A Normative Model of Delay Discounting Across the Lifespan: Tradeoffs Between Mortality, Fertility, and Parenting

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Abstract

The developmental trajectory of delay discounting has been debated for over 30 years, with empirical findings often inconsistent. The controversy stems partly from the absence of formal models to guide empirical investigation and theoretical construction. We proposed a normative model of delay discounting across the lifespan, building on the work of Sozou and Seymour (2003), which emphasizes the tradeoff between mortality, fertility, and parenting in determining delay discounting. We simulated the model across varying parameter spaces and identified a U-shaped association between age and delay discounting, with stronger parental investment postponing the turning point of the function and reducing the overall discount rate. Empirical data supported these predictions, demonstrating a U-shaped age effect and highlighting the role of parental care motivation in explaining cultural and age-related differences in delay discounting. The results suggest that variance in delay discounting can be understood as a rational adaptation to life history tradeoffs.

Keywords: age differences; delay discounting; intertemporal choice; time preference; life history theory

Introduction

Intertemporal choice, involving decisions with future consequences, is a fundamental aspect of many real-world human decisions (Frederick et al., 2002). Delayed rewards typically lose value over time, a phenomenon known as delay discounting. Since 1994, the developmental trajectory of delay discounting has been a topic of debate (Green et al., 1994). Understanding age differences in delay discounting is important for uncovering the mechanism underlying intertemporal decisions. For one perspective, delay discounting has been conceptualized as a measure of impulsivity and executive control (Bickel & Yi, 2008; Duckworth & Steinberg, 2015), suggesting its age-related changes may trace the development of the executive system. Additionally, aging involves complex physiological, affective, and motivational changes, making the developmental pattern of delay discounting valuable for identifying the psychological impetus drive intertemporal decisions.

Empirical findings over the past 30 years have yielded equivocal results. While early research suggested an age-related decline in delay discounting at least in some age ranges (Green et al., 1994; Jimura et al., 2011; Mok et al., 2020), later studies also revealed a U-shaped pattern, with middle-aged individuals showing the lowest discount rates (Göllner et al., 2018; Lu et al., 2022; Read & Read, 2004). In contrast, a competing perspective argue that delay discounting reflects a stable trait (Odum, 2011). Meta-analyses have added to the debate, with both minimal evidence for age effects (Seaman et al., 2022) and a U-shaped effect (Lu et al., 2023) were identified. This ongoing debate partly stems from the absence of formal models to guide investigation and theory development.

To address this gap, we propose a normative model of lifespan delay discounting. A normative model, or a computational theory, addresses why certain behaviors are beneficial under specific ecological conditions (Marr, 1982). This perspective extends beyond cognitive domains like perception (where optimization targets accuracy) to situations involving rewards and costs, closely aligning with evolutionary accounts (Ma et al., 2023). Our model builds upon Sozou and Seymour's mathematical framework (2003). Rather than assuming a predetermined functional relationship, we derive the age-discounting association from fundamental driving factors and their lifelong development, emphasizing the interplay between mortality, fertility, and parenting.

According to life history theory (LHT), organisms must optimally allocate limited resources between somatic (survival-enhancing) and reproductive efforts (Charnov, 1993). This fundamental tradeoff shapes the organism's life history strategies (LHS). Fast strategists prioritize early reproduction, while slow strategists favor later reproduction. Natural selection favors strategies maximizing reproductive fitness. From this perspective, individuals raised in harsh environments perceive high extrinsic mortality and tend to favor immediate rewards over delayed ones. Conversely, those from stable environments typically anticipate longer lifespans and conserves resources to maximize reproductive potential (Griskevicius et al., 2011; Martinez et al., 2022).

Beyond mortality, age-dependent fertility significantly shapes delay discounting. Optimal resource allocation should direct fitness-related resources toward periods of peak fertility to maximize reproductive success. As senescence reduces both survival probability and fertility in later life stages, fitness-related resources are subject to increasing temporal discounting. Since money provides material advantages and signals social status (Buss, 1989), monetary discounting likely falls under fertility's influence.

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A crucial yet often overlooked factor in determining optimal allocation strategies is parental investment. Unlike precocial species, human neonates are remarkably underdeveloped at birth, necessitating extensive parental investment through pair bonding, grandparenting, and alloparenting (Dunsworth et al., 2012). This unique reproductive challenge has selected specific psychological mechanisms regulating caregiving behavior (Preston, 2013), which characterize all developing humans beyond parents (Schaller et al., 2017). Empirical evidence supports this view, demonstrating that parental care motivation influences various behaviors (Eibach & Mock, 2011; Li et al., 2019; Sherman et al., 2009). For example, activation of parental motivation making nonparents behave more similarly to parents in terms of risk-taking (Sherman et al., 2009).

Within the fundamental social motive framework, parental care motivation emerges after satisfying status-seeking and mate acquisition goals (Schaller et al., 2017). In humans, this developmental stage requires a long-term caregiving commitment adapted to offspring development. Therefore, the activation of parental care should shift goals toward securing resources for long-term development of children, such as future economic stability. This is evidenced by the role of future household expenses, particularly children's needs, in financial planning and saving behavior (Canova et al., 2005). Therefore, the chronic development of parental care motivation should regulate delay discounting, with stronger activation corresponding to reduced discounting.

Based on the discussion of mortality, fertility, and parenting and their associations with delay discounting, we propose a normative model of lifespan delay discounting, extending Sozou & Seymour's work (2003). Our model characterizes the resource allocation problem organisms face and its optimal solution under given constraints. Following Marr's (1982) levels of analysis, our model operates at the computational level. We begin by defining the discount rate and its driving forces, solving the computational problem to derive lifespan discount rates, and discuss potential proximal mechanisms underlying this adaptation.

Model Specification and Simulations

We defined the instantaneous discount rate θ as in prior studies (Rogers, 1994; Sozou & Seymour, 2003):

$$\theta = \lim_{\mathrm{d}\tau \to 0}\left[\frac{u_i(0) - u_i(\mathrm{d}\tau)}{u_i(0) \times \mathrm{d}\tau}\right] = -\frac{u'_i(0)}{u_i(0)}$$

where τ is the delay of rewards, u is the utility of the reward (e.g., its contribution to fitness), and u' is its derivative with respect to delay. The instantaneous rate θ should not be confused with the discount parameter (e.g. the k in a hyperbolic function). However, for both exponential and hyperbolic discounting, θ increases monotonically with the discount parameter and thus our predictions on θ can be generalized to discount parameters in the psychology literature. Next, we defined the three components outlined in the introduction and analyzed how they relate to the instantaneous rate.

According to LHT, organisms maximize fitness across the lifespan by balancing somatic and reproductive efforts. In Sozou and Seymour (2003), the overall fitness w is modeled as:

$$w = \int_0^{+\infty} m\,(t)s(t)dt$$

where $m(t)$ is the reproductive output at age *t*, and $s(t)$ is the probability of surviving to age *t*. We argued that $m(t)$ can be decomposed into fertility F and parental investment P, which contribute to the survival and development of offspring:

$$w = \int_0^{+\infty} F\,(t)P(t)^p s(t)dt$$

Fertility represents reproductive capacity or mating opportunities; parental investment is the biological and material investment of parents to offspring. We further added a scaling exponent p to capture the relative importance of parental investment. To simplify the specification, the following derivation was based on p = 1. The formula highlights that fertility alone does not ensure reproductive success without sufficient parental investment.

Next, we defined the three components of the integral. The survival function follows the exponential form in Sozou and Seymour (2003):

$$s(t) = \exp\{-\lambda t + at - a(\exp(\beta t) - 1)/b\}$$

which implies that the instantaneous mortality rate increases with age *t* at an increasing rate:

$$\mu(t) = -\frac{s(t)'}{s(t)} = \lambda + a[\exp(bt) - 1]$$

where s' is the derivative of s with respect to age, λ represents the external mortality rate, and a, b control the steepness of the function.

We assumed that the function between age and fertility and parental investment follows the probability density function of a Gamma distribution with a shape parameter α greater than 1:

$$F(t; \alpha_f, \beta_f) = \frac{\beta_f^{\alpha_f} t^{\alpha_f - 1} e^{-\beta_f t}}{\Gamma(\alpha_f)}$$

$$P(t; \alpha_p, \beta_p) = \frac{\beta_p^{\alpha_p} t^{\alpha_p - 1} e^{-\beta_p t}}{\Gamma(\alpha_p)}$$

where α is the shape parameter, β is the rate parameter, and $\Gamma(.)$ is the gamma function. The Gamma distribution resembles a positively skewed normal distribution, resulting in an inverse U-shaped. The function was selected based on empirical findings on age-related fertility decline (Pal & Santoro, 2003). Parental investment follows a similar shape but with a delayed onset relative to the fertility function. This delay was induced by setting $\alpha_p > \alpha_f$ while keeping the rate parameter β constant, reflecting the sequential prioritization of mating before parenting (Schaller et al., 2017).

Following Sozou and Seymour, we assumed that LHS vary with external hazard rate (λ). LHS is represented by *y*, a value ranges from 0 to 1 that governs somatic efforts. We assumed that somatic efforts influence survival, fertility, and parental investment. First, somatic effort reduces the internal mortality rate brought by senescence:

$$s(t) = \exp\{-\lambda t + a(1-y)t - a(1-y)(\exp(\beta t) - 1)/b\}$$

$$\mu(t) = -\frac{s(t)'}{s(t)} = \lambda + a(1-y)[\exp(bt) - 1]$$

where greater somatic efforts (larger y), the slower the internal but not external mortality rate. Second, following Sozou and Seymour, somatic efforts reduce current reproductive efforts. We further assumed a delayed sexual maturity implied by LHT. These two assumptions were achieved by multiplying the rate parameter by y and thus shifting the peak of fertility function to a later age and decreasing the fertility before the peak:

$$F(t; \alpha_f, y\beta_f) = \frac{(y\beta_f)^{\alpha_f} t^{\alpha_f - 1} e^{-y\beta_f t}}{\Gamma(\alpha_f)}$$

Third, the delayed mature is accompanied by delayed and prolonged parental investment:

$$P(t; \alpha_p, y\beta_p) = \frac{(y\beta_p)^{\alpha_p} t^{\alpha_p - 1} e^{-y\beta_p t}}{\Gamma(\alpha_p)}$$

Based on these functions, the optimal LHS y can be estimated by maximizing the fitness w. Once the y is determined, the shapes of $F(t)$ and $P(t)$ are fixed and can be used to derive the utility. The utility of an immediate reward is defined as:

$$u(0) = \delta F(t) P(t)$$

where δ is the magnitude. For a delayed reward, the utility of the reward of the same magnitude is:

$$u(d\tau) = \delta F(t + d\tau) P(t + d\tau) \frac{s(t + d\tau)}{s(t)}$$

The instantaneous discount rate θ at any age t is then derived following Sozou and Seymour, yielding:

$$\theta = -\frac{\dot{u}(0)}{u(0)} = \mu(t) - \frac{\dot{F}(t)}{F(t)} - \frac{\dot{P}(t)}{P(t)}$$

The functions are normalized by dividing their modes.

In summary, we extend the original model in two aspects. First, by incorporating an inverse U-shaped fertility function, we expand the model's predictions across the entire lifespan instead of solely adulthood. This also establishes that early life decreases in delay discounting emerge endogenously from future reproductive potential rather than from environmental uncertainty as in the original model. Second, we integrated parental investment as a fundamental regulator of human delay discounting. The model predicted that higher fertility and greater anticipated parental investment in the future correspond to lower discount rates. Regarding proximal mechanism, these effects may operate through motivational systems. Individuals with increasing fertility may prioritize somatic efforts like status seeking to maximize reproductive potential. Similarly, the evolved parental caregiving motivational system can be activated based on the demands of parental investment, enhancing offspring survival and success (Beall & Schaller, 2019; Schaller, 2018).

To generate model prediction, we simulate delay discounting across 7560 conditions by varying six parameters: external mortality rate λ (0.005-0.060, by 0.01); survival steepness parameters a (0.001-0.005, by 0.001) and b (0.01-0.07, by 0.01); shape parameters that control the peak of fertility α_f (3-6, by 1) and parenting α_p (6-8, by 1); and the relative importance of parenting p (0.9-1.1, by 0.1). The shape parameters for fertility were informed by OECD family database reports on age-related fertility (*OECD Family Database*, 2022), whereas parental investment parameters were adjusted to ensure their maximum values occur later than peak fertility. We fixed the rate parameters for fertility and parental investment at 0.20. For each condition, we estimated the optimal LHS, then recovered the functions of survival, fertility, and parenting. The discount rate was then estimated. We evaluated: (a) the overall delay discounting across age; (b) the critical point where the derivative equals 0; (c) the overall steepness of the change of discount rate before and after the critical point; (d) the optimal LHS. ANOVAs were used to examine parameter effects on these outcomes.

We plotted incremental changes (changes in delay discounting relative to the previous time point) and estimated delay discounting across 500 randomly selected conditions (Figure 1A-1B). The results show a U-shaped age effect, with delay discounting declining early in life and increasing later. Samples with limited age ranges may only capture the declining phase. A specific simulation further highlights this trajectory (Figure 1C-1D).

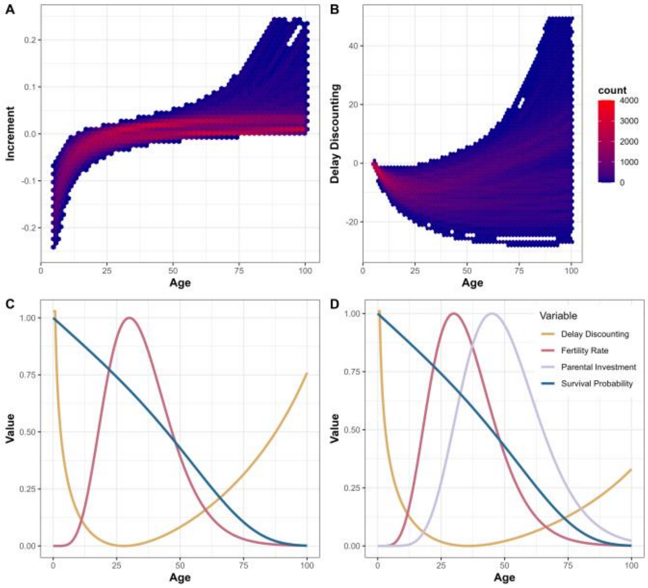

Figure 1: Simulated development of delay discounting across the lifespan: A. Incremental changes in delay discounting across the lifespan. B. The estimated delay discounting at each age. To minimize overplotting, point density is color-coded, with warmer colors (e.g. red) indicating higher density. C. A single simulation without parental investment based (λ = 0.01, a = 0.002, b = 0.05, α_f = 7). D. A single simulation with parental investment (λ = 0.01, a = 0.002, b = 0.05, α_f = 7, α_p = 10, and p = 1).

First, we investigated the influence of parental investment. A larger shape parameter (α_f) delayed the critical point (e.g., later reverse), $F(1,\ 7558) = 104.26, p < .001, \eta_g^2 = 0.014$. with post-hoc analysis showing increase in the critical point as α_f increased (alpha = 6: $M = 35.0$, $SD = 14.6$; alpha = 7: $M = 37.5$, $SD = 16.5$; alpha = 8: $M = 39.7$, $SD = 18.1$). Delay discounting decreased with higher α_f, $F(1{,}7558) = 1172.99$, $p < .001$, $\eta_g^2 = 0.134$ (alpha = 6: $M = -19.7$, $SD = 7.81$; alpha = 7: $M = -23.5$, $SD = 8.15$; alpha = 8: $M = -27.5$, $SD = 8.36$). It can be explained that an extended parenting period limits the influence of the gamma function's right tail within a finite lifespan. In addition, greater emphasis on parental investment (a greater p) reduced discount rate, $F(1,\ 7558) = 753.95$, $p < .001$, $\eta_g^2 = 0.091$.

Second, we examined the effect of fertility. Earlier sexual maturation (a smaller shape parameter α_p) shifted the critical point earlier, $F(1,\ 7558) = 177.35$, $p < .001$, $\eta_g^2 = 0.023$, and increased the discount rate, $F(1,\ 7558) = 1838.52$, $p < .001$, $\eta_g^2 = 0.196$. This occurs because earlier maturation implies earlier onset of senescence, thereby increasing overall discounting.

Third, we explored the interaction between age and life expectancy on delay discounting. The external mortality rate (λ) positively influenced the steepness of the age-discounting function, both before, $F(1{,}7558) = 18693.57$, $p < .001$, $\eta_g^2 = 0.712$, and after the critical point, $F(1{,}7558) = 1172.99$, $p < .001$, $\eta_g^2 = 0.134$. This was explained by the lower optimal value of somatic efforts under harsh environment, $F(1{,}7558) = 29827.99$, $p < .001$, $\eta_g^2 = 0.798$, which selects for earlier maturation and more contracted fertility functions. Therefore, the age-related change in discount rate is more pronounced for individuals with lower life expectancy.

In the remainder of this paper, we empirically test the model's chief prediction regarding the age effect and its novel predictions about parental investment using both cross-cultural and individual-level data.

Methods

Cross-Cultural Data

We examined the association between parental investment and delay discounting across cultures using parental care motivation as a proxy, derived from Pick et al. (2022). Participants completed the Fundamental Social Motives Inventory (FSMI), a 66-item instruments measuring 11 social motives (Neel et al., 2016). We focused on the Kin Care (Children) (KCC) motive, which measures parental care motivation. Participants with children rated 6 items on their attitude and investment toward their children from 1 (strongly disagree) to 7 (strongly agree) (e.g., "I like to spend time with my children."). Given the competitive relationship between parental care motivation and mate seeking motive, we also included Mate-Seeking subscale (MAT), a 6-item measure accessing motives for acquiring new sexual partners (e.g., I am not interested in meeting people to flirt with or date). Regional delay discounting data, obtained from Wang et al. (2016), was measured using a "wait-or-not" question, where participants chose between receiving 3400$ this month or 3800$ next month. Analyses were based on cultures recorded in both studies (*N* = 22).

Individual-Level Data

To further test the model predictions, we collected data from 401 participants via the online platform Credamo (age: *M* = 29.60, *SD* = 6.33, range = 17-57; 56% females).

Delay Discounting Delay discounting was measured using 7 intertemporal choices. Participants chose between a smaller but sooner reward ($120-$570) and a larger but later reward ($330-$1170), with delays ranging from 4 to 939 days. The subjective value of delayed rewards was characterized by a hyperbolic function. Discount rate (*k*) was estimated under the hierarchical Bayesian framework (Gelman et al., 2014) using Stan (Carpenter et al., 2017), with higher values indicating stronger preference for immediate rewards:

$$choice_{ij} \sim Bernoulli(\pi_{ij}),\ \pi_{ij} = \frac{1}{1+e^{-\beta_i (SV_2 - SV_1)}}$$

$$SV_1 = SS_j, SV_2 = \frac{LL_j}{1+k_i D_j}$$

$$k_i = \Phi(\mu_k + z_{k_i}\sigma_k),\ \beta_i = \Phi(\mu_\beta + z_{\beta_i}\sigma_\beta) * 5$$

$$\mu_k, \mu_\beta \sim StudentT(3{,}0{,}1),$$

$$\sigma_k, \sigma_\beta \sim Normal(0{,}0.2), z_{k_i}, z_{\beta_i} \sim Normal(0{,}1)$$

The jth choice of the ith participant has a Bernoulli likelihood function, with the probability calculated with a sigmoid function. SV denotes the subjective value of immediate reward (SS) and delayed reward (LL). The inverse temperature parameter β characterizes the noisiness of decisions. Φ is the cumulative probability function of a standard normal distribution, constraining the parameter within 0 to 1. We used non-centered parameterization to improve convergence, with *z* serving as the individual-level scaling factor. The model employed 4 Markov Chain Monte Carlo chains, each consisting of 1000 iterations after 1000 warm-up iterations. Subsequent analyses were based on the posterior mean estimation of the *k* parameter.

Parental Care and Mating Motivation We adopted two measures of parental care motivation. First, we used KCC as in the cross-cultural analysis. However, the brevity of KCC may limit its validity, and its restricted use among parents does not account for its relevance to non-parents. Thus, we also adopted the 25-item Parental Care and Tenderness (PCAT) questionnaire (Buckels et al., 2015), where participants rated their responses to 15 items regarding parental care (e.g., protection) and 10 items on tenderness they feel in scenarios involving children on 5-point scales (1 = No tenderness at all/Strongly disagree; 5 = A lot of tenderness/Strongly agree). A sample item is "When I see infants, I want to hold them". We calculated both parental care and tenderness scores. As in our cross-cultural analysis, we also measured the MAT scales. We investigated the reliability of these measures. Unexpectedly, KCC exhibited low reliability, McDonald's omega = 0.60 (95% CI [0.50, 0.70]), in sharp contrast to the original paper (Neel et al., 2016). The PCAT scores and tenderness showed good reliability, omega is 0.88 (95% CI [0.85, 0.90]) and 0.83 (95% CI [0.80, 0.86]), respectively. The MAT measure was also reliable, omega = 0.91 (95% CI [0.88, 0.93])

Life History Strategy Life history strategies were assessed using the Mini-K scale, a 20-item short form of the Arizona Life History Battery (Figueredo et al., 2006). A sample items is, "While growing up, I had a close and warm relationship with my biological mother." Higher total scores reflect a slower strategy. The Mini-K scale demonstrated good reliability (omega = 0.88, 95% CI [0.86, 0.90]).

Results

Parental Care Motivation Explains Cross-Cultural Variance in Delay Discounting

The parental care motive decreased delay discounting (Figure 2A), Spearman's ρ = -.44, *p* = .045. Given that parental care and mate acquisition motivations inhibit each other, we also investigated the effect of mate-seeking motivation on the discount rate. There was a significant positive correlation between delay discounting and mate-seeking motive (Figure 2B), Spearman's ρ = .44, *p* = .039. Controlling for GDP per capita did not weaken the association; the correlations remained substantial at -.41, *p* = .074, and .44, *p* = .044, respectively. Thus, cultural differences in delay discounting can be explained by social motives.

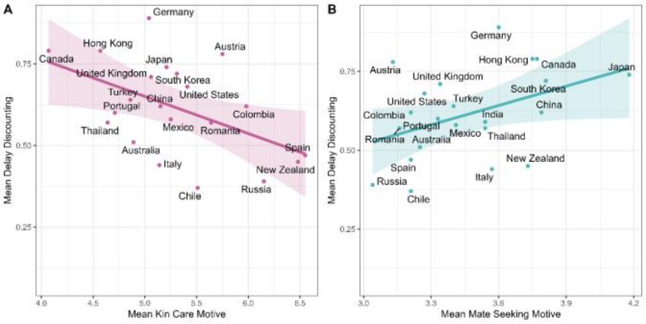

Figure 2: Regional correlations of kin care (A) and mate-seeking (B) motives with delay discounting.

A U-shaped Relationship Between Age and Delay Discounting at the Individual Level

To explore the relationship between age and delay discounting, we employed a generalized additive model (GAM) with smoothing splines (Sohil et al., 2021), allowing for a flexible functional form. The smoothing parameter (λ) was selected via leave-one-out cross-validation to minimize overfitting. The estimated regression spline revealed a U-shaped relationship between age and discount rate (Figure 3 left panel), with middle-aged adults exhibiting the lowest delay discounting. Model comparisons supported this nonlinear pattern over a linear model, *F*(2, 386) = 3.596, *p* = .059, suggesting a U-shaped age effect on delay discounting.

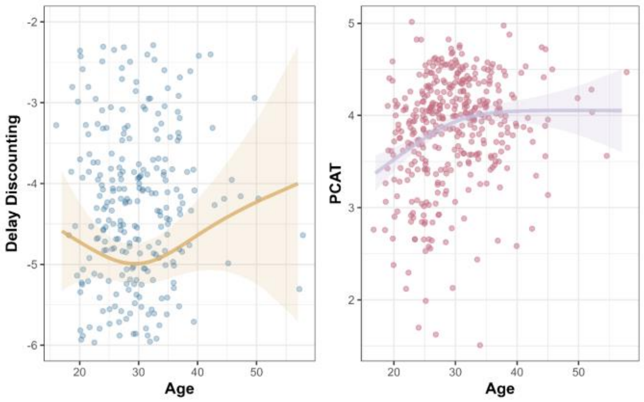

Figure 3: The relationship between age and (A) delay discounting and (B) PCAT scores. Points represent individual observations. Lines depict the estimated relationships derived from generalized additive models.

Parental Care Motivation Regulated Delay Discounting Across the Lifespan

We next investigated the effect of parental care motivation on delay discounting. Participants with higher PCAT scores showed lower delay discounting, Spearman's ρ = -.17, *p* < .001. The partial correlation between PCAT scores and delay discounting while controlling Mini-K scores remained significant, Spearman's ρ = -.12, *p* = .019.

For our second measure of parental care motivation, KCC scores showed no significant correlation with delay discounting, though the trend was in the expected direction, Spearman's ρ = -.05, *p* = .052. A potential explanation is range restriction, as our sample exhibited strong KCC motivation (*M* = 6.00, *SD* = 0.57) compared to the international mean (*M* = 5.30, *SD* = 0.63), which may have attenuated the association.

Contrary to our prediction, the correlation between MAT and delay discounting was insignificant, though it followed the expected direction, Spearman's ρ = .07, *p* = .196. We also failed to replicated the inverse relationship between KCC and MAT reported in previous studies (Neel et al., 2016), Spearman's ρ = -.08, *p* = .251.

Given the link between PCAT and discount rate, we tested whether parental care motivation mediated the age effect on delay discounting. A GAM with a smoothing spline revealed that PCAT increased with age at a declining rate, which significantly improved model fit compared to a linear model (Figure 4 right panel), *F*(1, 398) = 15.72, *p* < .001. Then, we tested mediation with a nonlinear mediation model, which showed a significant indirect effect of age on delay discounting via parental care, a × b = -0.04, *p* = .036, bootstrap 95% CI [-0.29, -0.01]. A similar age effect was found for tenderness, with tenders gradually increased with age, *F*(1, 398) = 9.28, *p* = .002. The mediation model showed a marginal mediation effect of tenderness, a × b = -0.23, *p* = .060, bootstrap 95% CI [-0.51, 0.00].

Discussion

An expanding collection of studies since 1994 has investigated age differences in delay discounting. We advance the field by proposing a normative model that explains the ultimate reasons for this development. The model predicts, for most cases, a U-shaped age effect, positing that prolonged parental investment delays the turning point and reduces overall discounting. Cross-cultural data supported this prediction, showing that parental care motivation accounts for cross-cultural differences in delay discounting. Individual-level data further supported the U-shaped age effect, modulated by the same parenting motivation. By synthesizing ultimate and proximal explanations, the model provides a unified account of developmental trends in delay discounting.

Central to the model is its alignment with prior evidence for a U-shaped age effect (Read & Read, 2004; Richter & Mata, 2018). The pattern represents the optimal strategy that organisms employ under specific environmental and somatic constraints. Age-related changes in delay discounting are conceptualized as a resource allocation process that maximizes inclusive fitness (Del Giudice et al., 2016; Griskevicius et al., 2011). Specifically, early-life declines in delay discounting reflect the increase in fertility and demands of parental investment, while later-life increases are driven by rising mortality rates, declining fertility, and reduced parental obligations. Beyond developmental trend, the model also captures the effect of life expectancy (Bulley & Pepper, 2017), childhood environment conditions (Martinez et al., 2022), and the interaction between age and life expectancy (Lu et al., 2023) observed in previous studies. Future studies could examine how fertility effects operate through proximal psychological mechanisms that are evolutionarily adapted to maximize reproductive potential.

Despite these findings, we emphasize that our model is normative rather than descriptive, distinguishing it from empirical models that prioritize statistical fit. Although the U-shaped pattern is statistically the most probable and has received empirical support (Liu et al., 2025; Richter & Mata, 2018), an lifelong increase or decrease in discounting may occur in samples with atypical characteristics, such as unusual longevity or mortality rates. Moreover, the U-shaped pattern may not generalize across species or domains without justifications. Unlike money, many natural goods are less fungible and more perishable (Holt et al., 2016), making delayed gratification less adaptive in some contexts.

Our findings also underscore the important role of parental investment and accompanying psychology (e.g., parental care motivation) in understanding human decision-making. The metabolic hypothesis of altriciality posits that human altriciality stems from the rapid energy demands of fetal development, which push maternal metabolic rates to their maximum capacity (Dunsworth et al., 2012). Therefore, there is a shift from intrauterine investment to external and prolonged postnatal care. We argue that, given this recurrent and fundamental evolutionary challenge, this shift in investment must be deeply integrated into various human behavior including delay discounting. The substantial nutritional and material demand of offspring should promote a resource-accumulation strategy, thereby lowering discount rates. However, previous studies on the relationship between parental care motivation and delay discounting have yielded inconsistent findings (Li et al., 2019; Li & Liu, 2018), with few examining the chronic developmental effects of parental care. One potential explanation for these discrepancies lies in cross-cultural and demographic variations in perceptions of the parenting role. For instance, Li et al. (2019) demonstrated that the effect of parenting motivation on delay discounting is moderated by gender-specific stereotypes. However, the notion that parental care motivation increases delay discounting is particularly challenging theoretically. Given the antagonistic relationship between mate-seeking and parental motivations (Beall & Schaller, 2019) and evidence that mate-seeking motivation heightens delay discounting (Wilson & Daly, 2004), this finding suggests a complex suppression effect, as indicated by conflicting direct and indirect path coefficients.

This study has several limitations. First, consistent with standard LHT approaches, our model assumes fixed mortality rates. This assumption may oversimplify the dynamic interactions between organisms and their environments, overlooking the active efforts organisms make to mitigate mortality risks (Del Giudice et al., 2016). A related issue of fixed mortality rates is their assumption that all individuals contribute equally across ages, ignoring that those facing higher extrinsic mortality often don't survive to older ages—creating potential selection bias in empirical data. However, Figure 1B suggests that even when individuals with the highest mortality rates perish (removing the upper section of curves) while those with middle-level rates survive to later life stages, the U-shaped pattern of discounting is preserved. Second, we did not collect individual-level data across cultures, leaving the age effect under varying socioeconomic conditions unexplored. The low reliability of KCC suggests potential cultural differences in how parental investment is conceptualized. Further investigation is needed to determine whether the influence of parental investment on delay discounting is tied to specific components of parental motivation. Third, we lack longitudinal data, particularly from childhood, which limits our ability to track developmental trajectories of discounting.

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