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1 Individual-specific mortality is associated with how individuals evaluate future discounting
2 decisions

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Abstract

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How organisms discount the value of future rewards is associated with many important outcomes, and may be a central component of theories of life-history. According to life-history theories, prioritising immediacy is indicative of an accelerated strategy (i.e., reaching reproductive maturity quickly and producing many offspring at the cost of long-term investment). Previous work extrapolating life-history theories to facultative calibration of life-history traits within individuals has theorised that cues to mortality can trigger an accelerated strategy; however, compelling evidence for this hypothesis in modern humans is lacking. We assessed whether country-level life expectancy predicts individual future discounting behaviour across multiple intertemporal choice items in a sample of 13,429 participants from 54 countries. Individuals in countries with lower life expectancy were more likely to prefer an immediate reward to one that is delayed. Individuals from countries with greater life expectancy were especially more willing to wait for a future reward when the relative gain in choosing the future reward was large and/or the delay period was short. These results suggest that cues to mortality can influence the way individuals evaluate intertemporal decisions, which in turn can inform life-history trade-offs. We also found that older (but not very old) participants were more willing to wait for a future reward when there is a greater relative gain and/or shorter delay period, consistent with theoretical models that suggest individuals are more future-orientated at middle age.

42 Individual-specific mortality is associated with how individuals evaluate future discounting
43 decisions

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45 Organisms tend to favour immediate rewards over delayed rewards, even when the delayed
46 reward may be larger (1). This discounting of future gains (also known as temporal discounting) is
47 thought to be due to the inherent uncertainty associated with future rewards (2). As such, when
48 faced with a choice between a smaller, immediate reward, or a larger, delayed reward, it can be
49 more beneficial to capitalise on the immediate reward rather than to wait for a larger award that
50 may not materialise. The ability to navigate these intertemporal decisions is associated with many
51 important outcomes in humans; for instance, future discounting is associated with education
52 attainment (3) and predicts cognitive and attentional competencies (4), as well as well-validated
53 relationships with health-related outcomes, such as obesity (5) and addiction (6).

54 How organisms discount the value of future rewards may be integral to evolutionary
55 theories of life-history trade-offs. An organism adopting an *accelerated* life-history strategy,
56 characterised by fast reproductive development, quick senescence, and producing more offspring at
57 the cost of investment in those offspring (7), could be interpreted as that organism prioritising
58 immediacy (2). Indeed, future discounting is thought to influence mating and foraging strategies in
59 many species (e.g., 8, 9). In humans, men are found to engage more in future discounting compared
60 to women (10), which is consistent with predictions from life-history theories (2), and the
61 propensity to discount the future has been associated with traits relevant to life-history theories
62 (e.g., age of first sexual activity and relationship fidelity; 3).

63 Some research has extrapolated life-history theories to predict facultative adjustments of
64 life-history traits within individuals in response to external factors. For instance, ecological
65 unpredictability has been associated with increased future discounting and risk-taking behaviour
66 (11-13). Similarly, early-life environmental harshness has been found to be associated with life-
67 history traits and appears to carry through into adulthood (14). While individuals adopting an

68 accelerated life-history strategy under “harsh” conditions has become a popular hypothesis, we note
69 that this may be over-simplistic (i.e., the optimal life-history strategy may not be the same for all
70 individuals in a given environment), and whether the hypothesis is supported by life-history theory
71 itself is debated (see 15).

72 Another external factor proposed to lead individuals to adopt an accelerated strategy is high
73 local mortality (e.g., 2, 16). This is thought to be because environments where mortality is high can
74 lead organisms to prioritise immediacy in order to capitalise on fitness opportunities before the
75 increased likelihood of death. In humans, previous cross-national research has used country-level
76 life expectancy as a proxy for cues to mortality, and has provided insight into individual variation in
77 life-history traits; for instance, country-level mortality is associated with a younger average age of
78 first birth (17-20) and more violence and intrasexual competition (21), which could be interpreted
79 as an evolved strategy of prioritising immediacy in these ecologies.

80 In a recent study, Bulley and Pepper (22) reported that countries with a lower life
81 expectancy were more likely to have a higher proportion of individuals who favour an immediate
82 reward over a larger, delayed reward. However, while Bulley and Pepper (22) demonstrated that
83 ecological cues to mortality may influence propensity to discount future rewards, there are
84 methodological limitations that restrict the study’s conclusions. First, Bulley and Pepper (22)
85 measured future discounting using a single binary choice item (23). Previous research has indicated
86 that the likelihood an immediate reward is chosen over a larger, delayed reward depends on the
87 length of delay, and also the difference in relative gain between the immediate and delayed reward
88 (10). This type of variation cannot be captured with a single item; as such it is still unclear whether
89 ecological cues to mortality influence how individuals evaluate the length of delay period vs. the
90 relative gain of the future reward, or whether individuals from countries with lower life expectancy
91 simply favour immediacy overall.

92 Second, Bulley and Pepper (22) used aggregated proportions of future discounting choice
93 for each country and overall country-level life expectancy in their analysis; therefore, they are

94 unable to make inferences about the behaviour of individuals (assuming country-level and
95 individual-level data show the same pattern is known as the ecological fallacy; 24, 25). However,
96 we do note that a similar effect has been shown at an individual level, where cues to mortality are
97 associated with preference for an immediate reward over a future reward (26-28).

98 If future discounting underpins life-history strategies, we can also predict sex and age
99 differences in future discounting behaviour to emerge. Given that male reproductive success is
100 more variable than that of female reproductive success and that men (on average) face higher
101 senescence, men are more likely to benefit from capitalising on immediate opportunities compared
102 to women (e.g., capitalising on immediate mating opportunities can be highly advantageous for
103 men, while for women it may be more advantageous to wait for a high quality mate), we could
104 predict men would engage in future discounting more compared to women. This would be
105 consistent with previous a meta-analysis suggesting women are more likely to delay gratification
106 (29, but see 30). However, straightforward predictions of age effects on future discounting are less
107 clear; some models predict future discounting to increase with age as potential time to exploit future
108 rewards decreases, other models predict younger individuals to prefer immediacy as they are more
109 vulnerable during development (for a review, see 2), while some theoretical modelling suggests that
110 discounting should be at its lowest during middle age (31).

111 Here, we test the influence of ecological cues to mortality and future discounting behaviour
112 in a large, cross-country, online sample ($N = 13,204$ from 54 countries). Participants completed nine
113 intertemporal choice items that varied in the relative difference in gains between the immediate and
114 future rewards and the delay period of the future reward (32). We hypothesise that country-level life
115 expectancy is positively associated with preference for a larger, future reward compared to a
116 smaller, immediate reward. If ecological mortality influences how individuals evaluate
117 intertemporal choices, we would also expect country-level life expectancy to interact with a
118 discounting parameter that quantifies the relative gain in choosing the future reward compared to
119 the delay period. To address the ecological fallacy, we also conducted an additional model using

120 individual-specific life expectancy statistics (i.e., age-, sex-, year-, and country-specific life
121 expectancy for each participant). We also test for a sex effect, as well as linear and non-linear age
122 effects, on future discounting as predicted by life-history theories.

123

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Method

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Participants

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128 Participants were online volunteers that completed the future discounting task at
129 www.faceresearch.org between 2006 and 2017. Participants were recruited by following links from
130 social bookmarking websites (e.g., stumbleupon.com) and were not compensated for participation.
131 Online data has been used in many previous studies of regional differences in human behaviour
132 (e.g., 33, 34). The full sample included 16,065 participants from 120 countries. Participants who did
133 not report their country of residence ($N = 2141$), age ($N = 119$), reported an unrealistic age (< 6
134 years or > 100 years, $N = 69$), or did not identify as either male or female ($N = 97$) were removed
135 from analyses. Analyses were restricted to participants from countries with at least 10 participants
136 to aid in model convergence, which removed an additional 183 participants. Participants from an
137 additional two countries were removed because country-level statistics were not available ($N = 27$).
138 The final sample included in analyses was 13,429 participants from 54 countries ($M = 24.85$ years,
139 $SD = 9.24$ years, min = 6.20 years, max = 91.50 years).

139

Future Discounting Measure.

141

142 Future discounting was measured using the intertemporal choice task in Wilson and Daly
143 (35). This involved nine trials where participants were presented with a choice of either choosing a
144 specified amount “tomorrow” or a larger amount (difference ranging from \$1 to \$25) after a delay
145 (ranging from 7 days to 186 days). For each trial a discounting parameter (k) was calculated such
146 that:

146

147 $k = (\text{future\$} - \text{tomorrow\$}) / ((\text{delay}(\text{in days}) \times \text{tomorrow\$}) - \text{future\$})$

148

(1)

149

150 Larger k values indicate a greater future reward relative to the immediate reward with a
151 shorter wait period (32). Across the 9 trials, k ranged from 0.000159 (equivalent to \$34 tomorrow or
152 \$35 in 186 days) to 0.404255 (equivalent to \$11 tomorrow or \$30 in 7 days). Hypothetical
153 intertemporal choice items have been shown to be comparable to those with actual monetary
154 rewards (36); however, this is debated (37).

155

156 *Country-Level Statistics*

157 Participants reported their current country of residence. Following Bulley and Pepper (22),
158 the geographical region of each country was taken from the World Bank's "Country and Lending
159 Groups" classifications (38). This was included in the model to control for potential non-
160 independence between countries based on geographical location (e.g., similar climate, cultural
161 history, see 24). For more detailed descriptive statistics for the country-level data, including number
162 of participants per country, and mean life expectancy and GDP for participants in our sample,
163 please see the supplementary materials.

164 *Life Expectancy.* The average life expectancy for each country refers to the statistical
165 average time in years an individual in that country is expected to live if mortality rates remain
166 steady. This statistic is often used to reflect quality of healthcare in countries. Both overall life
167 expectancy at birth, and individual-specific life expectancy (i.e., age-, sex-, year- and country-
168 specific life expectancy for each participant) were obtained from the World Health Organisation
169 data repository (39). At the time of data analysis, life expectancy statistics were available for every
170 year of data collection up to 2015. For data collected in a year where a life expectancy statistic for
171 that country was not available, the statistic for the closest available year for that country was used

172 (never more than two years). Age specific life expectancy statistics for each country were available
173 in 5-year groups.

174 *Gross Domestic Product.* Gross domestic product (GDP) refers to the monetary value of all
175 final goods and services produced within a country's market in a year. GDP is often used as an
176 indicator for a country's wealth. GDP for each country was obtained from The World Bank (40). At
177 the time of data analysis, GDP was available for every year of data collection up to 2016. Similar to
178 with life expectancy, for data collected in a year where GDP was not available, the value for the
179 closest available year for the country was used (never more than one year).

180

181 *Statistical Analysis*

182 Data were analysed using binomial linear mixed effect modelling using the lme4 (41) and
183 lmerTest (42) packages in the R statistical software (43). For both models using overall life
184 expectancy and individual-specific life expectancy, the outcome variable was whether the
185 immediate (tomorrow) or delayed (future) choice was chosen in a given trial (coded 0 and 1
186 respectively). For the overall life expectancy model, separate country-level statistics within a
187 country were used according to the year a participant completed the discounting measure. For the
188 model including individual-specific life expectancy, given that years of life remaining and age are
189 very highly correlated (leading to issues of multicollinearity), years already lived were included in
190 individual-specific life expectancy. All predictors were z-standardised at the appropriate group-
191 level (i.e., country level for overall life expectancy and GDP, trial level for the k -parameter) before
192 being entered into the analysis. To aid model convergence, all outlier values on life expectancy
193 (overall and specific) and GDP were windsorised ($\pm 3 SD$). To assess the influence of the predictors
194 on how individuals evaluate intertemporal decisions, an interaction term was added between both
195 life expectancy and GDP, and the k -parameter. Participant sex (coded as -.5 for female and .5 for
196 male), linear and non-linear effects of age, and their interactions with the k -parameter were also
197 included in both models. To account for non-independence, random intercepts were specified for

198 each trial, participant, country, and region, and random slopes were specified maximally following
199 recommendations in Barr, Levy (44) and Barr (45). The fixed effects for both models are reported
200 here; for full model specifications and full output for this analysis, including the estimated random
201 effects, see the supplementary materials. The dataset and analysis code supporting this article can be
202 accessed at <https://osf.io/xyc8j>.

203

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Results

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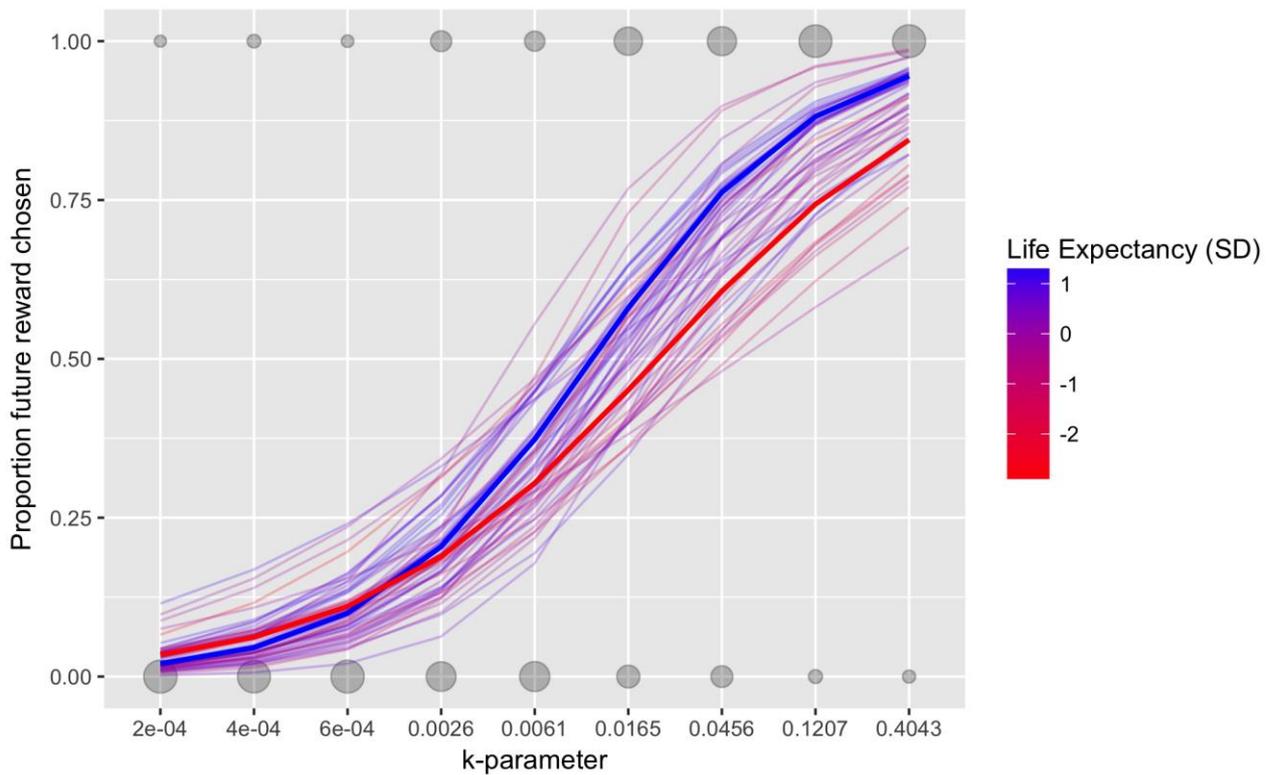
206 The models predicting whether a larger, future reward was chosen over a smaller, immediate
207 reward using overall country life expectancy and individual-specific life expectancy are reported in
208 Table 1. For both models, when random slopes were maximally specified, the model failed to
209 converge, as such, random slopes for covariates and respective interactions were omitted (GDP), as
210 recommended in Barr (45).

211 The model intercepts were both negative (significant in the individual-specific life
212 expectancy model), suggesting that participants tended to favour the immediate reward over the
213 future reward. As should be expected, there was a significant main effect of the k -parameter in both
214 models, such that the future reward is more likely to be chosen when the relative gain is greater and
215 the delay time is shorter. Consistent with predictions, in both models we found a significant positive
216 effect of life expectancy on choosing the greater, delayed reward. Also, there was a significant
217 interaction between life expectancy and the k -parameter in both models, suggesting that when the
218 relative gain was large with a short delay period, individuals from countries with greater life
219 expectancy were more willing to wait for a future reward (see Figure 1).

220 Table 1. The fixed effects for the mixed effect models predicting whether the future reward was chosen over the immediate reward using overall
 221 country life expectancy (left) and individual-specific life expectancy (right).

	Overall Country Life Expectancy			Individual-Specific Life Expectancy		
	Estimate (Std Error)	z value	p value	Estimate (Std Error)	z value	p value
Intercept	-.67 (.66)	-1.00	.316	-.71 (.29)	-2.50	.013*
k-parameter	3.11 (.62)	5.03	<.001***	5.40 (.23)	23.16	<.001***
Life Expectancy	.74 (.15)	4.86	<.001***	.28 (.11)	2.60	.009**
GDP	.15 (.12)	1.28	.202	.20 (.12)	1.69	.092
Participant Sex	.04 (.12)	.33	.738	.42 (.17)	2.50	.013*
Participant Age	.22 (.04)	5.36	<.001***	.20 (.04)	5.02	<.001***
Participant Age ²	-.02 (.02)	-.91	.360	-.01 (.02)	-.36	.716
k-parameter * Life Expectancy	.94 (.36)	2.58	.010**	.59 (.24)	2.46	.014*
k-parameter * GDP	.09 (.07)	1.23	.218	.12 (.04)	3.18	.001**
k-parameter * Participant Sex	.22 (.42)	.53	.597	1.14 (.49)	2.34	.019*
k-parameter * Participant Age	.22 (.06)	3.78	<.001***	.22 (.05)	4.63	<.001***
k-parameter * Participant Age ²	-.19 (.02)	-8.83	<.001***	-.10 (.04)	-2.60	.009**

222 Figure 1. Proportion of times the future reward is chosen over the immediate reward across multiple
 223 trials with varying k -parameter. The size of the circles represents number of times the future (top)
 224 or immediate (bottom) reward was chosen for each trial. Thick lines represent the binomial linear
 225 regression from countries above (blue) and below (red) the mean on life expectancy (across year
 226 and participants). Thin lines represent the binomial linear model for each country.



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229 Both models also found a significant main effect of age, such that older participants were
 230 more likely to choose the future reward. Both linear and non-linear effects of participant age also
 231 significantly interacted with the k -parameter, suggesting that older participants (but not very old)
 232 were more willing to wait for a future reward when the relative gain was large and/or the delay
 233 period was short. See the supplementary materials for the Figure involving participant age. In the
 234 overall life expectancy model, there were no significant effects involving country GDP or
 235 participant sex. However, in the individual-specific life expectancy model, there was a significant
 236 interaction between GDP and the k -parameter, such that when the relative gain is large with a short
 237 delay period, individuals from countries with greater wealth were more likely to choose the future
 238 reward. Also, in the individual-specific life expectancy model, we found significant a significant

239 main effect and interaction for participant sex, such that men were more likely to be future-
240 orientated, particularly when the relative gain was large and/or the delay period was short.

241 Life expectancy and GDP were windsorised aid model convergence; re-running the model
242 without windsorising outliers did not change the pattern of results with the exception that GDP and
243 its interaction with the k -parameter were both positively significant in the overall life expectancy
244 model.

245

246 Discussion

247

248 Here, we find across 54 countries an association between country-level life expectancy and
249 future discounting behaviour. As expected, individuals from countries with higher life expectancy
250 were more willing to wait for a relatively larger reward. However, compared to previous cross-
251 national research, we are able to make better inferences about individuals' future discounting
252 behaviour in response to mortality risk. These effects remained even when using age-, sex-, year-,
253 and country-specific life expectancy for each participant, which more likely represents cues to
254 mortality faced by each participant compared to that of overall country life expectancy. Effects also
255 persisted despite controlling for country-level wealth (i.e., GDP), or accounting for regional non-
256 independence through mixed effects modelling.

257 Overall, as shown by the significant main effect of the k -parameter, individuals were less
258 willing to wait for the future reward when the difference between this and the immediate reward
259 was relatively small and/or the delay period was relatively long. This association was influenced by
260 country-level life expectancy, providing insight into how ecological cues to mortality influences
261 different future discounting scenarios that vary on delay period and relative gain. We find that when
262 the relative gain is large with a short delay period, individuals from countries with lower life
263 expectancy were less likely to choose the future reward. This suggests that mortality cues are not
264 merely associated with an overall preference for immediacy (i.e., the main effect of life

265 expectancy), but that ecological factors could potentially influence the way individuals use
266 information regarding delay and relative gain when evaluating intertemporal decisions. This could
267 not have been detected without testing future discounting using multiple intertemporal choice trials.

268 Extending our findings to facultative responses on life-history traits in general, our findings
269 suggest that cues to mortality could influence how organisms evaluate future fitness opportunities
270 respective of the delay period and the gain in fitness. This strategy is advantageous over a general
271 preference for immediacy as it allows organisms in ecologies where mortality is low to still
272 capitalise on immediate fitness opportunities when the perceived delay for any potential future
273 opportunity is long and/or the additional gain in fitness is small. Such intertemporal decisions are
274 relevant to many domains relevant to life-history theories; for instance, when an organism is faced
275 with a choice between an immediate mating opportunity, or the chance of potentially procuring a
276 higher quality mate in the future. While our data are on humans, this challenge is present for other
277 species as well.

278 While our finding of a positive effect of age on future discounting are in line with the notion
279 that younger participants may prioritise immediacy due to being more vulnerable during
280 development. Another alternative explanation is that older participants having accrued more capital
281 throughout their lifespan, and therefore are more able to afford waiting for a future reward. We also
282 found a significant, negative interaction between the k -parameter and the nonlinear age coefficient.
283 This combined with the positive linear interaction between the k -parameter and age suggests that
284 older participants (but not too old) were more future-orientated when there is greater relative gain
285 and/or the delay period is shorter. This is consistent with theoretical models that future discounting
286 occurs the least during middle-aged adulthood, with future discounting increasing in older
287 adulthood due to higher intrinsic mortality, and declining fertility (31).

288 Similar to Bulley and Pepper (22), we did not find a main effect of GDP on future
289 discounting behaviour when overall life expectancy was included in the model. This was thought to
290 be because country-level life expectancy and wealth are in part linked, and that ecological, rather

291 than economical factors are more likely to influence future discounting choices. However, in the
292 individual-specific life expectancy model, we found a significant interaction between GDP and the
293 k -parameter, which could not have been detected without having multiple observations at the
294 individual-level. This interaction suggests that individuals in richer countries were more willing to
295 choose the future reward when the relative gains were small and/or the delay period was long. One
296 possible explanation is that individuals from richer countries possess an abundance of resources,
297 and as such can afford the luxury of waiting for a future reward, even if the added benefit is small.
298 This should be interpreted cautiously, however, as the interaction between GDP and the k -parameter
299 was not significant in the overall life expectancy model. Also, contrary to predictions, we found that
300 men were more likely to be future orientated compared to women in individual-specific life
301 expectancy model. This is contrary to previous findings that men discount the future more than
302 women (3, 10, 29). However, we did not find a sex difference in future discounting behaviours in
303 the overall life expectancy model; therefore, sex differences should be interpreted cautiously.
304 Overall, our findings suggest that while life-history theories can account for some findings (e.g.,
305 mortality and age effects), other findings (e.g., a potential opposite sex effect) are harder to
306 reconcile. Social and economic factors are also likely to also play a role in future discounting
307 behaviour.

308 While we have taken the perspective that ecological factors are influencing individual future
309 discounting behaviour, our data equally suggest that the reverse causality could be true, where
310 countries in which individuals are more likely to favour immediacy lead to higher rates of mortality.
311 Indeed, health behaviours often have delayed benefits; accordingly, future discounting behaviour is
312 associated with engaging in risky or unhealthy behaviours, such as alcohol and tobacco use, which
313 can significantly account for the mortality of a country (for a review, see 46). Our analysis used
314 national level statistics of life expectancy, and though finer geographic statistics (e.g.,
315 neighbourhoods as used in 47), would provide a more accurate proxy for local mortality cues, using
316 country-level statistics has previously provided insight into variation in life-history related traits

317 (17, 18, 20-22). Participants were also presented the choices in the same currency regardless of their
318 country (\$), which could potentially influence results as \$1 is worth more in some countries than in
319 others. Our data also cannot speak to whether future discounting behaviours are flexibly adaptive in
320 response to ecological conditions. In order to investigate this, within-subjects studies with
321 experimental manipulations are required; though previous work indicates that individual propensity
322 to discount the future can be malleable (26, 35, 48).

323

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Acknowledgements

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Authors' Contribution

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Ethical Approval

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Data Accessibility

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Data and code supporting this article are available at <https://osf.io/xyz8j>.

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