters for bad news (α_B) were entered as the dependent variable
550 and changes in self report, SCL, and cortisol as independent variables (all entered together in
551 one regression). To ensure that effects were valence-specific and could not be accounted for
552 by general changes to information integration, information integration parameters for good
553 news (α_G) were added as a covariate as done before (Moutsiana et al., 2013) [note that the
554 same pattern of results pertains if we omit this covariate (self-reported anxiety: $F(1,17) =$
555 $4.75, p = 0.04$, SCL: $F(1,17) = 8.81, p = .009$)]. We also controlled for all other possible
556 confounds (see **Methods**). The analysis revealed that changes in self-reported anxiety
557 ($F(1,16) = 6.90, p = .02, b_i = .03, \eta_p^2 = .030$) and change in physiological stress indicated by
558 SCL ($F(1,16) = 4.99, p = .04, b_i = .05, \eta_p^2 = .24$) explained the variance in information
559 integration parameters for bad news, each of which remained significant if estimation errors
560 were also controlled for (self-reported stress: $F(1,15) = 4.61, p = .048$, SCL: $F(1,15) = 4.67, p$
561 $= .047$) (Garrett and Sharot, 2017). In other words, participants who showed the greatest
562 increase in SCL (which reflects the sympathetic component of the autonomic nervous system
563 stress response (Bechara et al., 1996; Figner and Murphy, 2011) and self-reported anxiety
564 were most likely to change their beliefs in proportion to the difference between their first
565 estimates and the bad news received. Change in cortisol (which is suggested to reflect the
566 hypothalamic-pituitary-adrenal (HPA) axis (Gunnar and Quevedo, 2007) component of the
567 stress response) did not relate to information integration for bad news ($F(1,16) = .46, p > .25$,

568 $b_i = -.04, \eta_p^2 = .03$). The null result for cortisol may indicate either that the increase in bad
569 news information integration is not associated specifically with cortisol level increase, or a
570 Type II error. Ratings of emotional arousal, familiarity and information integration
571 parameters for good news (α_G) were also significant predictors in the regression (see **Table 2**
572 for parameter estimates of covariates).

573

574 For completeness we repeated the analysis on information integration parameters for good
575 news, α_G (including information integration parameters for bad news, α_B , and all possible
576 covariates mentioned above) and found no significant effects (change in self report: $F(1,16) =$
577 $.47, p > .25, b_i = -.01$; change in SCL: $F(1,16) = .61, p > .25, b_i = .03$; change in cortisol:
578 $F(1,16) = .72, p > .25, b_i = .07$).

579

580 Finally, we examined whether the same results are observed when controlling for within-
581 subject covariates at the within-subject level and between-subject factors at the between-
582 subject level. Specifically, for each participant we computed an alternative set of information
583 integration parameters by correlating absolute estimation error and update controlling for the
584 same within-subject covariates as above (first estimate, vividness, familiarity, past experience
585 and emotional arousal) but controlling for them on a trial by trial basis. We then examined
586 whether these alternative information integration parameters for bad news related to changes
587 in self-reported anxiety and/or changes in SCL (additional between subject factors - initial
588 self-report and the alternative information integration parameters for good news - were also
589 entered as control variables). Indeed, both effects were significant using this approach
590 (change in self report: $F(1,31) = 10.57, p = .003, b_i = .05$; change in SCL: $F(1,31) = 4.51, p =$
591 $.04, b_i = .08$, **Fig. 4a, b**), while the equivalent analysis on information integration parameters
592 from good news was not (change in self report: $F(1,31) = .001, p > .25, b_i = -.001$; change
593 in SCL: $F(1,31) = .55, p > .25, b_i = .036$).

594

595 The results of Experiment I suggested that inducing threat abolishes valence dependent
596 asymmetry in information integration. Thus, the previously observed bias in information
597 integration (Garrett et al., 2014; Korn et al., 2013; Kuzmanovic et al., 2015; Moutsiana et al.,
598 2013, 2015; Sharot et al., 2011, 2012a, 2012b) is not constant but changes with perceived
599 threat in the environment.

600

601 **Experiment II**

602 Next we set out to extend our findings from Experiment I in a natural setting. Here, we did
603 not fashion a perceived threat, but instead measured anxiety in an environment in which
604 perceived threats would be naturally volatile. Specifically, firefighters from the state of

605 Colorado performed the belief update task whilst on duty at their respective fire stations. We
606 targeted this group of participants because they would have a naturally large range of anxiety
607 levels owing to the volatile nature of their profession. Changes in cortisol levels were not
608 found to be a significant predictor of information integration parameters for bad news in
609 Experiment I. Therefore, we ruled out collecting this as a measure in Experiment II. Whilst
610 changes in self-reported anxiety and changes in SCR were both found to be significant
611 predictors in Experiment I, these two measures were correlated with one another ($r(33) = .39$,
612 $p = .02$). Since self-reported anxiety had the larger effect size and was easier to collect, we
613 opted to make this our main measure.

614

615 Self-reported anxiety was significantly correlated ($r(26) = -.51$, $p < .01$) with the bias in
616 information integration (that is α_G minus α_B). In particular, heightened anxiety was associated
617 with a reduction in the bias. This result remained significant when controlling for possible
618 confounds (see **Methods**), $F(1,23) = 6.67$, $p = .02$, $\eta_p^2 = .23$, $b_i = -.05$.

619

620 To examine whether the relationship between heightened anxiety and reduced bias was the
621 result of increased sensitivity to bad news, reduced sensitivity to good news, or both we first
622 constructed a GLM in which information integration parameters for bad news (α_B) was
623 regressed on self-reported anxiety, controlling for possible confounds (mean first estimates,
624 mean ratings of prior experience and number of bad news trials, see **Methods** for details). In
625 addition, to ensure effects were valence-specific and could not be accounted for by general
626 changes in information integration, information integration parameters for good news (α_G)
627 were also added as a covariate (note however that the self-reported anxiety effect pertains if
628 we omit this covariate: $F(1,23) = 9.77$, $p = .005$). This analysis revealed that self-reported
629 anxiety significantly explained the variance in information integration parameters for bad
630 news, α_B ($F(1,22) = 10.52$, $p = .004$, $\eta_p^2 = .32$, $b_i = .05$; **Table 4**), an effect which remained
631 significant if estimation errors are also controlled for ($F(1,21) = 9.79$, $p = .005$) (Garrett and
632 Sharot, 2017). The higher the acute anxiety reported by a firefighter, the more likely the
633 firefighter was to integrate bad news into beliefs in proportion to the difference between their
634 first estimations and the information provided. In this model, information integration from
635 good news ($F(1,22) = 4.69$, $p = .04$) was also a significant predictor of information integration
636 from bad news. There were no floor or ceiling effects for α_G or α_B (all at $p < .001$, one sample
637 t-tests against values of 0 and 1).

638

639 We then conducted the same analysis on information integration parameters for good news
640 (α_G) with information integration parameters for bad news (α_B), mean first estimates, mean
641 ratings of prior experience and number of good news trials as covariates. This revealed a non-

642 significant trend in the opposite direction than for information integration parameters for bad
643 news, α_B ($F(1,22) = 3.86, p = .06, \eta_p^2 = .15, b_i = -.05$), such that greater self-reported anxiety
644 was related to a trend for *less* information integration in response to good news. Information
645 integration parameters for bad news (α_B) was also significant ($F(1,22) = 7.44, p = 0.01, \eta_p^2 =$
646 $.25, b_i = 0.75$).

647

648 Finally, we examined whether the same results are observed when controlling for within-
649 subject covariates at the within-subject level and between-subject factors at the between-
650 subject level. Under this alternative approach higher self-reported anxiety was related to
651 greater information integration in response to bad news ($F(1,24) = 8.34, p = .008, b_i = .03,$
652 **Fig. 5a**). For good news the opposite effect was found such that higher self-reported anxiety
653 was related to reduced information integration ($F(1,24) = 4.80, p = .038, b_i = -.045, \mathbf{Fig. 5b}$).
654 It is interesting that this latter effect was observed only in Experiment 2 and not Experiment
655 1, which may indicate that natural real-life threats could have an especially strong impact on
656 information integration processes.

657

658 These results suggest that anxiety is related to a valence-dependent enhancement in the ability
659 to adjust beliefs in response to new information. We highlight that whilst in Experiment I,
660 threat was manipulated and thus causation could be inferred by comparing the threat
661 manipulation and control groups, Experiment II was conducted to reveal an *association* in
662 “real life”. Together, the experiments suggest that under a perceived threat (whether
663 manipulated or naturally occurring) positively biased integration of information is not
664 observed.

665

666 **Discussion**

667 Our results provide evidence that the well-documented asymmetry in belief formation
668 evaporates under perceived threat. Specifically, Experiment I shows that in a low threat
669 environment individuals integrated information asymmetrically, faithfully incorporating good
670 news into their existing beliefs while relatively disregarding bad news (Eil and Rao, 2011;
671 Sharot et al., 2011). Under perceived threat however, this asymmetry disappeared;
672 participants showed an increased capacity to integrate bad news into prior beliefs. Increased
673 physiological arousal and self-reported anxiety were found to correlate with enhanced
674 integration of unfavorable information into beliefs. In Experiment II, firefighters on duty who
675 reported higher state anxiety also exhibited greater selective integration of bad news. Because
676 the increase in information integration in both experiments was valence specific it cannot
677 reflect a general improvement in learning, and because memory for the information presented
678 was not affected, modulation of attention is an unlikely explanation.

679

680 The finding that the positivity bias in belief updating alters flexibly as a function of perceived
681 threat reveals a potentially adaptive mechanism. In particular, the relative failure to
682 incorporate bad news into prior beliefs leads to positively biased beliefs (also known as the
683 optimism bias). This bias can lead to both positive effects – including increased exploration
684 (Berger-Tal and Avgar, 2012) and motivation (Bandura, 1989) - and negative effects –
685 including failure to take precautionary action. It has been suggested that overestimating the
686 likelihood of attaining rewards and underestimating the likelihood of harm is adaptive in
687 environments where potential gains are sufficiently greater than costs (Johnson and Fowler,
688 2011). This is because under uncertainty, optimistically biased individuals will claim
689 resources (e.g., a spouse or a job) they could not otherwise attain, as better but less optimistic
690 competitors may walk away from the fight. Moreover, overestimating the value of novel
691 environments can lead to increased rate of exploration allowing the opportunity for the true
692 value of an environment to be learned quicker (Berger-Tal and Avgar, 2012; Sutton and
693 Barto, 1998), which is associated with superior performance in behaviours such as
694 reproduction (Egas and Sabelis, 2001) and foraging (Rutz et al., 2006). However, in
695 environments where potential harm is considerably greater than potential reward,
696 computational models suggest the optimism bias to be disadvantageous (Johnson and Fowler,
697 2011). Thus, a valence dependent bias in information integration that disappears under threat
698 could be optimal in enabling a more accurate assessment of risk.

699

700 In our experiments, the source of the threat was unrelated to the information content of the
701 task. Thus, acute stress had a valence-specific, yet general, effect on how participants used
702 information to alter their beliefs (i.e. in response to a social threat, participants did not
703 selectively increase their response to information about social judgment, but to negative
704 information in general). Indeed, many threat induction methods, including threat of electric
705 shock, Cold Pressor Tasks and the Trier Social Stress Test, produce general changes to
706 behavior and neural responses that are not confined to the source of the threat itself
707 (Cavanagh et al., 2010; Lenow et al., 2017; Otto et al., 2013; Robinson et al., 2013; Youssef
708 et al., 2012). Similar findings have been observed in non-human animals, where different
709 stressors have been shown to alter the degree of positive biases in a range of decision-making
710 tasks (Harding et al., 2004; Matheson et al., 2008; Rygula et al., 2013). This may be adaptive,
711 as threat may signify a dangerous environment that requires a general enhancement of
712 caution.

713

714 However, if perceived threat is prolonged or dissociated from reality, enhanced integration of
715 negative information over long periods of time could lead to psychiatric problems. We have

716 previously shown that patients suffering from Major Depressive Disorder (MDD) exhibit
717 increased updating of beliefs in response to negative information relative to healthy controls
718 (Garrett et al., 2014). MDD is often triggered by a stressful life event (Caspi et al., 2003;
719 Roiser et al., 2012). In individuals predisposed to MDD such a stressful life event (or series of
720 such events) could result in prolonged periods of perceived threat and thus increased
721 sensitivity to negative information. This in turn can form pessimistic beliefs, a symptom of
722 MDD (American Psychiatric Association, 2013; Strunk et al., 2006), leading to even greater
723 perceived threat about one's environment. It is possible that a similar mechanism may
724 contribute to symptoms observed in other clinical pathologies such as in clinical anxiety and
725 phobia.

726

727 We speculate that stress in response to perceived threat may interfere with top down control
728 mechanisms that may normally inhibit integration of unwanted information (for review see
729 Yu, 2016). A second, not mutually exclusive, possibility is that the stress reaction directly
730 boosts the neural representation of estimation errors generated from bad, but not good, news.
731 Indeed, it has been shown that negative prediction errors in dopamine rich striatal nuclei are
732 selectively amplified under threat (Robinson et al., 2013) - a modulation that could be
733 mediated by stress-induced changes to dopamine release (Frank et al., 2004; Lemos et al.,
734 2012; Schultz et al., 1997; Sharot et al., 2012a). Future studies are required to test these
735 hypotheses.

736

737 In sum, our results provide evidence that asymmetric information integration is not set in
738 stone, but changes acutely in response to the environment, decreasing under perceived threat.
739 Such flexibility could be adaptive, potentially enhancing our likelihood to respond to
740 warnings with caution in environments where future costs may be high, but enabling us to
741 maintain positive beliefs otherwise, a strategy that has been suggested, on balance, to increase
742 well-being (McKay and Dennett, 2010).

743

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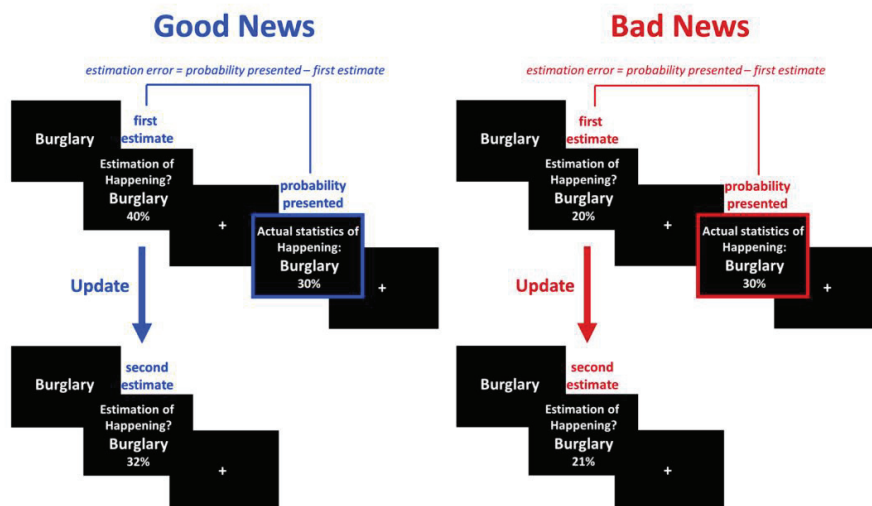
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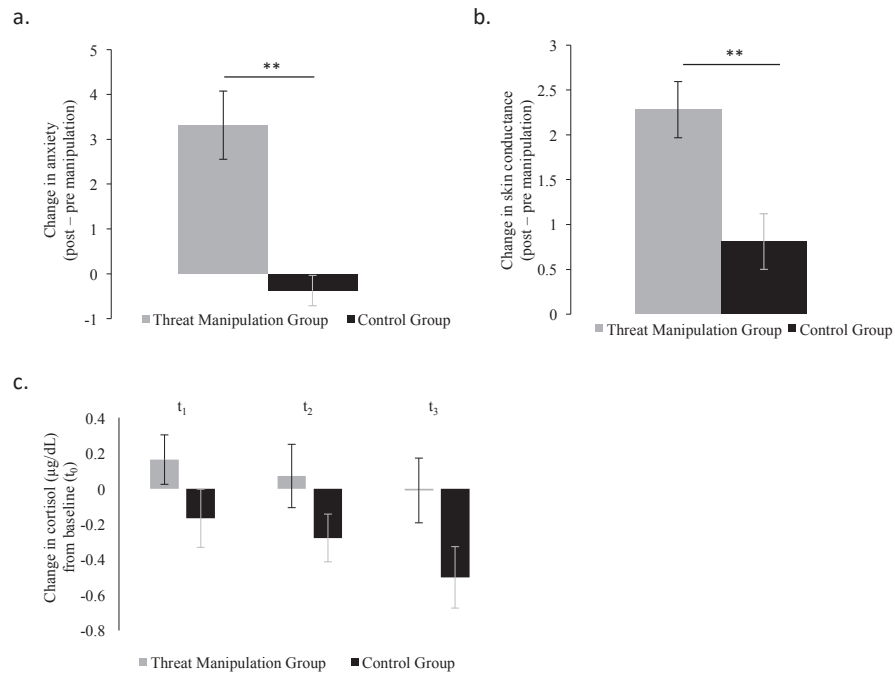


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870 **Figure 1. Behavioral Task.**

871 On each trial, participants were presented with a short description of an adverse event and
 872 asked to estimate how likely this event was to occur to them in the future. They were then
 873 presented with the probability of that event occurring to someone from the same age, location
 874 and socio-economic background as them. The second session was the same as the first except
 875 that the average probability of the event to occur was not presented. Examples of trials for
 876 which the participant's estimate was (a) higher or (b) lower than the statistical information
 877 provided leading to receipt of good and bad news respectively.

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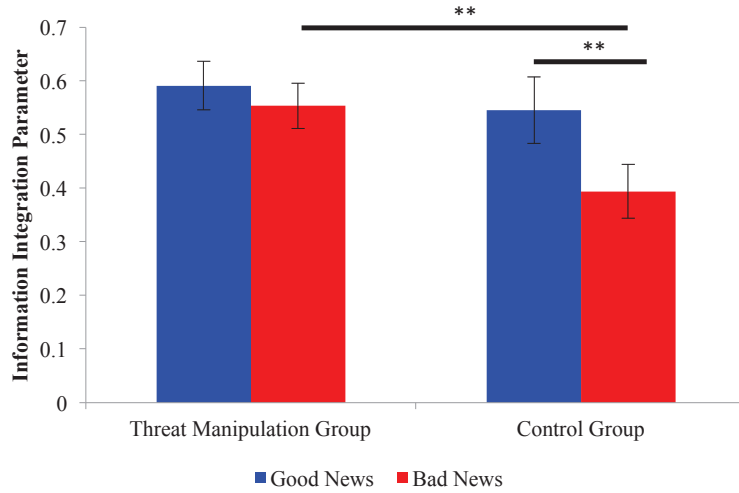
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880 **Figure 2. Manipulation Check.**

881 Measures of (a) self-reported state anxiety, (b) skin conductance and (c) cortisol levels were
 882 greater after manipulation relative to before in the threat manipulation group compared to the
 883 control group. Time points for cortisol measurements are as follows: t₀ = before threat/control
 884 manipulation procedure; t₁ = immediately after threat/control manipulation procedure, prior
 885 to undertaking the task (+10 min from t₀); t₂ = halfway through the task (+30min from t₀); t₃
 886 = after completion of task and post experiment questionnaires (+1hr from t₀).

887 ** $p < .050$; Error bars represent standard error of the mean.

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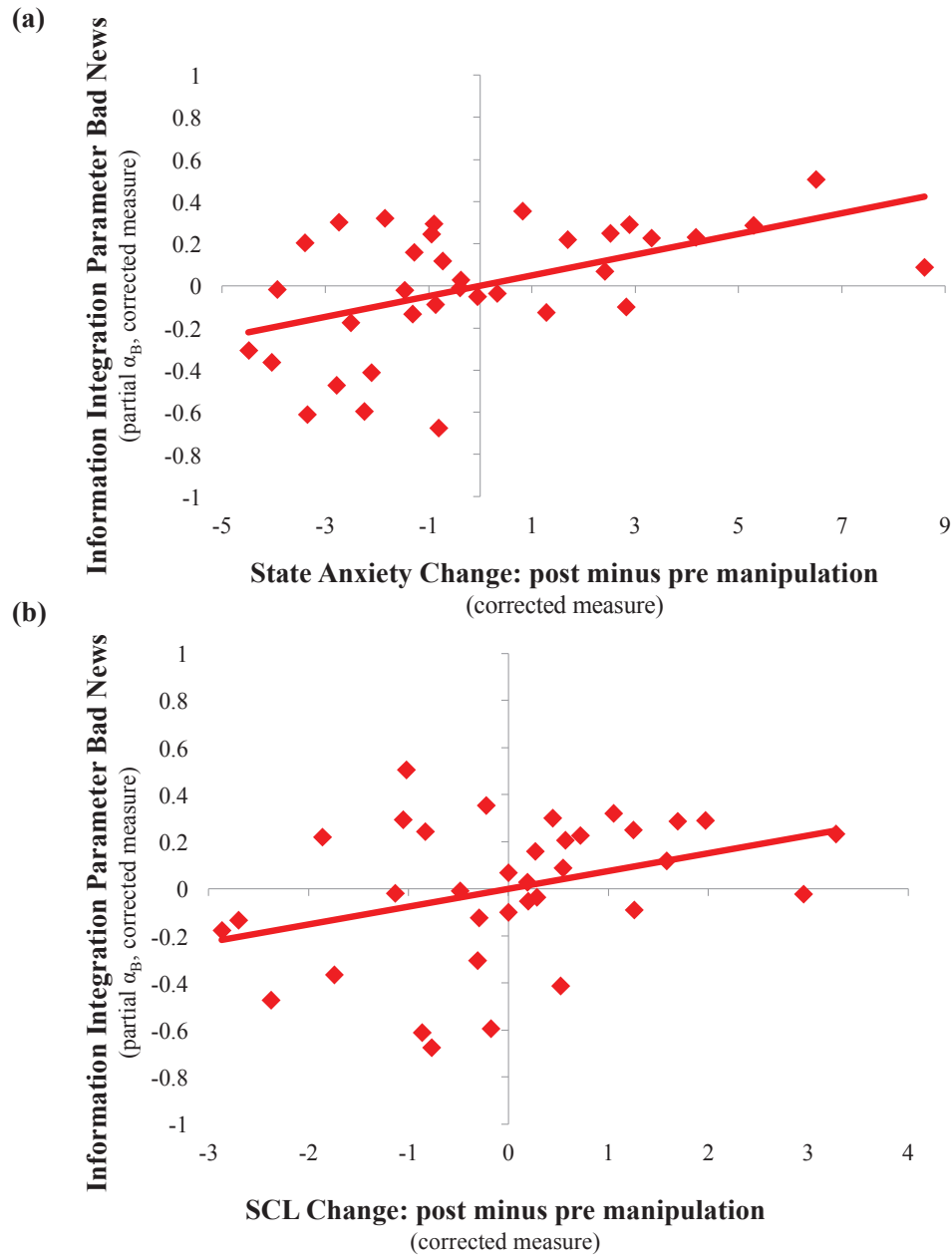


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890 **Figure 3. Bias in Information Integration Parameters Vanishes under Threat**
 891 **manipulation.**

892 While the control group showed asymmetrical information integration parameters (α) in
 893 response to good and bad news, this bias vanished in the threat manipulation group, due to an
 894 increase in α_B (information integration parameter for bad news). The Group*Valence
 895 interaction was significant, controlling for all covariates identified in Table 1 (see Methods).
 896 ** $p < .05$ independent/paired sample t test as appropriate; Error bars represent standard error
 897 of the mean.

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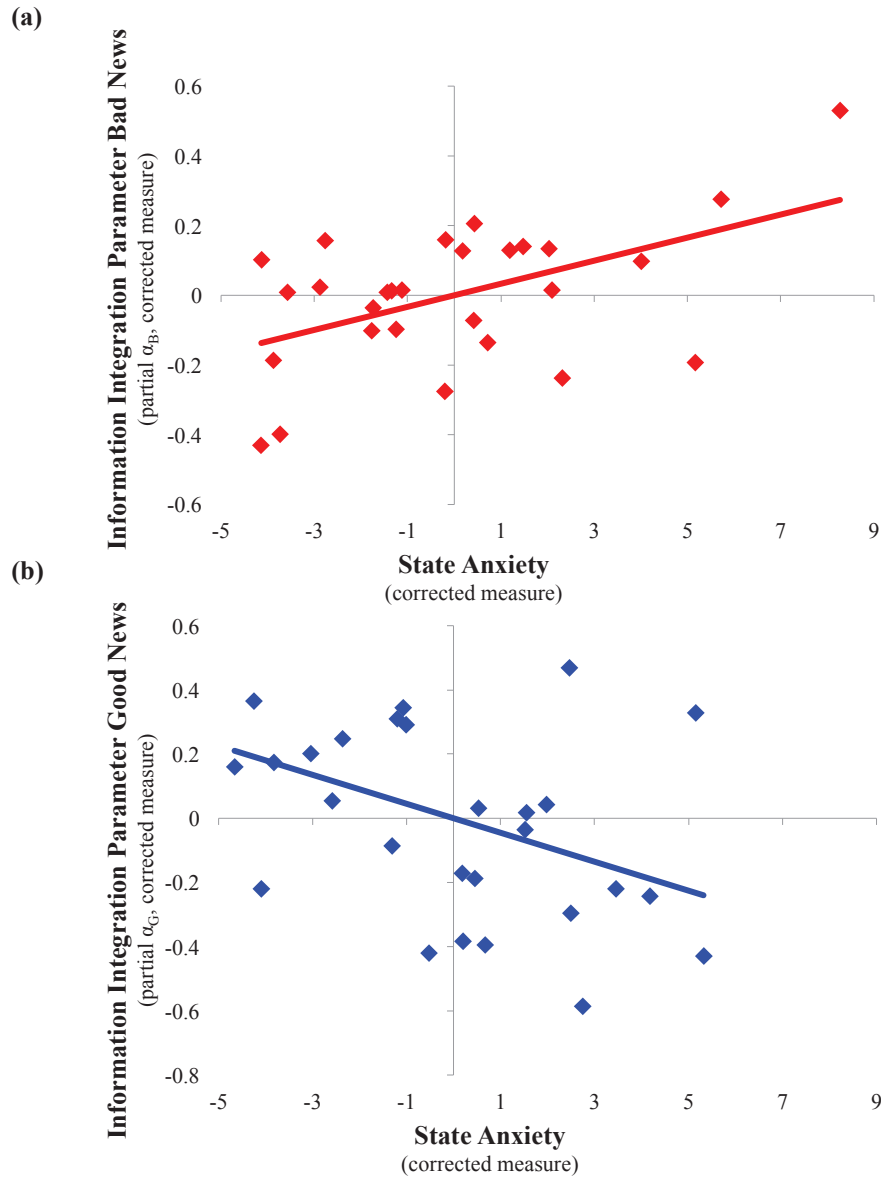


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900 **Figure 4. Greater integration of bad news related to state anxiety and SCL.**

901 Following the manipulation, an increase in both **a.** self-reported anxiety ($b_i = .049, p = .003,$
 902 $\eta_p^2 = .25$) and **b.** skin conductance (SCL) ($b_i = .076, p = .042, \eta_p^2 = .13$) were related to larger
 903 information integration from bad news, correcting for possible confounds. Plotted are the
 904 partial regression plots from two linear models (one for self-report and one for SCL) that
 905 control for additional covariates.

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Figure 5. State anxiety in firefighters differentially relate to integration of good and bad news. Subjective state anxiety scores (STAI) of firefighters on shift were related to larger information integration from bad news ($b_i = .03, p = .008, \eta_p^2 = .26$) and lower information integration from good news ($b_i = -0.045, p = .038, \eta_p^2 = .17$), correcting for possible confounds. Plotted are the partial regression plots for **a.** bad news (partial α_B) and **b.** good news (partial α_G) from 2 separate linear models (one for bad news and one for good news) that control for additional covariates.

	Threat Manipulation Group mean (SD)	Control Group mean (SD)
BDI and Baseline Stress Levels		
BDI	5.79 (5.23)	4.69 (3.22)
Initial Self Report STAI ^G	10.37 (2.65)	8.63 (1.36)
Initial SCL	6.27 (3.29)	5.90 (3.20)
Initial Cortisol (log transformed)	-1.99 (0.59)	-1.79 (0.53)
Task Variables		
First Estimates	29.82 (5.62) ^V	31.05 (5.89) ^V
Subjective Scales Questionnaire		
<i>1 = low to 6 = high</i>	Bias <i>(Good News – Bad News)</i>	
Vividness	0.41 (0.72) ^V	0.72 (0.65) ^V
Familiarity	0.30 (0.69)	0.49 (0.62) ^V
Prior experience	0.18 (0.61)	0.33 (0.41) ^V
Emotional arousal	0.33 (0.63) ^V	0.13 (0.86)
Negativity	0.20 (0.49)	-0.13 (0.58)
Other Task-related variables		
Number of Trials	-1.58 (8.99)	-1.56 (9.70)
Memory errors	-1.23 (3.16)	-0.21 (4.52)
Estimation errors (absolute)	-0.82 (5.27)	1.11 (5.84)
Update	2.60 (12.67)	4.21 (7.83) ^V

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918 **Table 1. BDI, Initial Self-Report STAI, Initial SCL, Initial Cortisol, Task-related**
 919 **variables, subjective scales, memory in Experiment I.** Note that Estimation errors and
 920 Update (the final two rows) are the variables used to compute the information integration
 921 parameters (α_G and α_B) for each participant.

922 ^G Difference between Threat Manipulation and Control Groups, tested using independent
 923 sample t-tests ($p < 0.05$).

924 ^V Significant effect of valence ($p < 0.05$), tested using one sample t-test on the bias scores
 925 (difference between good and bad news) on each group separately.

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	b_i	<i>Std. Error</i>	t	p	<i>95% Confidence Interval</i>		η_p^2
					<i>Lower Bound</i>	<i>Upper Bound</i>	
Initial Self Report STAI	-0.01	0.01	-1.10	0.29	-0.04	0.01	0.07
First estimates	0.01	0.01	0.89	0.39	-0.01	0.02	0.05
Vividness rating	-0.09	0.05	-1.84	0.09	-0.20	0.01	0.17
Familiarity rating	0.08	0.04	2.16	0.05	0.00	0.16	0.23
Prior experience rating	-0.04	0.06	-0.76	0.46	-0.17	0.08	0.04
Emotional arousal rating	-0.13	0.04	-3.03	0.01	-0.22	-0.04	0.37
Information integration parameter, good news (α_G)	0.39	0.15	2.60	0.02	0.07	0.71	0.30

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Table 2. Parameter estimates of covariates in Experiment I.

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First estimates (i.e. mean initial estimations), mean ratings on subjective scales (vividness,

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familiarity, past experience and emotional arousal) and α_G (information integration

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parameters for good news) were entered as covariates to account for fluctuations in α_B

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(information integration parameters for bad news).

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	Mean (SD)
BDI	6.82 (7.45)
Task Variables	
First Estimates ^V	31.22 (6.96)
Subjective Scales Questionnaire	
<i>1 = low to 6 = high</i>	
Bias <i>(Good News – Bad News)</i>	
Prior experience ^V	0.54 (0.94)
Negativity	0.31 (0.90)
Other Task-related variables	
Number of Trials ^V	-10.89 (9.41)
Memory errors	-2.18 (6.51)
Estimation errors (absolute) ^V	-2.91 (5.16)
Update ^V	9.49 (12.04)

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943 **Table 3. Task-related variables, subjective scales and memory in Experiment II.** Note
 944 that Estimation errors and Update (the final two rows) are the variables used to compute the
 945 information integration parameters (α_G and α_B) for each participant.

946 ^V Significant effect of valence ($p < 0.05$), tested using one sample t-test on the mean bias
 947 scores (difference between good and bad news) for each participant.

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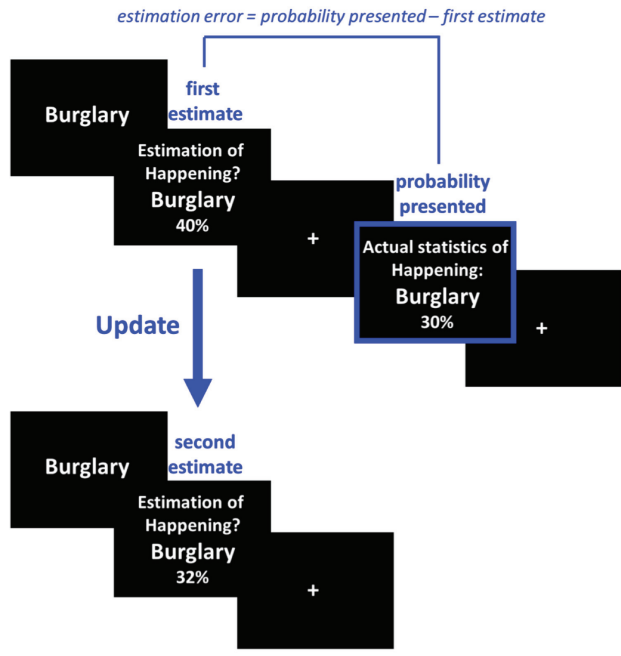
	b_i	Std. Error	t	p	95% Confidence Interval		η_p^2
					Lower Bound	Upper Bound	
First estimates	0.00	0.01	-0.03	0.97	-0.02	0.02	0.00
Prior experience rating	-0.03	0.09	-0.31	0.76	-0.21	0.15	0.00
Number of bad news trials	0.00	0.02	-0.01	0.99	-0.03	0.03	0.00
Information integration parameter, good news (α_G)	0.34	0.16	2.17	0.04	0.02	0.67	0.18

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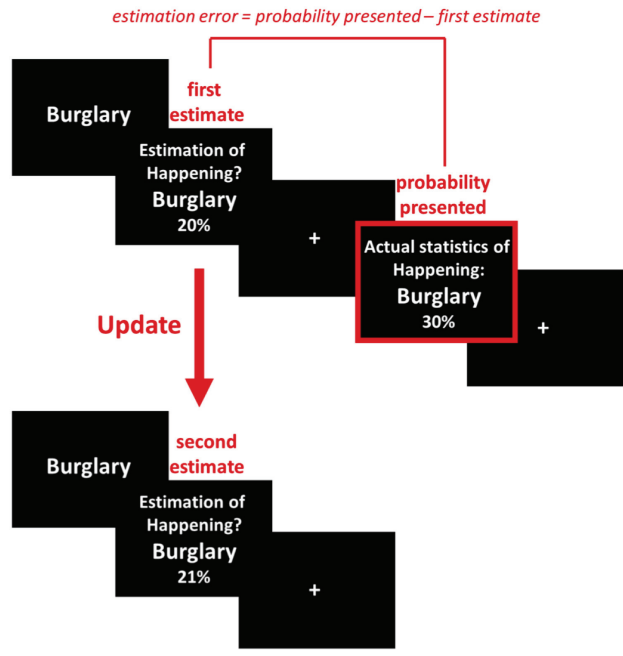
950 **Table 4. Parameter estimates of covariates in Experiment II.**

951 First estimates (i.e. mean initial estimations), mean ratings of past experience, number of bad
 952 news trials and α_G (information integration parameters for good news) were entered as
 953 covariates to account for fluctuations in α_B (information integration parameters for bad news).

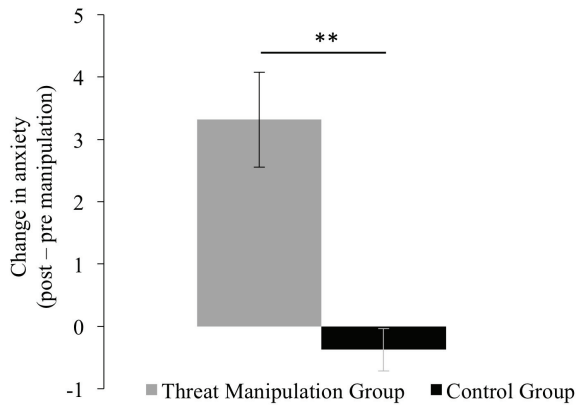
Good News



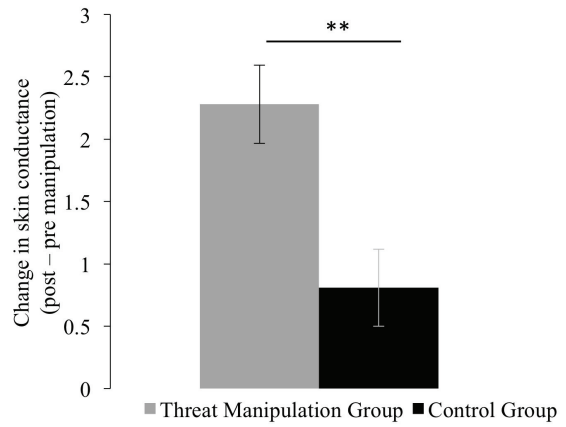
Bad News



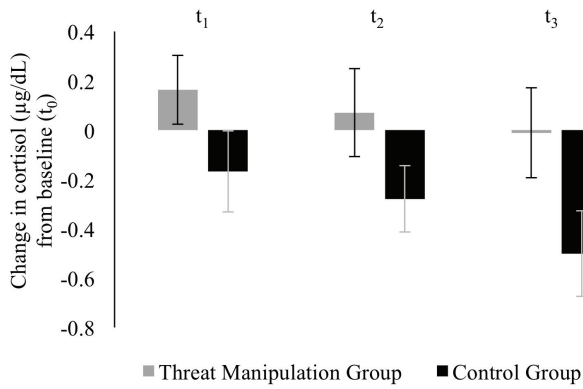
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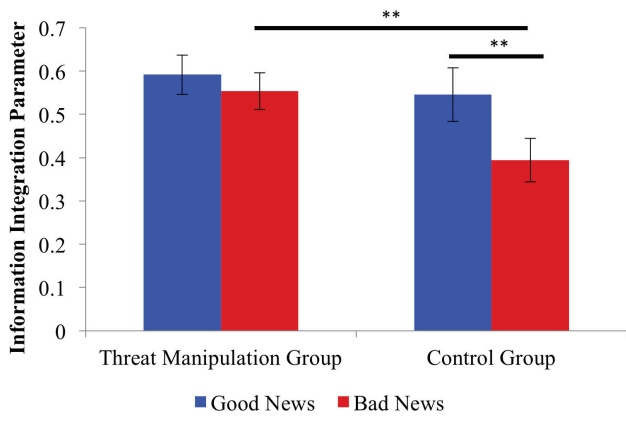


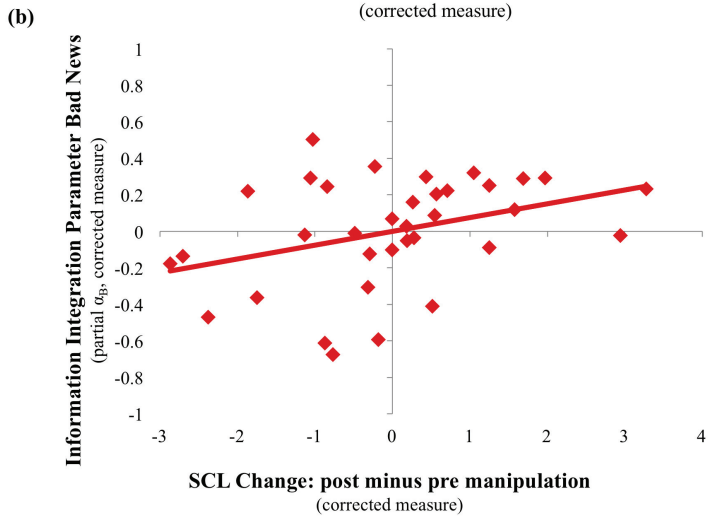
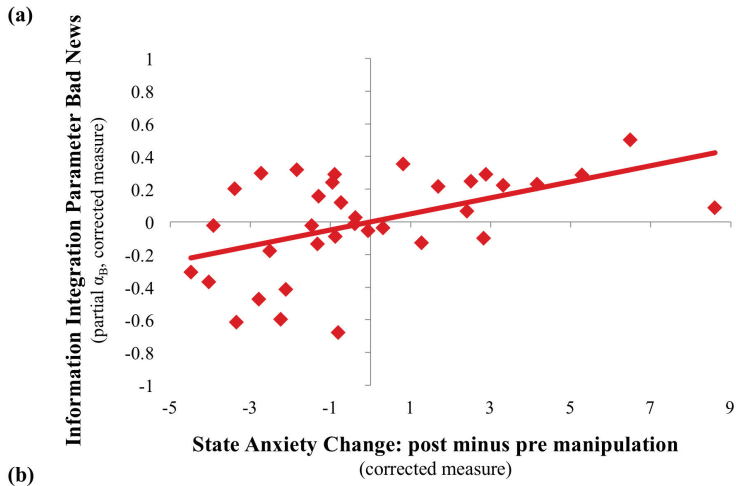
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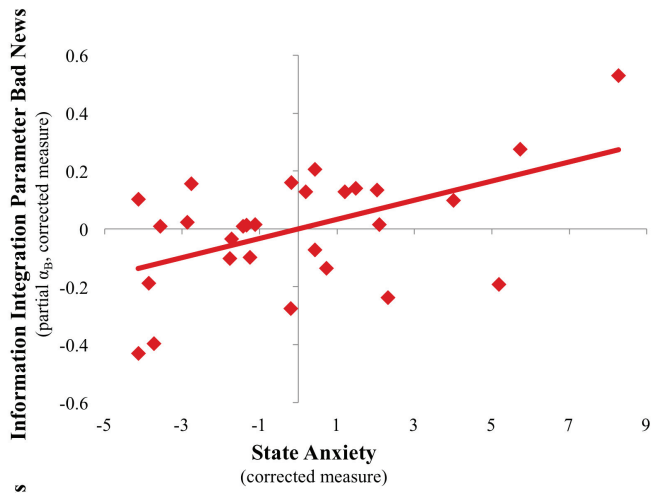
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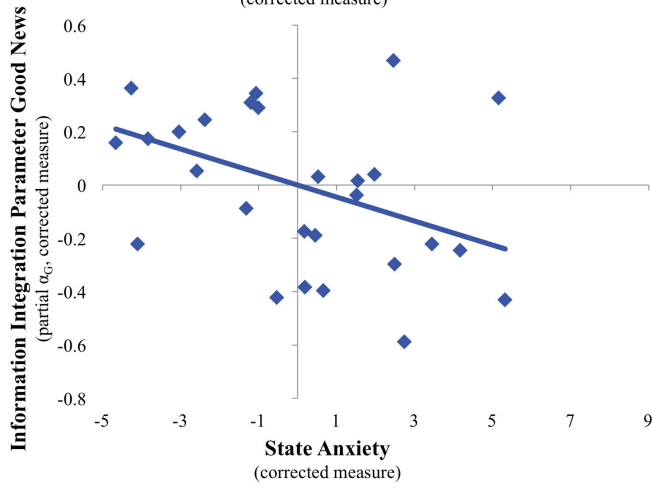




(a)



(b)



	Threat Manipulation Group mean (SD)	Control Group mean (SD)
BDI and Baseline Stress Levels		
BDI	5.79 (5.23)	4.69 (3.22)
Initial Self Report STAI ^G	10.37 (2.65)	8.63 (1.36)
Initial SCL	6.27 (3.29)	5.90 (3.20)
Initial Cortisol (log transformed)	-1.99 (0.59)	-1.79 (0.53)
Task Variables		
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Subjective Scales Questionnaire <i>1 = low to 6 = high</i>	Bias <i>(Good News – Bad News)</i>	
Vividness	0.41 (0.72) ^V	0.72 (0.65) ^V
Familiarity	0.30 (0.69)	0.49 (0.62) ^V
Prior experience	0.18 (0.61)	0.33 (0.41) ^V
Emotional arousal	0.33 (0.63) ^V	0.13 (0.86)
Negativity	0.20 (0.49)	-0.13 (0.58)
Other Task-related variables		
Number of Trials	-1.58 (8.99)	-1.56 (9.70)
Memory errors	-1.23 (3.16)	-0.21 (4.52)
Estimation errors (absolute)	-0.82 (5.27)	1.11 (5.84)
Update	2.60 (12.67)	4.21 (7.83) ^V

Table 1. BDI, Initial Self-Report STAI, Initial SCL, Initial Cortisol, Task-related variables, subjective scales, memory in Experiment I. Note that Estimation errors and Update (the final two rows) are the variables used to compute the information integration parameters (α_G and α_B) for each participant.

^G Difference between Threat Manipulation and Control Groups, tested using independent sample t-tests ($p < 0.05$).

^V Significant effect of valence ($p < 0.05$), tested using one sample t-test on the bias scores (difference between good and bad news) on each group separately.

	b_i	<i>Std.</i> <i>Error</i>	t	p	95% Confidence Interval		η_p^2
					<i>Lower</i> <i>Bound</i>	<i>Upper</i> <i>Bound</i>	
Initial Self Report STAI	-0.01	0.01	-1.10	0.29	-0.04	0.01	0.07
First estimates	0.01	0.01	0.89	0.39	-0.01	0.02	0.05
Vividness rating	-0.09	0.05	-1.84	0.09	-0.20	0.01	0.17
Familiarity rating	0.08	0.04	2.16	0.05	0.00	0.16	0.23
Prior experience rating	-0.04	0.06	-0.76	0.46	-0.17	0.08	0.04
Emotional arousal rating	-0.13	0.04	-3.03	0.01	-0.22	-0.04	0.37
Information integration parameter, good news (α_G)	0.39	0.15	2.60	0.02	0.07	0.71	0.30

Table 2. Parameter estimates of covariates in Experiment I.

First estimates (i.e. mean initial estimations), mean ratings on subjective scales (vividness, familiarity, past experience and emotional arousal) and α_G (information integration parameters for good news) were entered as covariates to account for fluctuations in α_B (information integration parameters for bad news).

	Mean (SD)
BDI	6.82 (7.45)
Task Variables	
First Estimates ^V	31.22 (6.96)
Subjective Scales Questionnaire	
<i>1 = low to 6 = high</i>	
Bias <i>(Good News – Bad News)</i>	
Prior experience ^V	0.54 (0.94)
Negativity	0.31 (0.90)
Other Task-related variables	
Number of Trials ^V	-10.89 (9.41)
Memory errors	-2.18 (6.51)
Estimation errors (absolute) ^V	-2.91 (5.16)
Update ^V	9.49 (12.04)

Table 3. Task-related variables, subjective scales and memory in Experiment II. Note that Estimation errors and Update (the final two rows) are the variables used to compute the information integration parameters (α_G and α_B) for each participant.

^V Significant effect of valence ($p < 0.05$), tested using one sample t-test on the mean bias scores (difference between good and bad news) for each participant.

	b_i	<i>Std. Error</i>	t	p	<i>95% Confidence Interval</i>		η_p^2
					<i>Lower Bound</i>	<i>Upper Bound</i>	
First estimates	0.00	0.01	-0.03	0.97	-0.02	0.02	0.00
Prior experience rating	-0.03	0.09	-0.31	0.76	-0.21	0.15	0.00
Number of bad news trials	0.00	0.02	-0.01	0.99	-0.03	0.03	0.00
Information integration parameter, good news (α_G)	0.34	0.16	2.17	0.04	0.02	0.67	0.18

Table 4. Parameter estimates of covariates in Experiment II.

First estimates (i.e. mean initial estimations), mean ratings of past experience, number of bad news trials and α_G (information integration parameters for good news) were entered as covariates to account for fluctuations in α_B (information integration parameters for bad news).