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Discounting Environmental Outcomes: Temporal and Probabilistic Air-Quality Gains and Losses

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Much human choice and decision-making research has employed a discounting framework to help aid our understanding of how time, uncertainty, and other factors influence an outcome's value. Most of this research, however, is limited to the study of monetary outcomes. The purpose of the present study was to assess the discounting of an environmental outcome—changes in air quality. Participants made repeated choices between a smaller, immediate (or certain) and larger, later (or uncertain) change in air quality. Using the Air Quality Index, an interval scale developed by the Environmental Protection Agency that quantifies the density of air particulate matter (e.g., pollution), these changes were framed as either an "improvement" (gain) or "worsening" (loss) of air quality. The rate of discounting delayed environmental gains did not differ significantly from delayed environmental losses, although a small-to-medium effect size was observed between these conditions. In contrast, probabilistic environmental gains were discounted substantially more than probabilistic environmental losses. Finally, the discounting of all environmental outcomes was well described by a hyperboloid in which the independent variable (delay until or odds against the outcome) is exponentiated. These findings not only show the potential for studying environmental decision making within a discounting framework, they are the first to demonstrate a sign effect (i.e., gain–loss difference) with probabilistic environmental outcomes.

Keywords: delay discounting, probability discounting, air quality, environment, decision making

The psychological dimensions of time and uncertainty likely lie at the heart of any attempt to understand and alter anthropogenic climate exchange (Gifford, 2011). That is, many of the untoward consequences of human behavior (e.g., excessive resource consumption, burning of fossil fuels) are delayed, and the likelihood of various environmental outcomes (e.g., global temperature rises) is less than certain. Fortunately, time and uncertainty has been studied extensively within the "discounting" paradigm—an empirical framework to examine how changes in various factors influence the value of an outcome (Madden & Bickel, 2010). An important finding

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to emerge from this research is that both delay and uncertainty reduce the value of an outcome in a manner that is well described by a hyperbola (Mazur, 1987; Rachlin, Raineri, & Cross, 1991):

$$V = \frac{A}{1 + bX}, \tag{1}$$

where V is the subjective value of an outcome of amount A, b is a free parameter that describes the rate of outcome devaluation (i.e., discounting), and X is the physical variable along which discounting is assessed. Thus, in delay-discounting tasks, X is a unit of time that represents the delay until an outcome's occurrence, while in probability discounting tasks, X is typically expressed as the odds against an outcome ($X = [1 - p]/p$, where p = probability of outcome).

Discounting data are often better described when the denominator of Equation 1 includes an exponent (Myerson & Green, 1995; Rachlin, 2006). In Rachlin's (2006) hyperboloid, the physical variable, X, is exponentiated:

$$V = \frac{A}{(1 + bX^s)}. \tag{2}$$

Note that Equation 2 reduces to Equation 1 when $s = 1.0$. When $s < 1.0$, V declines more and less rapidly across smaller and larger values of X, respectively, than is predicted by Equation 1. Although the theoretical interpretation of s may differ depending on whether one is discussing delay or probability discounting (see McKerchar, Green, & Myerson, 2010), descriptively this model provides a good-to-excellent characterization of both delay and probability discounting.

It is important to note, however, the vast majority of research on discounting has involved monetary outcomes (but see, e.g., Charlton & Fantino, 2008; Estle, Green, Myerson, & Holt, 2007; Odum, Baumann, & Rimington, 2006). Somewhat surprisingly, there has been relatively little research directed at understanding choice in a discounting framework with environmental outcomes (Berry et al., 2017; Hardisty & Weber, 2009; Kaplan, Reed, & McKerchar, 2014). Nevertheless, one approach to assessing the discounting of environmental outcomes was described by Hardisty and Weber (2009). In their Studies 2 and 3, participants made hypothetical choices between smaller, immediate, and larger, delayed improvements or decrements in local air quality. Air quality improvements or decrements were expressed as points of the Air Quality Index (AQI), a scale developed by the U.S. Environmental Protection Agency (EPA) that quantifies the density of air particulate matter (see EPA, 2009). The AQI was developed to help provide the public with information about their local air quality; its score is determined from four major air pollutants: ground-level ozone, particle pollution, carbon monoxide, and sulfur dioxide. The value of an AQI score ranges from 0 to 500, with higher values indicating greater pollution and health risks (<100 generally considered safe). Thus, the AQI has the properties of an interval measure (Stevens, 1946) and, as such, may provide an easily quantifiable metric for presenting environmental outcomes within a discounting framework.

With changes in the AQI score as an outcome for studying environmental discounting, Hardisty and Weber (2009) found that delayed environmental gains were discounted significantly more than delayed environmental losses. Thus, participants frequently chose a smaller, immediate (rather than a larger, delayed) change in air quality when it was an improvement, but they also frequently chose the smaller, immediate change in air quality when it was a decrement. Colloquially, the former pattern might be considered "impulsive," whereas the latter might be considered "self-controlled." The greater discounting of delayed gains than losses has frequently been demonstrated with *monetary* outcomes, at least at smaller amounts—a finding known as the "sign effect" (e.g., Estle, Green, Myerson, & Holt, 2006; McKerchar, Pickford, & Robertson, 2013). The sign effect has also been observed with probabilistic monetary outcomes, with greater discounting of probabilistic gains than probabilistic losses, particularly at larger amounts (e.g., Estle et al., 2006). More specifically, when making choices between smaller, but certain and larger, but uncertain monetary outcomes, people more frequently choose the smaller, certain outcome when it is a gain whereas they more frequently choose the larger, uncertain outcome when it is a loss. Thus, people tend to be more "risk averse" with gains and "risk seeking" with losses.

Recently, Berry et al. (2017) assessed environmental discounting among college students and online participants in which the outcome was a *duration* of air quality improvement. Specifically, across a series of tasks participants chose between shorter, but immediate improvements (e.g., "50 days of better air quality now") and larger, but delayed improvements ("100 days of better air quality in 1 month"). They found that large air quality gains were discounted less than small air quality gains. In addition, the discounting of air quality was well described by a hyperboloid.

In the present study, we replicated the procedure originally described by Hardisty and Weber (2009) to examine both the delay discounting of environmental gains and losses, with changes in the AQI score as the outcome. Furthermore, we extended this procedure to the domain of uncertainty by assessing the probability discounting of air quality gains and losses. To our knowledge, this is the first study to examine the discounting of probabilistic air quality outcomes.

Method

Twenty college students (15 female) were recruited from an undergraduate psychology course and received course points as remuneration. The Institutional Review Board at Jacksonville State University approved all study procedures prior to their conduct. The participants' average age was 24.7 (range = 18–37) years, with 75% of the sample identifying as Caucasian (15% African American, 5% Hispanic, and 5% Native American). The experimenter tested participants individually during a 30-min scheduled visit in a small office with a table, two chairs, and a desktop computer and monitor. After a participant provided informed consent and completed a brief demographic questionnaire, the experimenter presented them with an 11-page pamphlet published by the EPA (2009), *Air Quality Index: A Guide to Air Quality and Your Health*. The experimenter briefly described the purpose of the pamphlet to the participant (i.e., an informational brochure on air quality and its measurement via the AQI), before drawing their attention to several sections particularly relevant to the discounting tasks. These sections discussed the importance of local air quality and the nature of the AQI (EPA, 2009, pp. 2–3; see Appendix). Next, the experimenter told the participant to take as much time as they needed to read the pamphlet, before the experimenter left the room. Usually within 5 min, the participant notified the experimenter they had read the pamphlet, and the experimenter returned to instruct them in the remaining portion of the study.

All participants completed each of four tasks: delayed environmental gains, delayed environmental losses, probabilistic environmental gains, and probabilistic environmental losses. Participants were randomly assigned to receive either two gains tasks followed by two losses tasks, or two losses tasks followed by two gains tasks, with the order of the domain (delay or probability) randomly determined within each sign. Prior to the first task, participants were told they would make a series of choices about their local air quality, and that although these choices were hypothetical, they should make their choices as though they were real. Then, depending on the task to which they were first assigned, they were presented with a vignette to help establish the context of their choices. In the delayed gains (or losses) task, the following description was presented to participants on the computer monitor:

> Imagine that county officials are considering two different emissions policies, both of which would IMPROVE [WORSEN] the air quality in your area of residence. Under one policy, the air quality would improve [worsen] RIGHT NOW by some amount. Under another policy, the air quality would improve [worsen] LATER by another amount, and the screen will show you how long until the air quality will improve [worsen] by that amount.

In the probabilistic gains (or losses) task, the following description was presented:

> Imagine that county officials are considering two different emissions policies, both of which could IMPROVE [WORSEN] the air quality in your area of residence. Under one policy, the air quality would improve [worsen] FOR SURE by some amount. Under another policy, the air quality MIGHT POSSIBLY improve [worsen] by another amount, and the screen will show your chances the air quality will improve [worsen] by that amount.

All subsequent screens within a task constituted a series of choice trials, with the first two series consisting of practice trials. At the top of each of these screens, the following statement was included, "Assuming the AQI score is 125, would you rather have the AQI score IMPROVE [WORSEN] by . . .?"[1] Below this statement were two options, each presented as text within a square. In the delayed gains and losses tasks, the two options were presented as a choice between a smaller, immediate (left side of screen) and a larger, later (right side) change in air quality, expressed as points of the AQI. In the probabilistic gains and losses tasks, the two options were presented as a smaller, certain ("for sure") change in air quality and a larger, uncertain change in air quality. Participants indicated their choice by pressing either the *Z* (for the smaller amount) or *M* (larger amount) key. The amount of the smaller, immediate (or certain) outcome was initially half the amount of the larger, delayed (or uncertain) outcome, which was always 100 points (e.g., 50-point improvement now vs. 100-point improvement in 1 day). In the subsequent trial, the amount of the smaller, immediate (or certain) outcome was increased or decreased by half of the initial amount of the smaller outcome, while the larger, delayed (or uncertain) outcome remained fixed. For example, in the delayed gains task, if a participant chose the smaller, immediate improvement on the first trial, the second trial was a choice between a "25-point improvement now" and a "100-point improvement in 1 day." If instead the participant chose the larger, later improvement on the first trial, the second trial was a choice between a "75-point improvement now" and a "100-point improvement in 1 day." Thereafter, the size of each adjustment of the smaller outcome decreased by half the size of the previous adjustment, for a total of five choice trials, converging on a point of subjective equality (indifference) at each delay or uncertainty level (see Du, Green, & Myerson, 2002). The method of adjusting the smaller outcome was identical for gains and losses, except with losses the direction of the adjustment was opposite to that of gains. For example, if a participant chose an immediate 50-point decrement in air quality (rather than a delayed 100-point decrement), the amount of the immediate air-quality decrement on the subsequent trial was 75 points. The range of delays until the later outcome was 1 week to 25 years, and delays were presented in the following order across each series of trials: 1 month, 5 years, 25 years, 1 week, and 1 year. The probability of the uncertain outcome ranged from 10% to 90% and were presented in the following order: 70%, 30%, 10%, 90%, and 50%.

Results and Discussion

Figure 1 shows the group median indifference points in each of the four tasks (top panels). Across all tasks, a hyperboloid (Equation 2) provided a good-to-excellent description of the discounting of environmental outcomes (see top row). Specifically, in the delayed gains and losses task, Equation 2 accounted for 89.1% and 97.4% of variance, respectively (*Sy.x* [SD of residuals] = .119 and .044). In the probabilistic gains and losses tasks, Equation 2 accounted for 98.1% and 97.1% of the variance, respectively (*Sy.x* = .049 and .059). The parameter values of *b* and *s* from Equation 2, derived from the group medians, are shown in Table 1. Using a similar procedure, Berry et al. (2017) found that Myerson and Green's (1995) hyperboloid, in which the entire denominator of Equation 1 is exponentiated, described the discounting of delayed air quality gains. These findings are the first to show that Equation 2 generally provides an excellent fit to the discounting of air quality outcomes, and they extend Berry et al. (2017) by showing hyperboloid discounting of probabilistic environmental outcomes.

To assess for nonsystematic discounting among individual participants, we applied a method reported by Franck, Koffarnus, House, and Bickel (2015). Specifically, this procedure compares a "random noise" model (i.e., delay invariance with deviations attributed to random chance) to a family of discounting models, including the hyperbola and hyperboloid, to identify a model of best fit. Importantly, all of the models against which the noise model is tested

[1] An AQI score of 125 was chosen as the current local air quality because it represents the median value of a score in the *unhealthy for sensitive groups* range (101–150). Scores below this range become increasingly safer for everyone, and scores above this range begin to be unhealthy for sensitive populations (e.g., children, older adults, people with lung diseases). With further increases in the AQI score, the air quality becomes unhealthy for everyone (see Appendix; EPA, 2009).

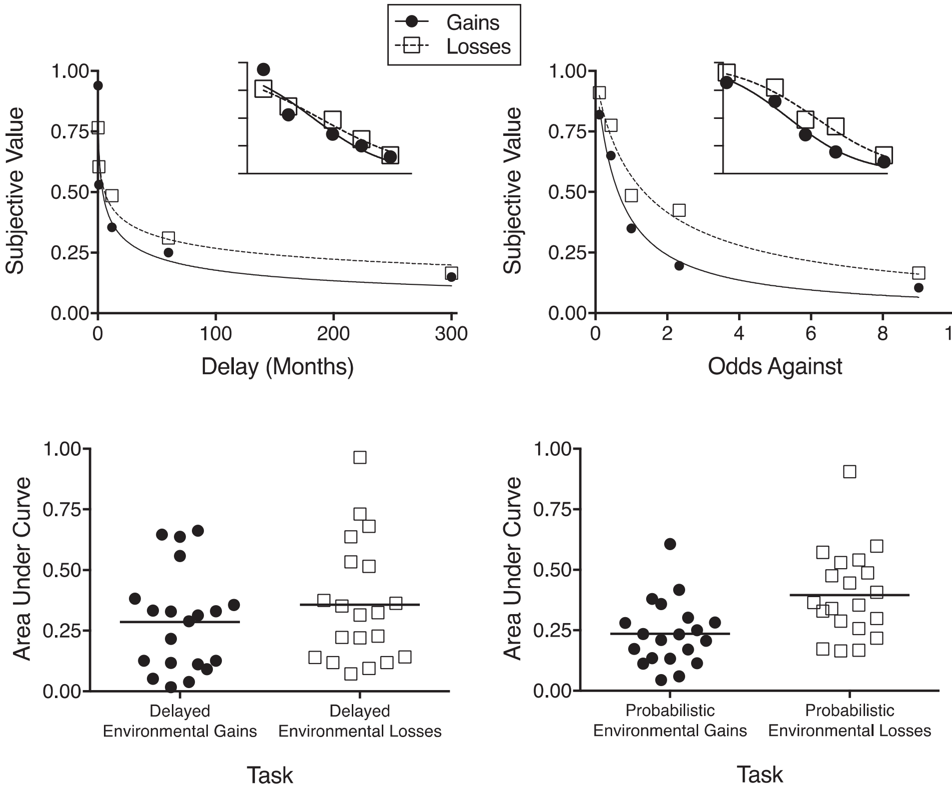

Figure 1. Median subjective values obtained from the delay (top left) and probability (top right) discounting tasks as well as each individual's area under the curve (bottom panels). Closed circles and open squares represent the environmental gains and losses tasks, respectively. The horizontal lines in the bottom panels depict the mean of the area under the curve in each task. The insets in the top two panel shows the subjective values from the tasks on a log-*x*-axis to provide more detail at the smaller values of *X*.

are curvilinear functions. Using this procedure, we found that data from zero of 20 and two of 20 participants in the delayed gains and losses task, respectively, were best fit by a noise model; in the probabilistic gains and losses task, data from zero of 20 and three of 20 participants, respectively, were best fit by a noise model. Thus, only five of 80 (6%) data sets were identified as nonsystematic.

To quantify the degree of discounting in each task, we calculated the area under the curve (AUC) for each participant in each task (Myerson, Green, & Warusawitharana, 2001, see Figure 1, bottom panels).[2] The mean AUCs in the delayed gains and losses tasks were .287 (*SEM* = .047) and .357 (*SEM* = .055), respectively. Following a $\log_{10}$-transformation of the AUCs, which normalized all distributions, a paired-*t* test suggested no difference in the AUC between delayed environmental gains and losses ($p > .10$). However, we obtained a corresponding Cohen's *d* value of 0.38, suggesting a small-to-medium effect size (Cumming, 2012, pp. 290–294). Thus, the lack of a significant sign effect with delayed environmental outcomes might be due to a lack of power in the current study. Alternatively, the sign effect previously reported by Hardisty and Weber (2009) may be less robust than originally reported. The mean AUCs in the probabilistic gains and losses

[2] All statistical comparisons reported on the AUC were conducted with and without the nonsystematic datasets. Independent of analytic method, we obtained the exact same qualitative pattern of statistical results. Thus, we retained all participants in our analyses.

Table 1
Parameter Estimates (and Standard Errors of the Mean) Derived From the Indifference Points Fitted to Equation 2 in All Four Tasks

Task	Parameter estimates	
	b	*s*
Delay		
Gains	.51 (.18)	.47 (.14)
Losses	.54 (.07)	.35 (.04)
Probability		
Gains	1.59 (.20)	1.00 (.13)
Losses	.77 (.11)	.87 (.14)

Note. All estimates determined from the fits to the group median data.

tasks were .235 ($SEM = .030$) and .396 ($SEM = .041$), respectively. This difference was statistically significant, $t(19) = 3.25$, $p < .01$, and the corresponding effect size was large (Cohen's $d = 1.06$).[3] Thus, participants were substantially more risk averse with environmental gains than losses.[4] To our knowledge, this is the first demonstration of a sign effect with probabilistic environmental outcomes.

These findings illustrate the feasibility of investigating environmental discounting, with changes in the AQI score as the outcome of interest. Furthermore, they show that consistent with prior research with monetary outcomes, the discounting of environmental outcomes is well described by a hyperboloid and that the sign effect may not be limited to monetary outcomes. Of course, we cannot be sure how well participants understood the AQI or the nature of the discounting tasks (but see procedural details above). Furthermore, we did not attempt to provide additional context by telling them their local AQI score. However, we deliberately chose to minimize task instructions to decrease the potential for priming them and affecting demand characteristics.

Our finding that participants were substantially more risk averse with gains than with losses suggests that educators and interventionists may need to be careful in choosing whether to emphasize the potential benefits or potential losses of environmental action—they may not be similarly perceived. Instead, these findings suggest the framing of the information conveyed can impact how much risk people are willing to incur. In future studies, researchers could assess the construct or concurrent validity of air-quality discounting by assessing its correspondence to related measures and behavior (e.g., recycling, transportation choice). Researchers might also combine aspects of delay and probability into a single procedure to study environmental discounting. This will almost certainly increase the face validity of studies that aim to experimentally assess environmental decision-making processes.

[3] We identified a potential outlier from the probabilistic losses condition (AUC = .905). In a separate statistical comparison with this value removed, the effect remained highly significant and the effect size remained large. Thus, we retained all data in this analysis.

[4] We also calculated the AUC using an ordinal method, recently described by Borges, Kuang, Milhorn, and Yi (2016), which assigns an equal weighting to the areas (i.e., each trapezoid) that contribute to the overall AUC value. This ordinal method produced the same qualitative pattern of results as the standard method—a significant sign effect with probabilistic, but not delayed, environmental outcomes.

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(*Appendix follows*)

Appendix

Extract of the Air Quality Index

Extract of the Air Quality Index (AQI; EPA, 2009) described by the experimenter and read to participants prior to completing the discounting tasks

Air Quality Index (AQI) Values	Levels of Health Concern
When the AQI is in this range:	*...air quality conditions are:*
0 to 50	Good
51 to 100	Moderate
101 to 150	Unhealthy for Sensitive Groups
151 to 200	Unhealthy
201 to 300	Very Unhealthy
301 to 500	Hazardous

Good: The AQI value for your community is between 0 and 50. Air quality is satisfactory and poses little or no health risk.

Moderate: The AQI is between 51 and 100. Air quality is acceptable; however, pollution in this range may pose a moderate health concern for a very small number of individuals. People who are unusually sensitive to ozone or particle pollution may experience respiratory symptoms.

Unhealthy for Sensitive Groups: When AQI values are between 101 and 150, members of sensitive groups may experience health effects, but the general public is unlikely to be affected.

> *Ozone*—People with lung disease, children, older adults, and people who are active outdoors are considered sensitive and therefore at greater risk.
>
> *Particle pollution*—People with heart or lung disease, older adults, and children are considered sensitive and therefore at greater risk.

Unhealthy: Everyone may begin to experience health effects when AQI values are between 151 and 200. Members of sensitive groups may experience more serious health effects.

Very Unhealthy: AQI values between 201 and 300 trigger a health alert, meaning everyone may experience more serious health effects.

Hazardous: AQI values over 300 trigger health warnings of emergency conditions. The entire population is even more likely to be affected by serious health effects.

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