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ORIGINAL ARTICLE

The Value of Clean Air: Comparing Discounting of Delayed Air Quality and Money Across Magnitudes

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Abstract The detrimental health effects of exposure to air pollution are well established. Fostering behavioral change concerning air quality may be challenging because the detrimental health effects of exposure to air pollution are delayed. Delay discounting, a measure of impulsive choice, encapsulates this process of choosing between the immediate conveniences of behaviors that increase pollution and the delayed consequences of prolonged exposure to poor air quality. In Experiment 1, participants completed a series of delay-discounting tasks for air quality and money. We found that participants discounted delayed air quality more than money. In Experiment 2, we investigated whether the common finding that large amounts of money are discounted less steeply than small amounts of money generalized to larger and smaller improvements in air quality. Participants discounted larger improvements in air quality less steeply than smaller improvements, indicating that the discounting of air quality shares a similar process as the discounting of money. Our results indicate that the discounting of delayed money is strongly related to the discounting of delayed air quality and that similar mechanisms may be involved in the discounting of these qualitatively different outcomes. These data are also the first to demonstrate the malleability of delay discounting of air quality, and provide important public health implications for decreasing delay discounting of air quality.

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Nearly seven million premature deaths occur globally each year as a result of air pollution (World Health Organization; WHO, 2014; 2017). These estimates nearly double previous estimates, as air pollution is now directly linked to higher rates of disease including ischemic heart disease and stroke, chronic obstructive pulmonary disease, lower respiratory infections, and lung cancer (WHO, 2014). The negative effects of air pollution are felt in both developed and developing countries. Within the United States, the American Lung Association (ALA) estimates that more than 50% of Americans (166 million people) live in areas of poor air quality that could cause negative health outcomes such as lung cancer (2016). Reducing outdoor air pollution and emissions would drastically reduce the burden of stroke, heart disease, and lung cancer, and would also help to mitigate the environmental effects of anthropogenic driven global climate change (WHO, 2014, WHO, 2015).

Air pollution is caused, in part, by emissions from industries, factories, and widespread and frequent private car use. As a society and as individuals, air pollution could be reduced by altering behavior to promote air pollution regulations and emission controls (EPA, 2016), switching to energy efficient light bulbs and appliances, reducing use of electricity, and reducing private car use, for example. People tend to engage in behaviors that are more immediately rewarding but also contribute to pollution, such as driving to work in a comfortable personal car, instead of engaging in behaviors that decrease long-term pollution, such as using public transportation. One major barrier to enacting immediate reductions in air pollution for long-term benefits may be driven in part by delay discounting (e.g., Hardisty & Weber, 2009). Delay discounting can be described as the decrease in value of an outcome as the delay to the receipt of that outcome increases (Mazur, 1987). In other words, the more delayed reductions in pollution become, the less value people may place on those reductions.

Delay discounting is a general process that describes how delay decreases the value of outcomes generally, not just delayed reduction in pollution outcomes. Humans discount improved air quality because the deleterious consequences (e.g., lung cancer, stroke, climate change) may be relatively far in the future. Humans also discount those same deleterious consequences because they are probabilistic, which is important as probability discounting (decrease in the value of an outcome as the probability of that outcome occurring decreases) is a process closely linked to delay discounting. Often, future consequences fail to influence present behavior, resulting in present-bias decision-making (e.g., Hepburn et al., 2010). Given the multifaceted and complex decision-making involved in delay discounting, supporting behavior change leading to better air quality will be complex.

To foster decision-making and behaviors leading to improved air quality then, it is essential to understand how delayed consequences in the context of environmental outcomes affect behavior. Both psychologists and economists have conducted extensive experimental assessments of delay discounting for different outcomes (Alessi & Petry, 2003; Chabris, Laibson, Morris, Schuldt, & Taubinsky, 2008; Friedel, DeHart, Madden, & Odum, 2014; Madden, Petry, Badger & Bickel, 1997). Much of this research has focused on the similarities and differences in discounting between monetary and non-monetary outcomes. Recent lines of research have also examined delay discounting of various environmental outcomes (Kaplan, Reed, & McKerchar, 2014) including water quality improvements (Meyer, 2013; Viscusi, Huber, & Bell, 2008), air quality (Hardisty & Weber, 2009), support for long-term conservation management (Johnson & Saunders, 2014), and implications of delay discounting and environmental policy (Hardisty & Weber, 2009; Hepburn, Duncan, & Papachristodoulou, 2010; Weitzman, 1998). Far less research, however, has focused on the potential relations between monetary and environmental discounting. Understanding whether delay discounting of environmental outcomes is related to delay discounting of monetary outcomes is important, because such a relation could indicate similar processes driving delay discounting of money and environmental outcomes.

The degree of delay discounting is likely to be caused by multiple factors. The degree to which individuals discount future consequences is in part a function of individual differences (e.g., genetic influences, Anokhin, Golosheykin, Grant, & Heath, 2011; neurocognitive influences, McClure, Laibson, Loewenstein, & Cohen, 2004; Peper, Koolschijn, & Crone, 2013), as well as environmental influences (e.g., Odum, 2011a, b; Stein, Wilson, Koffarnus, Daniel, Epstein & Bickel, 2016). If similar underlying processes drive monetary delay discounting and air quality delay discounting, targeting the same underlying processes may help reduce delay discounting on a global scale (see Odum, 2011a,b for discussion). Therefore, reductions in monetary delay discounting as have been previously shown through various techniques (e.g., working memory training, Bickel, Yi, Landes, Hill & Baxter, 2011; exposure to nature, Berry, Sweeney, Morath, Odum & Jordan, 2014; Berry, Repke, Nickerson, Conway, Odum & Jordan, 2015; van der Wal, Schade, Krabbendam & Vugt, 2013; future episodic thought, Peters & Büchel, 2010; framing effects, DeHart & Odum, 2015; LeBoeuf, 2006; Radu, Yi, Bickel, Gross & McClure, 2011; acceptance and commitment therapy, Morrison, Madden, Odum, Friedel, & Twohig, 2014; for a review see Koffarnus, Jarmolowicz, Mueller, & Bickel, 2013) may also reduce delay discounting of air quality.

The purpose of Experiment 1 was to compare directly delay discounting of monetary gains, monetary losses, and temporary improvements in air quality. The purpose of Experiment 2 was to determine if participants demonstrated the magnitude effect with delay discounting of air quality. The magnitude effect is a common experimental finding in which greater magnitudes of money tend to be discounted less steeply than smaller magnitudes of money. Finding the magnitude effect for delay discounting of air quality would suggest that delay discounting of air quality and delay discounting of money are affected in the same way by the same variables. In Experiment 1, we predicted that air quality (equated to money) would be more steeply discounted than monetary gains and monetary losses because other outcomes are often discounted to a greater degree than money (Friedel et al., 2014; Friedel, DeHart, Frye, Rung, & Odum, 2016). In Experiment 2, we predicted that greater improvements in air quality would be discounted less steeply than smaller improvements in air quality (i.e., the classic magnitude effect would be observed in the context of delay discounting of air quality, as has previously been shown with money).

Experiment 1

Experiment 1 Method

Participants

Participants ($N = 88$; 49 women; Mean age = 23.69 years, $SD = 5.07$) were recruited from introductory psychology courses at Utah State University via in-class announcements and an online registration system. Students were compensated 10 USD for participation in this study. All procedures were approved by the Utah State University Institutional Review Board, and all participants read and signed an informed consent form prior to completing experimental tasks.

Procedure

All participants completed three laboratory-based tasks: a delay-discounting assessment with four different delayed outcomes, an implicit associations assessment, and a virtual pollution similarity judgment assessment. The order of task presentation was randomized across participants. As air-quality discounting was the focus of the present study, the implicit associations assessment and the virtual pollution similarity judgment are not discussed here. The mean completion time for the delay-discounting task was 12.75 min.

Delay discounting The delay-discounting task was presented via custom-written E-Prime software. The delay-discounting task was an adjusting amount task (Du, Green, & Myerson, 2002; Frye, Galizio, Friedel, DeHart, & Odum, 2016; Rodzon, Berry, & Odum, 2011), and the procedures used are similar to those reported in Friedel et al. (2016). In a trial of the delay-discounting task, participants made a choice between a smaller hypothetical amount of an outcome that was to be delivered immediately and a larger hypothetical amount of that same outcome that was to be delivered after a delay. The choices were presented on the screen simultaneously, and the participants would indicate their choice by clicking the mouse in a box that surrounded the text for each outcome. After each choice, the text "You chose", followed by the outcome that the participant selected, was displayed. For the first trial in a block of delay-discounting trials, the amount of the small, immediate outcome was set to half of the larger, delayed outcome.

Across trials within a block, the amount of the small, immediate outcome was adjusted based on the choices that participants made in the preceding trials. If a participant chose the small, immediate outcome on a trial, then on the following trial the small, immediate outcome was made less desirable by decreasing the amount of the small, immediate outcome. If a participant chose the larger, delayed outcome on a trial, then on the following trial the small, immediate outcome was made more desirable by increasing the amount of the small, immediate outcome. The amount of the adjustment to the small, immediate outcome depended on the within-block trial number. After the first trial, the adjustment of the small, immediate outcome was one fourth of the amount of the larger, delayed outcome. After each successive trial, the amount of the adjustment was one half of the preceding adjustment (*i.e.*, one fourth, one eighth, one 16th, etc.). Each block was ten trials. After the participant made the last choice within a block of trials, the amount of the small, immediate outcome was taken as the indifference point for that block of trials. The indifference point is the amount of the outcome delivered immediately that is, for the participant, equal to the larger and delayed outcome. There were six discounting blocks for each outcome. Across the blocks, the delay to receiving the larger and delayed outcome systematically increased (but did not change within blocks) and the amount of the delayed outcome remained constant. The delays were presented in the following order across all of the outcomes: 1 week, 2 weeks, 1 month, 6 months, 5 years, and 25 years.

The delay-discounting task described above was repeated four times with different outcomes for each iteration of the task. The order of presentation for the outcomes was randomly selected. The outcomes participants were asked about were a $10,000 monetary gain, a $10,000 monetary loss, a duration of clean air, and a duration of temporary relief from a debilitating disease caused by air pollution. When participants began the monetary gain and monetary loss delay-discounting tasks, the first trial of the first block was immediately presented. When participants began the air quality or the health delay-discounting tasks, they were first asked several questions to determine the duration of clean air or the duration of a temporary cure that was worth $10,000 to them. Participants were asked the duration of clean air or the duration of temporary cure that was worth $10,000 to use those durations as the larger, delayed amount in the discounting task so that larger, delayed amounts were equivalent in monetary value across each outcome.

To determine the duration of the improved air quality, the following text was presented to the participants:

> Imagine that the Cache County [where the experiment was conducted] government is considering a temporary change to its emissions policy to study the effects of air quality on human health and the local wildlife. The particulate output of nearby factories, power plants, and farms will be immediately reduced. After the temporary change, the air quality will return to its normal level. The government initiative will cost $10,000.
> How long should the better air quality last if it costs $10,000?

To answer the questions, participants were directed to type in a number and select the correct units (*i.e.*, days, weeks, months, years). After participants entered their answer, a screen was presented that asked participants to confirm their answer. The screen displayed the text, "You said that $10,000 of better air quality should last [value entered] [units]. Is that correct?" Participants could re-enter values until they confirmed their answer. For the discounting questions, the duration of air quality that the participants entered was then used as the delayed amount across all of the discounting questions. The immediate duration of air quality was changed based on the titrating procedure described above. For example, if a participant responded that $10,000 of better air quality should last for 6 months then in the first-choice alternatives that were presented to the participants were "3 months of better air quality now" and "6 months of better air quality in 1 week" and the small, immediate amount of air quality was adjusted across trials based on the algorithm described above.

Unlike the other tasks assessed, data for the temporary relief from disease showed nonsystematic data (see Johnson & Bickel, 2008) even at the median group level, a result that may be due to the complexity of the task. Therefore, the results of this task are not presented here or discussed further.

Data Analyses

Delay Discounting Across each outcome, all data from each participant were included as in previous studies of delay discounting across outcomes (e.g., Odum & Rainaud, 2003). This conservative approach was taken because there are currently no standard procedures for eliminating nonsystematic data across repeated measures (i.e., for multiple outcomes assessed as in the present experiments).

We used two primary methods to characterize delay discounting across all outcomes. First, four models of delay discounting were fit to the median indifference points obtained from each outcome. The models selected were a random noise model (see Franck, Koffarnus, House, & Bickel, 2015; $E(Y) = c$), the exponential model (Samuelson, 1937; $E(Y) = e^{-kD}$), the hyperbolic model (Mazur, 1987; $E(Y) = 1/(1 + kD)$), and the hyperboloid model (Myerson & Green, 1995; $E(Y) = 1/(1 + kD)^s$). The highest quality model for each outcome was selected using an Akaike information criterion (AIC) process (see Wagenmakers & Farrell, 2004). Akaike information criterion provides a measure of the goodness of fit of a model in relation to how many free parameters the model has. After calculating AIC for each model and each outcome type, we then calculated Akaike weights (*w*) to determine the likelihood that the highest quality model was in fact the correct model. For this analysis, we used AICc which includes a correction for small sample sizes (i.e., a small number of indifference points). The information needed to interpret the model selection process (Anderson & Burnham, 2002) is reported in the Appendix.

Second, we also calculated a newer measure of delay discounting, *log* Area Under the Curve (*log*AUC), for each outcome and each participant. Standard AUC (see Myerson, Green, & Warusawitharana, 2001) is calculated by taking the total sum of all the trapezoidal areas (as they would be plotted on a figure) between adjacent indifference points. The formula to calculate a single trapezoid is $(x_2 - x_1)\ [(y_1 - y_2)/2]$, where x_1 and x_2 are successive delays and y_1 and y_2 are the indifference points associated with those delays. *Log*AUC is similar to standard AUC, except that the logarithm of the delays is used instead of the actual delays. Using the logarithm of the delays allows for a relatively more equal weighting of each delay on the final *log*AUC measure (see Borges, Kuang, Milhorn, & Yi, 2016 for details). We also calculated standard AUC values to supplement the primary *log*AUC analysis.

*Log*AUC values were not normally distributed for any outcome as determined by a Shapiro-Wilk test of normality (all $p < .05$), and thus nonparametric statistics were used. First, to determine if there were relations between the degree of discounting across the monetary gains, monetary losses, and improvements in air quality, we calculated Spearman correlations between *log*AUC across these outcomes (as well as standard AUC). To determine if there were differences in the degree of discounting across the outcomes, we used Wilcoxon matched-pairs signed rank tests, and applied a Bonferroni correction to ensure a familywise error rate of $p = .05$ (α criterion of .0167).

Experiment 1 Results

Figure 1 displays the median indifference points with the best fitting hyperboloid lines (Myerson & Green, 1995). Across each outcome, median indifference points decreased as delay. Air quality was discounted more steeply than monetary gains or losses. Through the model selection process, we determined that the hyperboloid model (Myerson & Green, 1995) was the highest quality model and that it was extremely likely to be the correct model for the data (likelihood of greater than 99% for each outcome). The mean days of improved air quality equivalent to $10,000 were 26.85 (SD = 211.59, minimum = 1, maximum = 2000). Table 1 contains the parameter estimates (*k* and *s*) for each outcome type. See Table 5 in the

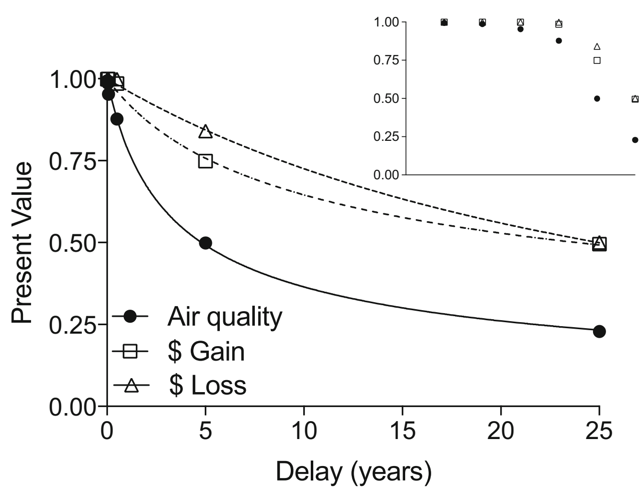

Fig. 1 Median indifference points as a function of delay (years) for the air quality (*closed circles*), monetary gain (*open squares*), and monetary loss (*open triangles*) conditions. Lines represent the best fit of the Myerson and Green (1995) hyperboloid model to the median indifference points. Inset displays the same indifference points expressed ordinally on the x-axis

Table 1 Experiment 1 model parameters for lines of best fit using the hyperboloid equation (Myerson & Green, 1995)

	k	*s*
Gains	0.018	0.385
Losses	0.002	1.358
Air Quality	0.044	0.549

Appendix for the full list of AICc, ΔAICc, and Akaike decision weights.

Table 2 contains the correlation coefficients (Spearman's rho) for both *log*AUC and AUC. There were moderate and significant positive correlations between *log*AUC for monetary gains and *log*AUC for monetary losses, as well as between *log*AUC for monetary gains and *log*AUC for improvements in air quality, indicating that a person who steeply discounted delayed monetary gains was also likely to steeply discount delayed monetary losses as well as steeply discount delayed improvements in air quality. Similarly, if a person demonstrated relatively shallow discounting, s/he was more likely to shallowly discount delayed monetary losses and shallowly discount delayed improvements in air quality. Similar patterns were observed for standard AUC.

Figure 2 presents the mean *log*AUC values for monetary gains, the monetary losses, and improvements in air quality. The mean *log*AUC for improvements in air quality was lower than the mean *log*AUC for either monetary gains or monetary losses. Wilcoxon signed-rank tests confirmed these visual assessments, revealing that *log*AUC for improvements in air quality was significantly lower than both *log*AUC for monetary gains ($W_{(87)} = -1911$, $p < .001$) and *log*AUC for monetary losses ($W_{(87)} = -1954$, $p < .001$). There was also no difference in *log*AUC for monetary gains and monetary losses ($W_{(87)} = -216$, $p = .63$). Similar patterns were observed for standard AUC.

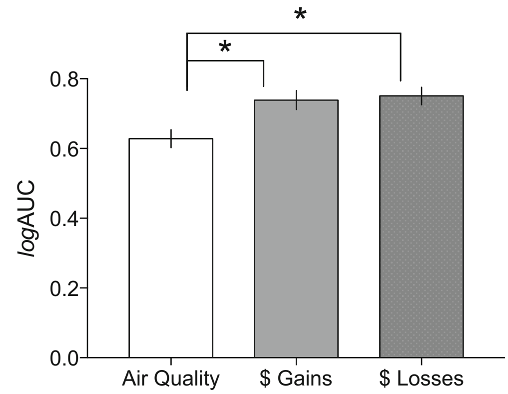

Fig. 2 Mean *log*AUC for the improvements in air quality (*open bar*), monetary gains (*light grey bar*) and monetary losses (*dark grey bar*). *Vertical lines* represent the standard error of the mean. *Asterisks* represent statistically significant differences in *log*AUC between conditions

Experiment 1 Discussion

Replicating and extending previous findings (e.g., Hardisty & Weber, 2009), the results of Experiment 1 revealed significant positive correlations between delay discounting of air quality and money. These results suggest that those who discount one outcome steeply are also likely to discount other outcomes steeply, supporting a trait-like interpretation of impulsive decision-making (e.g., Odum, 2011b). We failed to replicate the previously established sign-effect, in which delayed losses are discounted less than delayed gains; however, research suggests that the sign effect is more commonly found for small amounts (e.g., $100) than for larger amounts (e.g., $20,000, Estle, Green, Myerson, & Holt, 2006) as were used in Experiment 1.

To extend the results of Experiment 1, Experiment 2 was designed to determine whether the magnitude effect occurs with delay discounting of air quality. The magnitude effect commonly occurs when delay discounting is steeper for smaller amounts of monetary outcomes than for larger ones. Finding that delayed money and delayed air quality are discounted in a similar manner and respond in similar ways to experimental manipulations (i.e., differences in outcome magnitude) could suggest similar underlying decision-making processes are at play for both types of outcomes. This hypothesis was tested across longer delays (i.e., 75 years) than typically used in delay discounting research (e.g., 25 years). We extended the longest delay typically used, as increases or decreases in emissions resulting from decisions or policies that are enacted currently will affect air quality well into the future, and beyond 25 years (i.e., Richards & Green, 2015).

Table 2 Correlations (Spearman's) across outcomes for *log*AUC and AUC

*log*AUC	Gain	Air Quality
Loss	.50***	.34***
Air Quality	.53***	
AUC	Gain	Air Quality
Loss	.47***	.21*
Air Quality	.42***	

$^{+}$ $p < .1$, * $p < .05$, ** $p < .01$, *** $p < .001$

Experiment 2

Experiment 2 Method

Participants

Seventy-nine individuals registered on Amazon Mechanical Turk were recruited for the present experiment and were paid $1.50 for completing the study. Participants were 18 years of age or older, resided in the United States, and had an approval rating of at least 95%. The University of Montana Institutional Review Board approved all experimental procedures.

Setting and Apparatus

Participants completed the experiment at their leisure in a location of their choosing. Participants were asked to only complete the study if they could focus on present choices and there were no ongoing distractions. Average time to complete the study was 14 min (SD = 6.25; with approximately $6.43 for the realized hourly wage). Experimental manipulations and data recording were programmed using Qualtrics® (2016; Provo, Utah).

Procedure

As in Experiment 1, participants made choices between receiving hypothetical monetary outcomes, as well as between experiencing hypothetical air quality improvements immediately or in the future (see Hardisty & Weber, 2009). The instructions and air quality scenarios were similar to those described in Experiment 1 (as Experiment 2 reached a broader U.S. population than Experiment 1, descriptions focused on “your local county” as opposed to “Cache county”, where Utah State University is located). In Experiment 2, all participants completed two (small and large magnitude) air quality delay-discounting tasks, as well as two (small and large magnitude) monetary discounting tasks. The order of each task was randomly assigned across participants, and each task was completed prior to moving on to the next task.

In each of the four delay-discounting tasks, a simple survey assessed delay discounting, and participants chose between smaller immediate or larger delayed outcomes. For each outcome and each delay to receiving that outcome, the amount of the immediate outcome decreased in a fixed sequence (see e.g., Rodzon et al., 2011). The values used for the small magnitude discounting tasks (both monetary and air quality) were 100, 99, 95, 90, 85, 80, 70, 60, 50, 40, 30, 20, 15, 10, 5, and 1 either dollar(s) or day(s) of improved air quality. In the small magnitude tasks, the larger delayed amount was fixed at 100 dollars or days of improved air quality across questions. The values used for the larger magnitude discounting tasks were 1000, 990, 950, 900, 850, 800, 700, 600, 500, 400, 300, 200, 150, 100, 50, and 10 dollars or days of improved air quality. In the large magnitude tasks, the larger delayed amount was fixed at 1000 dollars or days of improved air quality across questions.

Therefore, participants answered 16 questions at each delay (e.g., “Would you rather experience 99 days of improved air quality now or 100 days of improved air quality in 1 month?”; “Would you rather experience 95 days of improved air quality now or 100 days of improved air quality in 1 month?”, etc.). Within each set of questions, the smallest immediate value chosen by the participant was considered the indifference point. For all tasks, the delays to receiving those outcomes increased from 1 day, 1 month, 1 year, 5 years, to 75 years, in that order. Following all experimental procedures, basic demographic information was collected (e.g., age, sex).

Data Analysis

Of the 79 individuals that completed the survey, 77 positively endorsed a statement that asked if the participant took their time and two participants indicated that they did not take their time. Data from those two participants were not considered further. As in Experiment 1, we characterized delay discounting by testing four models (see Experiment 1) to the median indifference points obtained, and selected the highest quality model using an AIC process. *Log*AUC (Borges et al., 2016) and standard AUC (Myerson et al., 2001) were also used to evaluate delay discounting of money and air quality and to compare discounting across the small and large magnitude conditions. The obtained *log*AUC values were not normally distributed for each outcome as determined by Shapiro-Wilk tests of normality, and thus nonparametric statistics were used. To assess potential relations among delay discounting across each of the outcomes, we calculated Spearman correlations. We used Wilcoxon matched signed-rank tests to determine if there were differences in AUC based on 1) magnitude and 2) outcome type. Multiple Wilcoxon tests were selected, as there is no readily available non-parametric equivalent for a two-way repeated measures ANOVA. Statistical comparisons accounted for familywise error rate by using a Bonferroni correction (α criterion of .0125).

Experiment 2 Results

Of the 77 participants, 44% were female. The mean age was 32.01 years (SD = 8.70). Figure 3 displays the median indifference points with the best fitting hyperboloid lines (Myerson & Green, 1995). Across each outcome, median indifference points decreased as delay increased. Monetary outcomes were discounted more steeply than air quality outcomes. Through the model selection process, we determined that the hyperboloid model (Myerson & Green, 1995) was the highest quality model and that it was extremely likely to be the correct model for the data (likelihood of greater than 99% for each outcome). Table 3 contains the parameter estimates (k and s) for each outcome type. See Table 6 in the Appendix for the full list of AICc, ΔAICc, and Akaike decision weights.

Table 4 presents the Spearman correlations for Experiment 2. There were significant positive correlations between *log*AUC from the small and large magnitude monetary outcomes as well as between *log*AUC from the small and large magnitude air quality outcomes. Across the commodities, there were significant positive correlations between the small magnitude monetary and small magnitude air quality

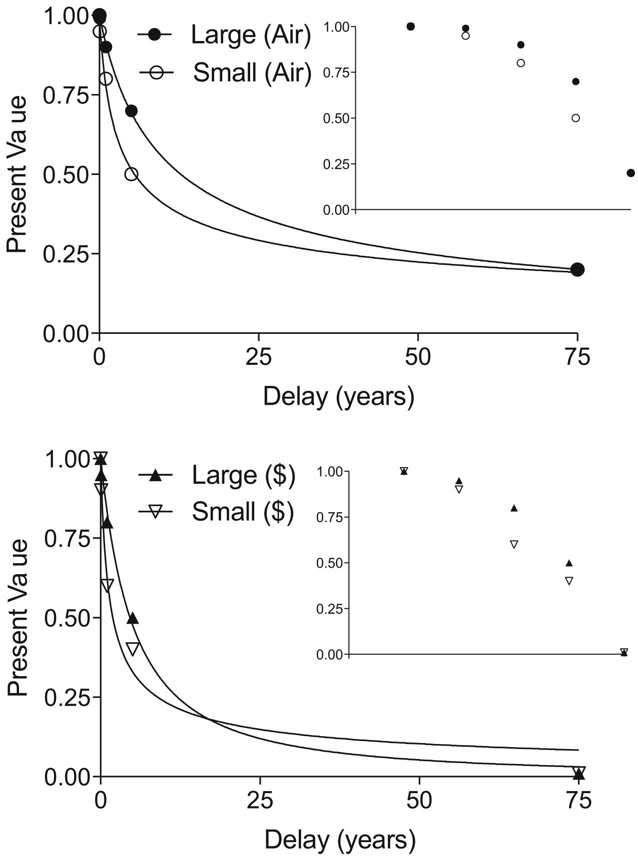

Fig. 3 The median indifference points as a function of delay (years) for the air quality large (*closed circles*) and small (*open circles*) magnitude conditions (top panel) and the monetary large (*closed triangles*) and small (*open triangles*) magnitude conditions (bottom panel). *Lines* represent the best fit of the Myerson and Green (1995) hyperboloid model to the median indifference points. Insets display the same indifference points expressed ordinally on the x-axis

outcomes as well as between the large magnitude monetary and large magnitude air quality outcomes. The pattern of results revealed was identical using standard AUC. These results indicate that individuals who more steeply discounted an outcome of some specific amount, also tended to 1) steeply discount a different amount of that outcome and 2) steeply discount the other outcome. Similarly, those individuals who more shallowly discounted an outcome of some specific amount, also tended to 1) more shallowly discount a different amount of that outcome and 2) more shallowly discount the other outcome.

Table 3 Experiment 2 model parameters for lines of best fit using the hyperboloid equation (Myerson & Green, 1995)

	k	*s*
Large ($)	0.134	1.444
Small ($)	1.408	0.531
Large (Air)	0.158	0.628
Small (Air)	0.873	0.393

Table 4 Correlations (Spearman's) across outcomes for *log*AUC and AUC

*log*AUC	Small ($)	Small (Air)	Large (Air)
Large ($)	.85***	.59***	.57***
Large (Air)	.55***	.77***	
Small (Air)	.59***		
AUC	Small ($)	Small (Air)	Large (Air)
Large ($)	.78***	.60***	.59***
Large (Air)	.58***	.77***	
Small (Air)	.58***		

$^{+}$ $p < .1$, * $p < .05$, ** $p < .01$, *** $p < .001$

Figure 4 displays the *log*AUC for the small and large magnitude monetary and air quality outcomes. *Log*AUC in the large magnitude condition was higher than *log*AUC in the low magnitude condition for the matched outcomes. Similarly, *log*AUC for air quality outcomes was higher than *log*AUC for the same magnitude of monetary outcomes. Wilcoxon matched-pairs signed-rank tests on *log*AUC values showed significant differences across small and large magnitudes of air quality ($W_{(77)} = -1097$, $p = .003$). Significant differences were also revealed across the small and large monetary outcomes ($W_{(77)} = -2272$, $p < .001$), differences in *log*AUC across small monetary and air quality outcomes

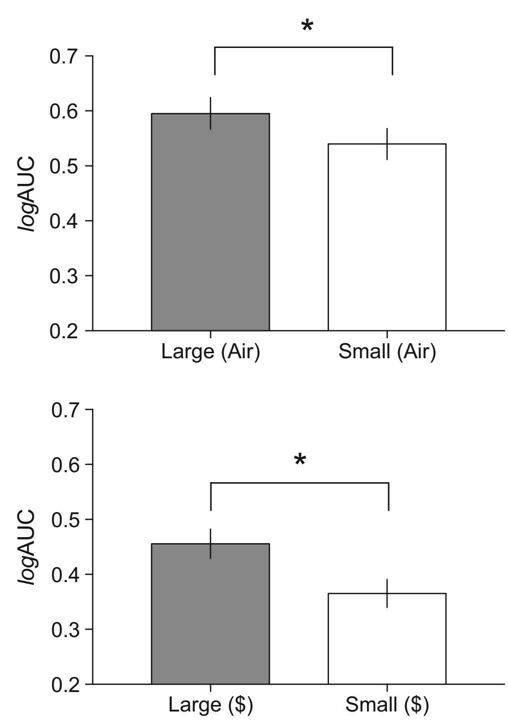

Fig. 4 Mean *log*AUC for the Large (*filled bar*) and Small (*open bar*) magnitude conditions for monetary outcomes (top panel) and air quality outcomes (bottom panel). *Vertical lines* represent the standard error of the mean. *Asterisks* represent statistically significant differences in *log*AUC between the large and small magnitude conditions

($W_{(77)} = -2363$, $p < .001$), and differences in *log*AUC across large monetary and air quality outcomes ($W_{(77)} = -1926$, $p < .001$). Similar patterns were observed for standard AUC.

Experiment 2 Discussion

The results of Experiment 2 show that delay discounting for money and air quality were positively correlated across both commodities and magnitudes. These results suggest that those who steeply discount money also tend to steeply discount air quality. Importantly, these results are also the first to show that delay discounting of air quality responds to experimental manipulations of amount, similar to delay discounting of money (i.e., smaller magnitudes are discounted more steeply than larger magnitudes). Overall, this finding suggests that similar processes may be at work for delay discounting of monetary outcomes and air quality.

General Discussion

We found several notable results in the present study, in which we assessed associations between delay discounting of monetary and air quality outcomes. First, across both experiments, we found significant positive correlations between the degree of discounting of money and the degree of discounting of air quality improvements, supporting the proposition that delay discounting encompasses trait-like properties (Friedel et al., 2016; Odum, 2011b). Second, Experiment 2 is the first demonstration that the magnitude effect also occurs in delay discounting of air quality, suggesting that delay discounting of air quality may share similar underlying decision-making processes as discounting of monetary outcomes. Third, we found different results when comparing the degree of discounting of air quality across Experiments 1 and 2. In Experiment 1, air quality was discounted significantly more steeply than monetary gains or losses, while in Experiment 2 air quality was discounted less steeply than money. Each of these results will be discussed in turn.

Replicating previous research (e.g., Hardisty & Weber, 2009), we found significant positive correlations between monetary discounting and air quality discounting across both Experiment 1 and Experiment 2. These results extend previous findings showing that individuals who discount one commodity steeply also tend to discount other commodities steeply (e.g., see Odum, 2011a, b for discussion). These results, combined with previous research, have implications for real world decision-making, as research has shown that impulsive decision-making in laboratory settings is predictive of impulsive decision-making in real world settings (e.g., Chabris et al., 2008). Delay discounting research in laboratory settings, therefore, may also be informative for understanding decision-making that proves relevant for air quality (e.g., private car use, use of energy efficient appliances). However, more research is needed to understand the potential links between delay discounting of air quality and decisions that may affect air quality (and other environmentally relevant decisions and behaviors; see Hirsh, Costello, & Fuqua, 2015 for discussion).

The results of Experiment 2 are the first to show that like monetary discounting, air quality discounting is susceptible to experimental manipulation. This result has not previously been demonstrated with air quality or with any other environmental outcome. These data suggest that delay discounting of air quality is malleable, as has been shown previously with money (see Koffarnus et al., 2013). In other words, certain environmental influences could encourage society and individuals to value the future and long-term air quality more. The magnitude effect, extended to air quality in the present experiment, implies that framing effects or making the long-term outcomes of clean air more salient might lead to greater future valuation of air quality. It may also be possible to encourage people to make environmentally conscious choices if people are reminded that those choices are in line with their stated preferences and values (e.g., acceptance and commitment therapy, Morrison et al., 2014).

Taken together, these experiments support the notion that similar decision-making processes may underlie delay discounting of monetary outcomes and air quality outcomes (see Hardisty & Weber, 2009 for discussion). We found significant positive correlations and a magnitude effect across the delayed monetary and air quality outcomes. If the same underlying decision-making processes undergird delay discounting of money and air quality, then techniques that have proven successful in decreasing delay discounting of monetary outcomes (e.g., episodic future thought, time salience, acceptance, and commitment therapy) may also be targeted to enable individuals to make long term-oriented environmental decisions (e.g., switching to energy efficient light bulbs and appliances). Future research could examine whether other manipulations designed to decrease delay discounting of money (e.g., future episodic thought, time salience manipulations), decrease discounting of air quality and other environmental outcomes.

In Experiment 1, air quality was discounted significantly more steeply than money, and in Experiment 2 air quality was discounted significantly less steeply than money. These divergent results are probably due to the differences in methodology employed across the experiments. In Experiment 1, each participant reported the amount of air quality that was subjectively equivalent to \$10,000, and that duration of air quality was then used as the delayed outcome. In Experiment 2, however, the durations of air quality improvements used were the exact same numerical values as those used in the monetary scenario (*e.g.*, \$100 and 100 days, which have previously been equated to monetary values, (see Hardisty & Weber, 2009), but were not equated to monetary values in the present experiment and sample). It is possible, though we did not confirm, that the durations of air quality in Experiment 2 had a higher present value than the comparable dollar amounts. If a duration of air quality has a higher relative value than a numerically identical amount of money, then we would expect a cross-commodity magnitude effect in which we would find air quality less steeply discounted than money—the pattern of results in Experiment 2. When the value of the air quality was controlled in relation to the value of the monetary outcomes in Experiment 1, we found a more typical pattern of results in which money was less steeply discounted than other types of commodities (Charlton & Fantino, 2008; Friedel et al., 2014; Friedel et al., 2016).

Along these lines, Experiment 1 also introduced a complex limitation that is relatively novel in terms of delay discounting research. In Experiment 1, we assessed discounting with a delayed gain of $10,000 and a delayed duration of air quality that each participant regarded as equivalent to $10,000. It is possible that monetary outcomes and air quality outcomes are fundamentally different, and cannot be equated. Additionally, although both the air quality and the $10,000 were to be "received" by the participant, the air quality change was to be affected by the local government and, therefore, the $10,000 of better air quality was never money that was in direct control of participants. It is possible that differences in how participants viewed personal money versus governmental money (and the extent to which an individual views governmental money as separate from their own money) lead to differences in the degree to which personal money and governmental money were discounted. These differences could influence how air quality that was equivalent to governmental money relative to personal money may be discounted. Although we cannot deduce potential differences in the underlying processes that govern the discounting of air quality and money with respect to personal versus governmental money, these scenarios do provide more robust external validity for this study. That is, most people do not have the financial resources to spend $10,000 to have better air quality in their county and, therefore, having a local government spend that money represents a more realistic scenario. Further, direct comparisons of the results of Experiments 1 and 2 should be made with caution, as in Experiment 1 we equated air quality to a monetary value, and in Experiment 2 we did not.

An additional limitation is that our decision-making scenarios are necessarily hypothetical. Previous research has shown, however, that decisions about hypothetical outcomes in a laboratory setting are associated with real world behavior and choices involving delays (e.g., Johnson & Bickel, 2002; Lagorio & Madden, 2005). By using hypothetical scenarios, we have been able to show that air quality preferences are influenced systematically by delay. For this reason, the present procedure may represent the best way to study these relations under controlled conditions.

Despite these limitations, these data derived from human decision-making are the first to reveal malleability in delay discounting of air quality and point to possible ways to decrease discounting of air quality. By developing and applying techniques designed to decrease the degree to which air quality is devalued in the future, as was shown with larger magnitudes of improved air quality in the present experiment, humans might improve conservation of clean air. For example, by decreasing delay discounting of air quality and engaging in more future-oriented decision-making, individuals may be more likely to engage in behaviors producing fewer emissions (e.g., riding a bike instead of driving to work) and policy makers may also be more likely to support initiatives that reduce pollution now. Reducing pollution *immediately* will be critical to produce both immediate and prospective air quality improvements—as carbon abatement and emissions reduction programs frequently produce some benefits that may not occur until far in the future (Richards & Green, 2015). Substantial reductions in emissions will be required to decrease the extensive morbidity resulting from poor air quality such as ischemic heart disease, stroke, lung cancer, and premature death (WHO, 2014, 2016). Current and continued emissions reductions will facilitate health improvements of current generations (e.g., Lepeule, Laden, Dockery, Schwartz, 2012; Langrish et al., 2012), as well as protect the health of future generations. These results may have far-reaching and important implications for policy-level action, as well as individual decision-making in the context of air quality.

Compliance with Ethical Standards

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Conflict of Interest All authors have declared that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

Appendix

We used an Akaike information criterion (AIC) model selection process to determine the highest quality model of delay discounting for each of the seven outcomes across Experiments 1 and 2. We used least-squares regressions to fit a random noise model, an exponential model (Samuelson, 1937), a hyperbolic model (Mazur, 1987), and a hyperboloid model (Myerson & Green, 1995) to the median indifference points for each outcome from each experiment. The residual sums-of-squares for each model fit were then used to calculate AIC. Because each model was fit to a small number of indifference points (5 or 6, depending on the experiment), we corrected AIC for the small sample sizes (AICc). For each outcome, we determined the ΔAICc which is the difference between the AICc for each model and the minimum AICc across all of the models. Finally, across each outcome we determined AIC weights (*w*), which are the normalized likelihood that each model was the correct model for that outcome.

Table 5

Model	Parameters	RSS	AICc	ΔAICc	*w*
Monetary Gain					
Noise	1	1.0447	-1.96	29.01	0
Exponential	2	0.0127	-13.53	17.44	0
Hyperbolic	2	0.0050	-15.39	15.58	0
Hyperboloid	3	0.0007	-30.97	0	0.99
Monetary Loss					
Noise	1	1.1123	-1.89	31.47	0
Exponential	2	0.0010	-18.69	14.68	0
Hyperbolic	2	0.0004	-20.52	12.85	0
Hyperboloid	3	0.0003	-33.37	0	0.99
Air Quality					
Noise	1	0.9018	-2.10	29.00	0
Exponential	2	0.0395	-11.26	19.84	0
Hyperbolic	2	0.0055	-15.21	15.89	0
Hyperboloid	3	0.0006	-31.10	0	0.99

Note. Akaike weights do not sum to one because the *w* for the unlikely models were each less than 10^{-5}

Table 6

Model	Parameters	RSS	AICc	ΔAICc	*w*
Small ($)					
Noise	1	0.6701	-2.40	20.67	0
Exponential	2	0.0511	-10.95	12.12	0
Hyperbolic	2	0.0209	-12.73	10.33	0
Hyperboloid	3	0.0128	-23.07	0	0.99
Large ($)					
Noise	1	0.7826	-2.25	24.90	0
Exponential	2	0.0059	-15.25	11.89	0
Hyperbolic	2	0.0042	-15.95	11.20	0
Hyperboloid	3	0.0033	-27.14	0	0.99
Small (Air)					
Noise	1	0.6325	-2.46	27.70	0
Exponential	2	0.0458	-11.17	19.00	0
Hyperbolic	2	0.0210	-12.72	17.44	0
Hyperboloid	3	0.0012	-30.16	0	0.99
Large (Air)					
Noise	1	0.7801	-2.25	33.50	0
Exponential	2	0.0389	-11.49	24.25	0
Hyperbolic	2	0.0041	-16.02	19.73	0
Hyperboloid	3	0.0002	-35.75	0	0.99

Note. Akaike weights do not sum to one because the *w* for the unlikely models were each less than 10^{-5}

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