Supplemental Materials

To accompany

How adolescents and adults translate motivational value to action: Age-related shifts in strategic physical effort exertion for monetary rewards

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Null Inference Tests

To draw conclusions based upon non-significant results, we used Bayesian methods to derive probability estimates assessing the likelihood that the observed null effect reflects a true underlying null distribution (Kruschke, 2011). Our results yielded null effects of age with respect to two outcome measures, both of which correspond to incentive motivation of the reward cues: peak grip force and speed dependent variables (see main text Results).

For the null inference tests, we used Bayesian parameter estimation with a Region of Practical Equivalence (ROPE) approach and the *brms* package in R (Bürkner, 2017). This approach provides additional information to aid inferences of whether a statistically null effect in the observed data is consistent with a true underlying null distribution. This is achieved by creating an interval surrounding a null value (e.g., a parameter estimate of zero), indicating a *region of practical equivalence* or ROPE, wherein estimates from the posterior distribution that fall within this interval are considered effectively zero and therefore not meaningful for inference. The degree of overlap between the posterior distribution and the ROPE interval(s), quantified as the percent of posterior distribution falling within the ROPE interval, informs the confidence with which we can infer that the observed effects do not represent a meaningful change of the dependent variable.

Because there are no agreed upon ranges denoting a meaningful or meaningless difference from zero for these dependent measures (i.e., no comparable *a priori* effect size from research examining the impact of differential reward levels on effortful output by age) to define the ROPE, we created a set of incrementally increasing ROPEs. We then compared the posterior distribution of parameter estimates against the ROPE intervals to identify the degree of overlap. The greater the proportion of the distribution falling within the narrower ROPE intervals, the greater confidence that the observed effects do not represent a meaningful change of the dependent variable. In the current approach, the set of ROPEs spanned from extremely narrow intervals, containing very little of the posterior distribution, to increasingly wider intervals, eventually containing nearly all of the posterior distribution. This approach allowed us to objectively characterize the data (e.g., point at which most of the distribution falls within a ROPE) in a transparent way over a series of ROPEs.

For peak grip force, we created a set of ROPE intervals spanning 0.1-1.0%, increasing by increments of 0.1%, where the narrower the interval, the more likely overlapping peak grip force parameter estimates are considered effectively zero (Table S3). This incremental set of ROPEs allows for greater insight into the likelihood of null effects, such that we examined a gradient of intervals and identified an approximate point at which the majority (i.e., > 50%) of the posterior distribution fell within a given ROPE. Using this point as a reference, findings revealed that 70% of the simple effect of age parameter posterior distribution fell between +/-0.3% of peak grip change, indicating that with each increasing year of age, peak grip force changed by less than 0.3%, and 83% of the reward by age interaction parameter posterior distribution fell between +/-0.1%, such that with each increasing year of age, peak grip force changed by less than 0.1% for high compared to low reward trials. These findings suggest a high likelihood of the observed null effect reflecting a true null effect and build confidence that incentive-driven modulation of peak grip force is equivalent across age.

A similar approach was taken for speed, we created a set of ROPE intervals spanning 1-10ms, increasing by increments of 1ms, where the narrower the interval, the more likely speed parameter estimates are considered effectively zero (Table S3). ROPE intervals were log transformed to match the dependent variable. Using the approximate point of plateau as a reference, findings revealed that 50% of the simple effect of age parameter posterior distribution fell between +/-4 ms of speed change, indicating that with each increasing year of age, speed changed by less than 4 ms, and 57% of the reward by age interaction parameter posterior distribution fell between +/-3 ms of speed change, such that with each increasing year of age, speed changed by less than 3 ms for high compared to low reward trials. These findings suggest that more likely than not, the observed effects reflect a true null effect wherein incentive-driven modulation of grip speed is equivalent across age.

Control Analyses

Examining influence of peak grip force on perseveration

We completed control analyses for the dependent variable *perseveration*, to determine whether effects are simply explained by the magnitude of the peak grip force for a given trial. Given that peak grip force reflects the maximum height of the grip function, it is inexorably linked with the measure of perseveration, quantified as the area-under-the-curve post-peak and above threshold. Therefore, greater perseveration could purportedly be a function of greater height of the grip function. To evaluate this possibility, we recomputed the primary statistical model described in the main text while also including each trial's peak grip force as a trial-wise nuisance regressor. All previously reported findings held, wherein perseveration increased with reward (B=0.045, SE=0.022, 95% CI: [0.001, 0.088], $p<0.05$), decreased with age (B=-0.036, SE=0.009, 95% CI: [-0.054, -0.018], $p<0.001$), and this age effect was especially true for low reward trials (age-by-reward interaction: B=0.017, SE=0.006, 95% CI: [0.005, 0.029], $p<0.01$), indicating that the age-related findings related to perseveration are not redundant with measures of peak grip force but rather, carry unique variance.

Characterizing preparation

We undertook additional analyses for the dependent variable preparation to help further characterize this latency before effort exertion. Specifically, we tested whether preparation time was associated with either peak grip force or opt-out tendency to determine whether longer preparation time might either facilitate the execution of the grip force action or reflect a putative decision-making process about whether to opt-out of trials. First, we computed a linear mixed-effects robust regression with preparation latency as the predictor, peak grip force as the dependent variable, and y-intercept as a random effect grouped by participant. Findings revealed that preparatory delay was positively associated with increased peak grip force (B=0.002, SE=0.001, 95% CI: [0.001, 0.003], p<0.001). Next, we computed a mixed-effects logistic regression with preparation latency as the predictor, opt-out trials as the outcome, and y-intercept as a random effect grouped by participant. Findings revealed no significant relationship between preparatory delay and whether individuals subsequently opted-out of that trial (B=0.0001, SE=0.0001, p=0.446), suggesting it served an instrumental purpose that is specific to executing grip force.

Intercorrelations of dependent variables

Intercorrelations of the dependent variables within their respective conceptual classes (i.e., incentive-guided effort exertion and strategic conservation of effort exertion) were computed in order to ensure that these measures were not redundant or requiring multivariate analyses. We undertook additional analyses to evaluate the degree of interrelatedness among dependent variables. After computing an aggregated value of each dependent measure to account for differing number of usable trials per measure, Pearson correlations were computed within each class: peak and speed within the class of *incentive-guided effort exertion*; perseveration, preparation, and opt-out trials within the class of *strategic optimization of effort exertion*. Findings revealed that correlations were only significant within the class of *incentive-guided effort exertion*, between peak grip force and speed (Table S4). However, because the amount of shared variance only amounted to 16%, a multivariate analysis was not deemed necessary.

Influence of previous trial on task behavior

Based on the reasoning that previous gains and losses could induce prediction-error like signals that could influence subsequent behavior, we examined whether reward level on the previous trial influenced the key findings of the present study. To do so, we used dummy coding at the trial level to classify whether the reward level of the previous trial was higher, lower, or the same as the subsequent trial. Trials were coded as (1) if the previous trial was a low reward level and the subsequent trial was a high reward level, as (-1) in the reverse instance, and as (0) if the trial was the same as the previous one. We then re-ran analyses for all dependent variables reported in the manuscript, while including this previous trial coding as a covariate. Findings revealed that all key findings held, even when accounting for the congruence of the previous trial's reward level. This suggests that the immediate reward history is not confounding the effects described in the paper.

Supplemental Figures and Tables

Table S1. Quadratic age terms for regression models of each dependent variable

Dependent variable	Covariate	*B*	*SE*	95% CI lower	95% CI upper	*p*
Peak Grip Force	Quadratic Age	-29.482	27.087	-82.572	23.609	> 0.05
	Quadratic Age by Reward	-14.554	13.078	-40.187	11.079	> 0.05
Speed (log transformed)	Quadratic Age	2.302	1.735	-1.098	5.703	> 0.05
	Quadratic Age by Reward	-0.537	0.591	-1.695	0.622	> 0.05
Perseveration (log transformed)	Quadratic Age	-2.596	3.387	-9.234	4.043	> 0.05
	Quadratic Age by Reward	-1.136	1.864	-4.789	2.518	> 0.05
Preparation (log transformed)	Quadratic Age	0.952	1.985	-2.939	4.843	> 0.05
	Quadratic Age by Reward	-0.778	0.977	-2.692	1.136	> 0.05
Opt-out	Quadratic Age	38.178	43.407	-46.900	123.255	> 0.05
	Quadratic Age by Reward	53.537	33.137	-11.411	119.810	> 0.05

Note: *B* = unstandardized coefficient, *SE* = standard error of coefficient

Table S2. Descriptive statistics for all dependent measures by reward x difficulty

	Peak (%)		Speed (ms)		Perseveration (a.u.)		Preparation (ms)		Opt-out (%)	
Condition	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Low Reward x Low Difficulty	55.63	9.41	655.61	257.89	0.63	1.01	1125.34	829.79	0.24	4.92
High Reward x Low Difficulty	57.95	10.79	645.71	258.20	0.85	1.63	1204.67	1068.09	0.00	0.00
Low Reward x High Difficulty	86.74	7.09	1053.84	471.35	0.30	0.52	1435.61	1364.30	9.59	29.46
High Reward x High Difficulty	88.01	7.17	1012.60	489.98	0.34	0.53	1533.88	1623.47	1.82	13.38

Note: *M* = mean, *SD* = standard deviation

Table S3. Bayesian ROPE null inference tests for peak grip force and speed

Dependent variable	Percentage of posterior distribution within ROPE									
Peak Grip Force ROPE	+/- 0.1%	+/- 0.2%	+/- 0.3%	+/- 0.4%	+/- 0.5%	+/- 0.6%	+/- 0.7%	+/- 0.8%	+/- 0.9%	+/- 1.0%
Simple effect of age	21%	46%	70%	88%	96%	99%	100%	100%	100%	100%
Age by reward interaction	83%	99%	100%	100%	100%	100%	100%	100%	100%	100%
Speed ROPE	+/- 1ms	+/- 2ms	+/- 3ms	+/- 4ms	+/- 5ms	+/- 6ms	+/- 7ms	+/- 8ms	+/- 9ms	+/- 10ms
Simple effect of age	13%	27%	39%	50%	60%	68%	76%	82%	86%	90%
Age by reward interaction	17%	37%	57%	75%	89%	96%	99%	100%	100%	100%

Note: Percentage refers to the percentage of estimates from the posterior distribution of a Bayesian hierarchical model (15,000 samples) fell between the region of practical equivalence (ROPE) indicated by a +/- range.

Table S4. Correlation matrix of aggregated dependent measures by class

Incentive-guided effort	Peak	Speed	
Peak	-		
Speed	-0.403***	-	
Strategic effort exertion	Perseveration	Preparation	Opt-out
Perseveration	-		
Preparation	-0.051	-	
Opt out	-0.181	0.077	-

Note: pearson r values reported. *=p<.05, **=p<.01, ***=p<.001

Supplemental Figure 1

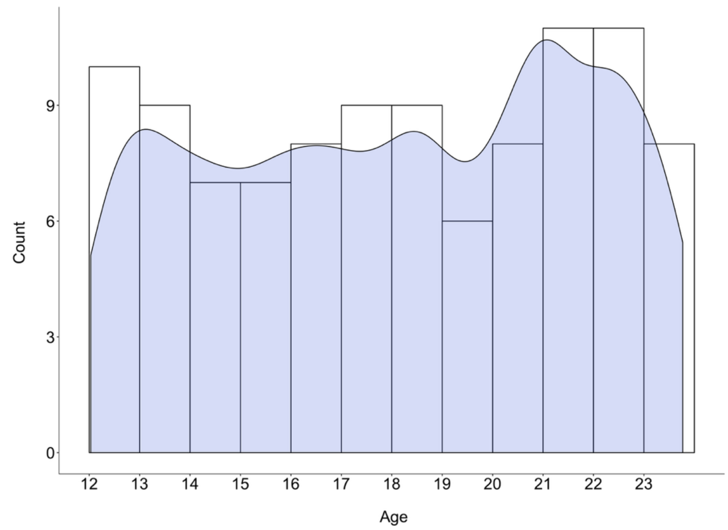

Figure S1. Age distribution of final usable sample. Bars represent the frequency of participants at each age, and shaded area represents a density plot overlaid onto the histogram.

REFERENCES

Bürkner, P.-C. (2017). brms: An R Package for Bayesian Multilevel Models Using Stan. *Journal of Statistical Software*, *80*(1). https://doi.org/10.18637/jss.v080.i01

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