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

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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, prioritizing 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 theorized 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.

1. Introduction

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

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

Some research has extrapolated life-history theories to predict facultative adjustments of life-history traits within individuals in response to external factors. For instance, ecological unpredictability has been associated with increased future discounting and risk-taking behaviour [11–13]. Similarly, early-life environmental harshness has been found to be associated with life-history traits and appears to carry through into adulthood [14]. While individuals adopting an accelerated life-history strategy under 'harsh' conditions has become a popular hypothesis, we note that this may be over-simplistic (i.e. the optimal life-history strategy may not be the same for all individuals in a given environment), and whether the hypothesis is supported by life-history theory itself is debated (see [15]).

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

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

Second, Bulley & Pepper [22] used aggregated proportions of future discounting choice for each country and overall country-level life expectancy in their analysis; therefore, they are unable to make inferences about the behaviour of individuals (assuming country-level and individual-level data show the same pattern is known as the ecological fallacy; [24,25]). However, we do note that a similar effect has been shown at an individual level, where cues to mortality are associated with preference for an immediate reward over a future reward [26–28].

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

Here, we test the influence of ecological cues to mortality and future discounting behaviour in a large, cross-country, online sample ($n = 13\,204$ from 54 countries). Participants completed nine intertemporal choice items that varied in the relative difference in gains between the immediate and future rewards and the delay period of the future reward [32]. We hypothesize that country-level life expectancy is positively associated with preference for a larger, future reward compared to a smaller, immediate reward. If ecological mortality influences how individuals evaluate intertemporal choices, we would also expect country-level life expectancy to interact with a discounting parameter that quantifies the relative gain in choosing the future reward compared to the delay period. To address the ecological fallacy, we also conducted an additional model using individual-specific life expectancy statistics (i.e. age-, sex-, year-, and country-specific life expectancy for each participant). We also test for a sex effect, as well as linear and non-linear age effects, on future discounting as predicted by life-history theories.

2. Method

(a) Participants

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

(b) Future discounting measure

Future discounting was measured using the intertemporal choice task in Wilson & Daly [35]. This involved nine trials where participants were presented with a choice of either choosing a specified amount 'tomorrow' or a larger amount (difference ranging from

\$1 to \$25) after a delay (ranging from 7 days to 186 days). For each trial a discounting parameter (k) was calculated such that:

$$k = (\text{future\$} - \text{tomorrow\$}) / ((\text{delay(days)} \times \text{tomorrow\$}) - \text{future\$}). \quad (2.1)$$

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

(c) Country-Level statistics

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

(i) Life expectancy

The average life expectancy for each country refers to the statistical average time in years an individual in that country is expected to live if mortality rates remain steady. This statistic is often used to reflect quality of healthcare in countries. Both overall life expectancy at birth, and individual-specific life expectancy (i.e. age-, sex-, year- and country-specific life expectancy for each participant) were obtained from the World Health Organisation data repository [39]. At the time of data analysis, life expectancy statistics were available for every year of data collection up to 2015. For data collected in a year where a life expectancy statistic for that country was not available, the statistic for the closest available year for that country was used (never more than two years). Age specific life expectancy statistics for each country were available in five-year groups.

(ii) Gross domestic product

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

(d) Statistical analysis

Data were analysed using binomial linear mixed effect modelling using the lme4 [41] and lmerTest [42] packages in the R statistical software [43]. For both models using overall life expectancy and individual-specific life expectancy, the outcome variable was whether the immediate (tomorrow) or delayed (future) choice was chosen in a given trial (coded 0 and 1 respectively). For the overall life expectancy model, separate country-level statistics within a country were used according to the year a participant completed the discounting measure. For the model including individual-specific life expectancy, given that years of life remaining and age are very highly correlated (leading to issues of multicollinearity), years already lived were included in individual-specific life expectancy. All predictors were z-standardized at the appropriate group-level (i.e. country level for overall life expectancy and GDP, trial level for the k-parameter) before being entered into the analysis. To aid model convergence, all outlier values on life expectancy (overall and specific) and GDP were winsorised (± 3 s.d.). To assess the influence of the predictors on how individuals evaluate intertemporal decisions, an interaction term was added between both life expectancy and GDP, and the k-parameter. Participant sex (coded as -0.5 for female and 0.5 for male), linear and non-linear effects of age, and their interactions with the k-parameter were also included in both models. To account for non-independence, random intercepts were specified for each trial, participant, country, and region, and random slopes were specified maximally following recommendations in Barr *et al.* [44] and Barr [45]. The fixed effects for both models are reported here; for full model specifications and full output for this analysis, including the estimated random effects, see the electronic supplementary material. The dataset and analysis code supporting this article can be accessed at https://osf.io/xcy8j.

3. Results

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

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

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

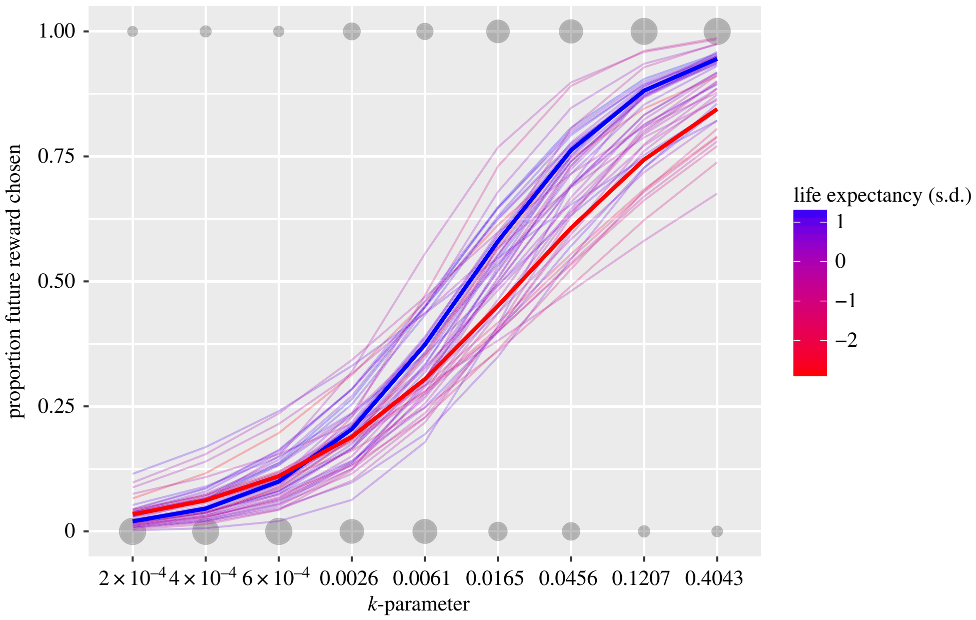

Figure 1. Proportion of times the future reward is chosen over the immediate reward across multiple trials with varying *k*-parameter. The size of the circles represents number of times the future (top) or immediate (bottom) reward was chosen for each trial. Thick lines represent the binomial linear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

Table 1. The fixed effects for the mixed effect models predicting whether the future reward was chosen over the immediate reward using overall country life expectancy (left) and individual-specific life expectancy (right). (*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.)

	overall country life expectancy			individual-specific life expectancy		
	estimate (std error)	*z* value	*p* value	estimate (std error)	*z* value	*p* value
intercept	−0.67 (0.66)	−1.00	0.316	−0.71 (0.29)	−2.50	0.013*
k-parameter	3.11 (0.62)	5.03	<0.001***	5.40 (0.23)	23.16	<0.001***
life expectancy	0.74 (0.15)	4.86	<0.001***	0.28 (0.11)	2.60	0.009**
GDP	0.15 (0.12)	1.28	0.202	0.20 (0.12)	1.69	0.092
participant sex	0.04 (0.12)	0.33	0.738	0.42 (0.17)	2.50	0.013*
participant age	0.22 (0.04)	5.36	<0.001***	0.20 (0.04)	5.02	<0.001***
participant age^2	−0.02 (0.02)	−0.91	0.360	−0.01 (0.02)	−0.36	0.716
k-parameter * life expectancy	0.94 (0.36)	2.58	0.010**	0.59 (0.24)	2.46	0.014*
k-parameter * GDP	0.09 (0.07)	1.23	0.218	0.12 (0.04)	3.18	0.001**
k-parameter * participant sex	0.22 (0.42)	0.53	0.597	1.14 (0.49)	2.34	0.019*
k-parameter * participant age	0.22 (0.06)	3.78	<0.001***	0.22 (0.05)	4.63	<0.001***
k-parameter * participant age^2	−0.19 (0.02)	−8.83	<0.001***	−0.10 (0.04)	−2.60	0.009**

Life expectancy and GDP were winsorised to aid model convergence; re-running the model without winsorising outliers did not change the pattern of results with the exception that GDP and its interaction with the *k*-parameter were both positively significant in the overall life expectancy model.

4. Discussion

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

Overall, as shown by the significant main effect of the *k*-parameter, individuals were less willing to wait for the future reward when the difference between this and the immediate reward was relatively small and/or the delay period was relatively long. This association was influenced by country-level life expectancy, providing insight into how ecological cues to mortality influences different future discounting scenarios that vary on delay period and relative gain. We find that when the relative gain is large with a short delay period, individuals from countries with lower life expectancy were less likely to choose the future reward. This suggests that mortality cues are not merely associated with an overall preference for immediacy (i.e. the main effect of life expectancy), but that ecological factors could potentially influence the way individuals use information regarding delay and relative gain when evaluating intertemporal decisions. This could not have been detected without testing future discounting using multiple intertemporal choice trials.

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

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

Similar to Bulley & Pepper [22], we did not find a main effect of GDP on future discounting behaviour when overall life expectancy was included in the model. This was thought to be because country-level life expectancy and wealth are in part linked, and that ecological, rather than economical factors are more likely to influence future discounting choices. However, in the individual-specific life expectancy model, we found a significant interaction between GDP and the *k*-parameter, which could not have been detected without having multiple observations at the individual-level. This interaction suggests that individuals in richer countries were more willing to choose the future reward when the relative gains were small and/or the delay period was long. One possible explanation is that individuals from richer countries possess an abundance of resources, and as such can afford the luxury of waiting for a future reward, even if the added benefit is small. This should be interpreted cautiously, however, as the interaction between GDP and the *k*-parameter was not significant in the overall life expectancy model. Also, contrary to predictions, we found that men were more likely to be future orientated compared to women in the individual-specific life expectancy model. This is contrary to previous findings that men discount the future more than women [3,10,29]. However, we did not find a sex difference in future discounting behaviours in the overall life expectancy model; therefore, sex differences should be interpreted cautiously. Overall, our findings suggest that while life-history theories can account for some findings (e.g. mortality and age effects), other findings (e.g. a potential opposite sex effect) are harder to reconcile. Social and economic factors are also likely to play a role in future discounting behaviour.

While we have taken the perspective that ecological factors are influencing individual future discounting behaviour, our data equally suggest that the reverse causality could be true, where countries in which individuals are more likely to favour immediacy lead to higher rates of mortality. Indeed, health behaviours often have delayed benefits; accordingly, future discounting behaviour is associated with engaging in risky or unhealthy behaviours, such as alcohol and tobacco use, which can significantly account for the mortality of a country (for a review, see [46]). Our analysis used national level statistics of life expectancy, and though finer geographical statistics (e.g. neighbourhoods as used in [47]), would provide a more accurate proxy for local mortality cues, using country-level statistics has previously provided insight into variation in life-history related traits [17,18,20–22]. Participants were also presented the choices in the same currency regardless of their country ($), which could potentially influence results as $1 is worth more in some countries than in others. Our data also cannot speak for whether future discounting behaviours are flexibly adaptive in response to ecological conditions. In order to investigate this, within-subjects studies with experimental manipulations are required; though previous work indicates that individual propensity to discount the future can be malleable [26,35,48].

Ethics. This research was approved by the University of Aberdeen's Psychology Ethics Committee.

Data accessibility. Data and code supporting this article are available at https://osf.io/xcy8j.

Authors' contribution. B.C.J. and L.M.D. designed the study and collected the data. A.J.L., B.C.J. and L.M.D. carried out data analysis. A.J.L. drafted the manuscript, which was revised by all authors.

Competing interests. We declare we have no competing interests.

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