

1 Spontaneous Blink Rate Correlates With 2 Financial Risk Taking

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7

Abstract

8 Dopamine has long been thought to play a role in risky decision-making, with higher
9 tonic levels of dopamine associated with more risk seeking behavior. In this work, we
10 aimed to shed more light on this relationship using spontaneous blink rate as an indirect
11 measure of dopamine. In particular we used video recording to measure blink rate and a
12 decision-making survey to measure risk taking in 45 participants. Consistent with
13 previous work linking dopamine to risky decisions, we found a strong positive correlation
14 between blink rate and the number of risky choices a participant made. This correlation
15 was not dependent on age or gender and was identical for both gain and loss framing.
16 This work suggests that dopamine plays a crucial and quite general role in determining
17 risk attitude across the population and validates this simple method of probing dopamine
18 for decision-making research.

19 **Introduction**

20 Many decisions in daily life are made under considerable uncertainty. This uncertainty
21 comes in many forms, from the well-defined risks of playing roulette, to the more
22 ambiguous odds that it will rain on your wedding day. Across the population, there is a
23 large amount of variability in how we deal with this uncertainty (e.g. Weber et al., 2002;
24 Tymula et al. 2013) and there is considerable interest in understanding how these
25 individual differences arise.

26 One factor that is thought to play a crucial role in risk taking is the neurotransmitter
27 dopamine. In particular dopamine is thought to be important for determining our
28 attitudes toward risk, the kind of uncertainty that arises when the odds of winning are
29 known (e.g. in a game of roulette). For example, dopamine-related genes have been
30 associated with risk taking (Kuhnen & Chiao, 2009; Dreber et al. 2009; Dmitrieva et al.
31 2010; Farrell et al. 2012) and dopamine drugs have been found to modulate risky
32 behavior in both humans and animals (Riba et al. 2008; St Onge & Floresco, 2009;
33 Norbury et al. 2013; Rutledge et al. 2015; although see Symmonds et al. 2013).
34 Moreover, prolonged treatment with L-DOPA (a dopamine agonist) in Parkinson's is
35 associated with pathological gambling in a subset of patients (Molina et al. 2000;
36 Santangelo et al. 2013).

37 Despite this progress, the exact nature of the relationship between dopamine and risk
38 taking is incompletely understood. For one thing, dopamine has different effects on
39 different receptors, which are themselves distributed differently in different areas of the
40 brain (reviewed in Hurley & Jenner, 2006). Moreover, some studies have found that

41 dopamine genes and drugs have different effects depending on range of other factors
42 including gender (Dreber et al. 2009), baseline sensation seeking (Norbury et al., 2013)
43 and whether the gambles involve gains, losses or a mixture of the two (Rutledge et al.,
44 2015).

45 In this work we sought to shed more light on dopamine's role in risk taking by using a
46 remarkable relationship between the rate at which someone blinks and the amount of
47 dopamine in their brains (Karson, 1983; Karson, 1988; Lawrence & Redmond 1991;
48 Kleven & Koek, 1996). In particular, more frequent blinking is associated with greater
49 dopamine in the striatum, a relationship that appears to be dependent on D2 (and possibly
50 D1) receptors (Elsworth et al., 1991; Jutkiewicz and Bergman, 2004). We therefore
51 hypothesized that if blink rate reflects dopamine and dopamine drives risk taking, then
52 we should see a positive relationship between individual differences in spontaneous blink
53 rate and risk taking across the population. By including age, gender and gambles of
54 different valence, we also aimed to test whether the relationship between dopamine and
55 risk was modulated by these factors as predicted by previous work.

56 **Methods**

57 **Participants**

58 Forty five adults (17 male, 28 female of which 21 were students all aged 18, and 24 were
59 older, ages 26-59) were recruited from the students, teachers and parents at BASIS school
60 in Phoenix. All subjects gave informed consent and the study was approved by the
61 institutional review board at BASIS.

62 **Experiment**

63 Each participant was seated in a quiet room judged to be quiet and lacking distractions.

64 The participant was given the consent form to read and then sign. Then the details of

65 what was expected of the participant were carefully explained by the experimenter (ES).

66 The experiment itself consisted of two parts, first measurement of spontaneous blink rate

67 and second a risk-taking survey.

68 *Measurement of blink rate*

69 We measured spontaneous blink rate by recording a movie of the participant while they

70 “stared into space”. The movie was recorded on the webcam of an Apple laptop

71 computer that was placed on the table in front of the participant. Participants were told to

72 look straight ahead for two minutes while we filmed them and they were instructed to act

73 as normally as possible during this period. They were informed that we were filming

74 them but were not told that we were measuring their blinks. Blink rates were then

75 computed manually by the experimenter while the participants completed the decision-

76 making survey. To ensure privacy for the participant, the video was deleted in front of

77 the participant at the end of the experiment. All other data is available in the

78 Supplementary Material (S1 Data) along with code we used to process it (S1 Code).

79 *Decision-making survey*

80 Once the two minutes had passed, the webcam of the computer was shut off and the

81 participant was handed a paper survey. The survey consisted of nine questions, with each

82 question offering participants a choice between a certain outcome (e.g. 100% chance of

83 \$240) and a risky outcome (e.g. 25% chance of \$1000). For each question, participants

84 had to choose which option they would prefer. The gambles were only ever hypothetical
85 and participants were not paid for their time or on the basis of their choices.

86 The questions themselves were chosen based on the results of a pilot study conducted at
87 the University of Arizona that had revealed a possible relationship between blink rate and
88 answers to these questions. In particular the nine questions were:

89 1. If you were faced with the following choice which alternative would you choose?

90 a. A sure gain of \$240

91 b. A 25 percent chance to gain \$1000 and a 75 percent chance to gain
92 nothing.

93 2. If you were faced with the following choice which alternative would you choose?

94 a. A sure loss of \$750

95 b. A 75 percent chance to lose \$1000 and a 25 percent chance to lose
96 nothing?

97 3. In addition to whatever you own you have been given \$2000. You are now asked
98 to choose between:

99 a. A 50% chance of losing \$1000

100 b. A sure loss of \$500

101 4. If you were faced with the following choice which alternative would you choose?

102 a. A 100 percent chance of losing \$50

103 b. A 25 percent chance of losing \$200 and a 75 percent chance of losing
104 nothing

105 5. If you were faced with the following choice which alternative would you choose?

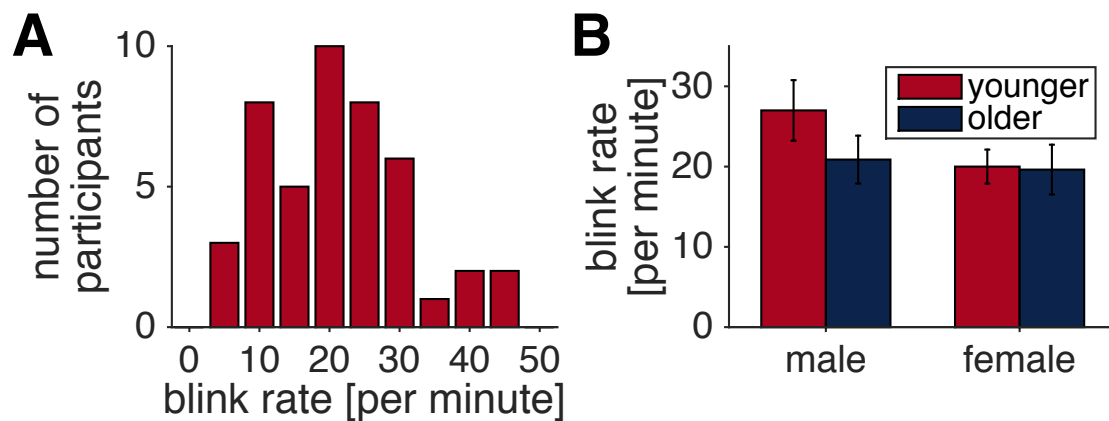
106 a. A sure loss of \$3000

- 107 b. An 80 percent chance to lose \$4000 and a 20 percent chance to lose
108 nothing.
- 109 6. If you were given a choice which of the following gambles would you prefer?
110 a. \$1,000,000 for sure
111 b. A 10 percent chance of getting \$2,500,000, an 89 percent chance of
112 getting \$1,000,000 and a 1% chance of getting \$0
- 113 7. In addition to whatever you own you have been given \$1000. You are now asked
114 to choose between:
115 a. A 50% chance of getting \$1000
116 b. A sure gain of \$500
- 117 8. If you were faced with the following choice which alternative would you choose?
118 a. A sure gain of \$3000
119 b. An 80 percent chance to gain \$4000 and a 20 percent chance to gain
120 nothing
- 121 9. Suppose you are offered the chance to play the following game: I flip a fair coin.
122 If it comes up heads you lose \$100. If it comes up tails you win \$125. Do you
123 accept?
124 a. Yes
125 b. No

126 Results

127 Distribution of blink rates is consistent with earlier findings

128 Across the population we observed a mean blink rate of 21 blinks per minute, a finding
129 which is consistent with the literature (e.g. Bentivoglio et al., 1997). In line with earlier
130 findings we also found a wide distribution of blink rates across the population (Figure
131 1A). Breaking out results for gender and age (treated as a discrete variable for younger,
132 age < 19, and older), there was a numerical hint of an interaction such that young male
133 participants blinked more frequently than other groups, although this was not statistically
134 significant (2x2 ANOVA with age group (young/old) and gender as factors: age $F(1,44)$
135 = 1.03, $p = 0.32$; gender $F(1,44) = 1.65$, $p = 0.21$; age \times gender $F(1,44) = 0.8$, $p = 0.38$)
136 (Figure 1B). Treating age as a continuous variable in a linear regression model with age,
137 gender and the age \times gender as factors, gave similar results ($\beta(\text{age}) = -0.10$, $p = 0.36$;
138 $\beta(\text{gender}) = -4.03$, $p = 0.29$; $\beta(\text{age} \times \text{gender}) = 0.06$, $p = 0.58$).



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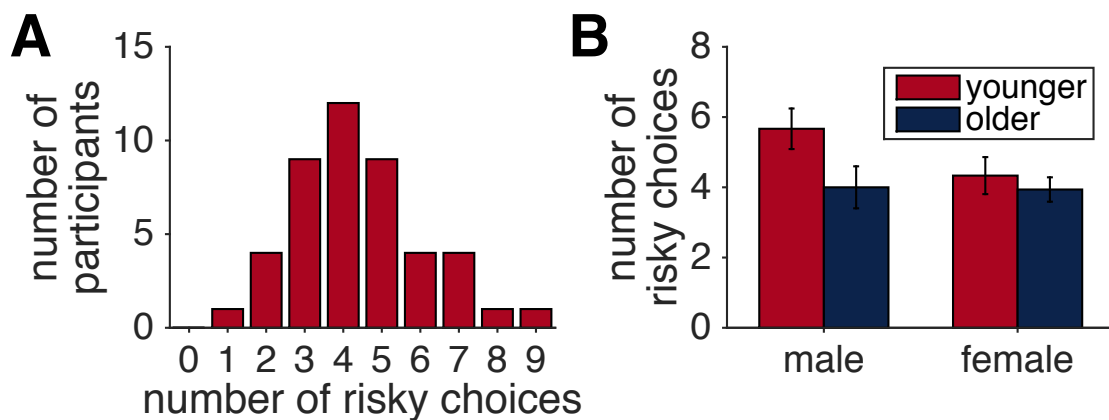
140 **Figure 1 – Blink rates across the population.** (A) Distribution of blink rates

141 across the population. (B) Blink rates are numerically higher for young male

142 participants than any other group, although this difference is not statistically
143 significant.

144 **Distribution of risk seeking across the population**

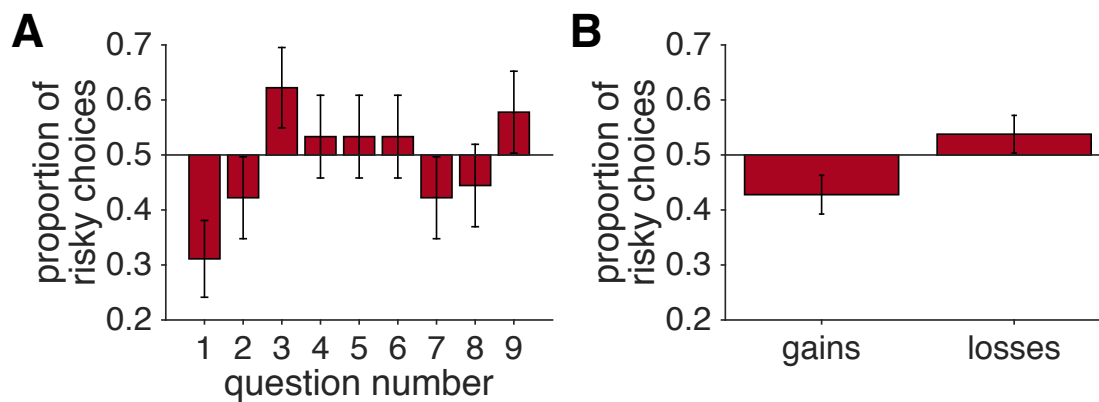
145 In our simplest measure of risk seeking, we counted the number of risky choices (out of
146 9) made by each participant. As with blink rate, there was a large range across the
147 population (Figure 2A). Unlike blink rate we found a weak main effect of age on blink
148 rate when treating age as a discrete variable, such that older participants were found to
149 blink less than younger adults (2x2 ANOVA with age and gender as factors, age $F(1,44)$
150 $= 4.17$, $p = 0.05$; gender $F(1,44) = 1.91$, $p = 0.17$; age \times gender $F(1,44) = 1.58$, $p = 0.22$).
151 This effect of age seemed to be stronger for men than for women (although the
152 interaction was not significant) and post hoc t-tests suggest a trend level effect for men
153 but not women (for men, two-sided t-test, $t(19) = 2.00$, $p = 0.06$; for women $t(26) = 0.65$,
154 $p = 0.52$). Treating age as a continuous variable in a regression yielded similar results,
155 although the significance of the age effect was reduced ($\beta(\text{age}) = -0.03$, $p = 0.10$;
156 $\beta(\text{gender}) = -0.75$, $p = 0.22$; $\beta(\text{age} \times \text{gender}) = 0.01$, $p = 0.50$)



157

158 **Figure 2 – Risk preference across the population. (A)** Distribution of risk
159 seeking across the population. **(B)** Risk seeking declined with age for male, but
160 not female, participants.

161 We also looked at behavior on the individual items. This revealed a relatively wide range
162 of preferences across the questions, from about 30% of people choosing the risky option
163 in question 1 to about 60% choosing the risky option in question 3 (Figure 3A). Given
164 the variation in expected value of the gambles in our questions, this wide range of
165 behavior was not unexpected. In line with classic findings from the literature (Kahneman
166 & Tversky, 1979), we also found risk seeking to be greater for the loss questions than the
167 gain questions (Figure 3B, $t(44) = -2.75$, $p = 0.009$). However, it is important to note that
168 (with the exception of questions 3 and 7) the questions did not equate expected value
169 between gain and loss domains so it is important not to over interpret this result.

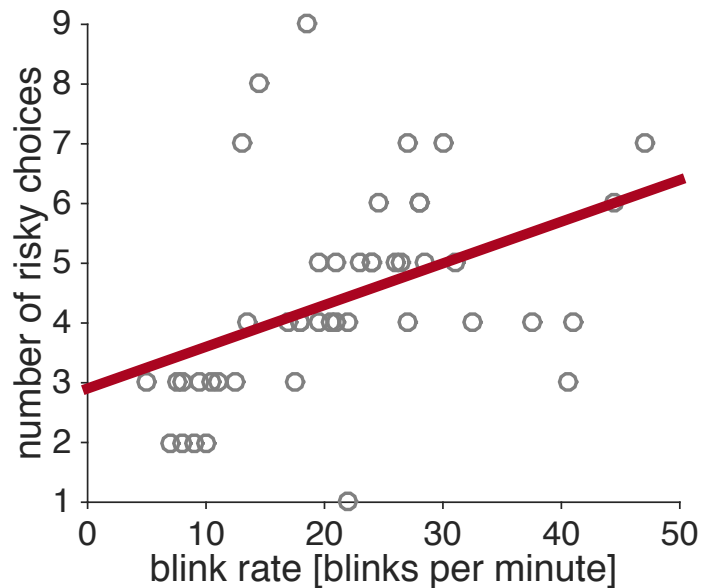


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171 **Figure 3 – Item analysis. (A)** The proportion of risky choices varied by about
172 30% across the nine different questions. **(B)** In line with classic findings,
173 participants were more risk averse for gains than losses, although differences in
174 expected value between gains and loss questions make it difficult to draw strong
175 conclusions.

176 **Blink rate is positively correlated with risk seeking**

177 In the most straightforward test of our hypothesis, we computed the correlation between
178 the blink rate and the number of questions in which participants selected the risky option.
179 This revealed a strong positive correlation between blink rate and risk seeking, such that
180 participants with higher blink rates chose the risky option more frequently (Spearman's
181 $\rho(43) = 0.57$, $p = 4.45 \times 10^{-5}$) (Figure 4). This correlation also survives correction for age
182 (treated continuously), gender and the interaction between age and gender, which we
183 achieved by regressing out the effects of age, gender and the interaction on both blink
184 rate and risk seeking (Spearman's $\rho(43) = 0.52$, $p = 2.6 \times 10^{-4}$).



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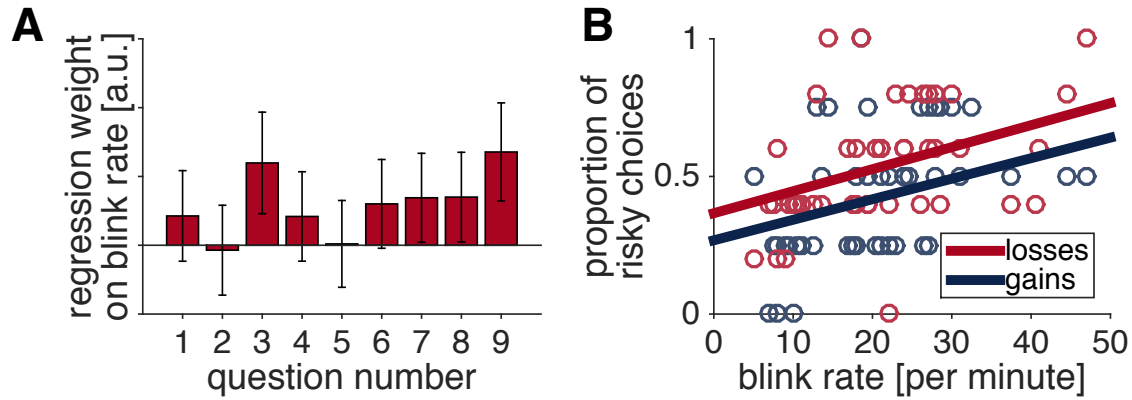
186 **Figure 4 – Individual differences in blink rate correlate with individual**
187 **differences in risk seeking.**

188 **Item analysis reveals effect is independent of gains and loss framing**

189 To quantify the effect of blink rate on the choices of individual questions we turned to
190 logistic regression. In particular we modeled the probability of choosing the risky option
191 on each question as

$$p(\text{choose risky}) = \frac{1}{1 + \exp(\beta_0 + \beta_{BR} \times BR + \beta_A \times A + \beta_G \times G + \beta_{AG} \times A \times G)}$$

192 where BR is the blink rate, A is the age group (-1 for young, +1 for old), G is gender (-1
193 for male, +1 for female). The regression coefficients (β_0 , β_{BR} , β_A , β_G and β_{AG}) were fit
194 separately for each question. In figure 5A we plot the blink rate coefficient, β_{BR} , for each
195 of the nine different questions. While this regression weight approaches significance
196 only for the last question ($p = 0.06$), it is interesting to note that, numerically, the size of
197 these coefficients is similar for all questions and the sign is positive for all but one,
198 suggesting that the same relationship between blink rate and risky decision making holds
199 for all questions. In addition, there is no obvious difference between the coefficients for
200 gain and loss questions, suggesting that blink rate modulates risk seeking regardless of
201 valence. This is further illustrated in Figure 5B, in which we plot the proportion of risky
202 choices for gain and loss questions against blink rate. This reveals a positive correlation
203 for both gains and loss framing, the slope of which is nearly identical in the two cases
204 (for gains, Spearman's $\rho(48) = 0.43$, $p = 0.004$; for losses $\rho(48) = 0.40$, $p = 0.007$).



205

206 **Figure 5 – Similar relationship between blink rate and risk seeking for all**
207 **questions.** (A) Logistic regression yields a similar weight on blink rate for all
208 nine questions. (B) Nearly identical relationship between blink rate and risk
209 seeking in both gains and losses domains.

210 Discussion

211 In this work we investigated the relationship between blink rate, a known measure of
212 dopamine (e.g. Karson 1983), and risky decision making in a sample of 45 participants
213 ranging in age from 18 to 59. Our findings suggest a strong relationship between blink
214 rate and risk taking that is independent of age and gender and does not appear to be
215 modulated by the valence of the decision, i.e. whether the risky choice is for gains or
216 losses. This suggests a relatively general role for dopamine in promoting risk seeking
217 over and above any biases induced by age, gender or framing of the problem.

218 The fact that we found almost identical relationships between blink rate and risk seeking
219 for both gains and losses contrasts with recent work by Rutledge et al. (2015). In
220 particular, these authors found that L-DOPA increases risk seeking only for gambles
221 involving gains, but not for gambles involving losses or a mixture of losses and gains.

222 While there are many differences between the two experiments, two possibilities would
223 be particular important to test. First is the difference in payoff structure. In our task the
224 rewards were hypothetical and participants were not paid, while in the Rutledge task,
225 participants were paid based on their choices. Thus participants in our experiment may
226 not have taken the choices as seriously as the participants playing for real money and
227 may have behaved differently as a result. Second is the different types of dopamine
228 under consideration in the two experiments. In particular, blink rate has been associated
229 with D2 (and possibly D1) related dopamine in striatum (Elsworth et al., 1991;
230 Jutkiewicz and Bergman, 2004), while L-DOPA increases dopamine in a non-specific
231 manner. It may therefore be the case that L-DOPA-related increases dopamine at other
232 receptors and in other brain areas may counteract the effects of increased D2 activity in
233 the Rutledge experiment. Combining blink rate and drug manipulation in a single study
234 would be a first step to resolving this differences.

235 One limitation of our study is the relatively small number of questions we asked our
236 participants. This was partly by design so that the experiment would be simple to run,
237 however this limited number of questions makes it impossible to assess whether there is
238 any interaction between blink rate, risk taking and the *quantitative* properties of the
239 gambles themselves. Such interactions include the effects of reward magnitude,
240 probability and outcome variance for the risky gamble are known to impact risk seeking
241 (Kahneman & Tversky, 1979). Indeed, recent work by Norbury and colleagues has
242 suggested that D2- and/or D3-related dopamine may play a role in how such quantitative
243 properties of the gambles affect choice (Norbury et al. 2013).

244 In addition to the association with blink rate, we also found age-related differences in the
245 risk-taking behavior of men, with young men taking more risk than older men. While this
246 trend was similar to the numerical changes we saw in the blink rates of younger and older
247 men, this numerical effect of age on blink rate was not significant, suggesting that
248 changes in the risk attitude of men with age is not mediated by blink rate. This was
249 slightly surprising given the well-known drop off in both dopamine level and receptor
250 availability with age (Volkow et al., 1996). However, it is possible that other age-related
251 changes in blinking, related to dryness of the eyes and mechanical changes to the eyelid,
252 could mask any dopamine related changes in blink rate with age (Sun et al., 1997).
253 Clearly more work will be needed to probe whether changes in dopamine drive changes
254 in risk attitudes with age.

255 An obvious question for future work is whether our findings for decision-making under
256 risk apply to other kinds of decision-making under uncertainty? For example, does blink
257 rate correlate with decisions under ambiguity, in which the odds of the gamble are not
258 known, in the same way that it correlates with risk? Previous work has suggested that
259 risk and ambiguity preference are not correlated with one another across the population
260 (Tymula et al., 2013) and may be driven by different neural processes (Hsu et al., 2005;
261 Huettel et al. 2006). It may therefore be the case that ambiguity seeking does not
262 correlate with blink rate in the same way that risk seeking appears to. Another example
263 of particular relevance is that of decisions involving other kinds of risk, such as drug
264 taking and sexual risk taking. Previous work has shown that risk preference can be highly
265 domain specific (Weber et al., 2002) and it would be interesting to see whether blink rate
266 correlates with risky behavior across decision-making domains.

267 **Acknowledgements**

268 We would like to thank XXX at BASIS Scottsdale for helpful comments on the design
269 and execution of this study.

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348 **Supporting information captions**

- 349 **S1 Dataset – Full dataset.** Including choices on individual questions, blink rate,
350 gender and age.

351 **S1 Code – Matlab code reproducing all analyses and figures.**