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Impacts of religious semantic priming on an intertemporal discounting task: Response time effects and neural correlates

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ABSTRACT

The purpose of this study is to test the hypothesis that religious primes would influence intertemporal discounting behaviors in neurotypical older adults, but not in participants with Parkinson's disease (PD). Furthermore, we predicted that this priming effect would be related to functional connectivity within neural networks mediating religious cognition, decision-making, reward valuing, and prospection processes. Contrary to past research with young adults, we found a significant positive relationship between religiosity and discounting rates. Religious semantic primes did not reliably shift individual discounting rates. But religious controls did respond more quickly to intertemporal decisions under the religious priming condition than the neutral condition, compared to response time differences among the participants with PD. Differences in response time were significantly associated with functional connectivity between the nucleus accumbens and various regions, including the left anterior cingulate cortex and Brodmann areas 10 and 46 in the right dorsolateral prefrontal cortex. These results suggest that religious primes influence discounting behavior via dopaminergic meso-limbic and right dorsolateral prefrontal supporting cognitive valuation and prospection processes.

1. Introduction

Multiple lines of research have supported a positive relationship between religiosity and self-control (McCullough and Carter, 2011). Some authors suggest this relationship underlies various health effects of religious belief and participation (McCullough and Willoughby, 2009) and others hypothesize that religion's capacity to foster self-control also promotes prosocial behaviors (Gervais and Norenzayan, 2012). Therefore, the relationship between religion and self-control is central to many contemporary debates within the scientific study of religion, especially those on the evolutionary origins of religious behaviors and beliefs.

With these debates in mind, the present study had three primary objectives. First we sought to corroborate prior findings that link religiosity with intertemporal discounting (Carter et al., 2012; Kim-Spoon et al., 2014; Paglieri et al., 2013), i.e. the degradation of value over time (Madden and Johnson, 2010), and extend this research by including older adults. Second, we developed a novel priming task to assess the impact of religious semantic priming on discounting behaviors. Third, using resting state fMRI (rsfMRI) analysis, we assessed the structural networks mediating the connection between religiosity and intertemporal discounting.

Furthermore, this study was conducted with neuro-typical adults and participants with Parkinson's disease, which involves a degradation of the dopaminergic systems. These dopamine systems, extending from the mesolimbic structures into the prefrontal and parietal cortices, have been linked with neurocognitive models of intertemporal discounting tasks (Bickel et al., 2007; McClure, 2004) and have been implicated by past studies in religious cognition changes (Butler et al., 2010, 2011a, 2011b). Comparisons of these two populations can therefore isolate behavioral and neurological differences, providing interpretive constraints on the religious modulation of intertemporal discounting.

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1.1. Intertemporal discounting

Intertemporal discounting tasks are experimental measures designed to assess an individual's perception of value degradation over time (Madden and Johnson, 2010), which is most often interpreted behaviorally as impulsivity (Odum, 2011). Participants are given a series of hypothetical choices between receiving a smaller reward sooner and a larger reward later (e.g. would you rather receive $25 today or $35 in a month?). By staggering the amount of the rewards and the delay, the results yield a discounting rate for each individual (Madden and Johnson, 2010). This discounting rate indicates how quickly value is perceived to degrade over time for an individual. Higher discounting rates, reflecting a more precipitous loss of value over time, are significantly correlated with health-risk behaviors such as substance abuse (Yi et al., 2010) or pathological gambling (Reynolds, 2006).

A growing body of research has suggested that discounting rates also increase with age, likely due to shortening time horizons (Green et al., 1999; Read and Read, 2004). Neurological studies suggest that older adults have reduced neural activation within reward systems relative to their younger counterparts (Dreher et al., 2008; Samanez-Larkin et al., 2010, 2012; Schott et al., 2007). In addition to the shortening time horizon, the salience of reward types changes across the lifespan. Rademacher et al. (2013) demonstrated age differences on incentive delay tasks involving money, but found no behavioral or neurological differences, between younger populations and older adults if the reward was social. In other words, the time horizon and the value landscape both shift across a lifetime, which subsequently influences discounting behaviors in response to monetary rewards.

Correlational research among US and Western European college students suggest a significant relationship between higher religiosity and lower discounting rates (Paglieri et al., 2013), and a preliminary longitudinal study among American youth suggests that religiosity may causally lead to lower discounting rates over time (Kim-Spoon et al., 2014). These studies fit the larger body of research connecting religiosity and self-control (McCullough and Willoughby, 2009), with one study finding that implicit religious priming led participants to forego a $5 payment and return the next day for $6 (Rounding et al., 2012). In Italy however, Paglieri and colleagues found this relationship between religiosity and discounting was reversed; Roman Catholics were more impulsive than their secular counterparts (Paglieri et al., 2013). This finding suggests that the relationship may vary in relation to shifting values within different religious contexts. A common interpretation of the broader relationship is that religious socialization and participation inculcates values, encoded within doctrines (Paglieri et al., 2013), and leads to habits supportive of delaying gratification (Carter et al., 2012). Given the effects of age on discounting behaviors, it is important to note that existing studies on this relationship have only used young adults, with mean ages ranging from thirteen (Kim-Spoon et al., 2014) to twenty-six (Paglieri et al., 2013).

Prospection has also been found to be an important process in relation to intertemporal choices, such that congruity with projected future selves may support lower discounting rates (Hershfield, 2011). Collectively these explanations cohere in the broader neuro-cognitive model of de-centering, which draws from Nichols and Stich's (2000) cognitive architecture of the self. This model suggests that religious beliefs and practices support a decoupling process through which an individual decenters from the current sense of self, thereby permitting association with a prospective ideal self, stored in semantic memory (McNamara, 2009). For religious individuals, the model of the ideal self is formed in relation to the values of the surrounding religious atmosphere. This practiced association with the prospective value-laden self leads to changes in habitual action-control patterns, such as delaying gratification.

In support of such a neuro-cognitive model, initial research suggests that religious priming does lead to increased tendencies toward delaying gratification (Rounding et al., 2012). Importantly, however, a recent meta-analysis suggests that religious priming is only reliably effective among religious participants (Shariff et al., 2015). The religious concept, or ideal self, must be salient and present within the semantic network of an individual in order to be cognitively activated and to influence behaviors. Given the shifting temporal horizon and changing values in older adulthood, it remains an open question how the relationship between religiosity and discounting behaviors will shift with age.

Neural models of intertemporal choice have pointed to the interaction of two neural systems guiding the decision-making process. The role of dopamine in valuation has been established in human (Rademacher et al., 2013; Zaghloul et al., 2009) and animal research (Schultz et al., 1993). Therefore, it is not surprising that the anticipation of rewards is mediated primarily by the dopaminergic mesolimbic system. Gauging the value of these expected rewards involves dopamine neurons of the ventral striatum, particularly the ventral tegmental area (VTA), and the nucleus accumbens (NAcc), such that elevated activation is related to increases in perceived value (Knutson et al., 2005; Spreckelmeyer et al., 2009). Within the decision-making process for intertemporal discounting, the prefrontal cortex (PFC) and parietal regions have been found to be engaged in overriding these impulses from the mesolimbic dopamine system, resulting in choosing the larger-later reward (Bickel et al., 2007; McClure, 2004).

Therefore, the neuro-cognitive model of intertemporal discounting, as presented by Bickel et al. (2007) and McClure (2004), strongly implicates the dopaminergic networks extending from the ventral striatum to regions in the PFC and parietal cortex. Importantly, these networks are those impacted by the neural degradation of Parkinson's disease (McNamara and Durso, 2006), and have been implicated in religious cognition (Butler et al., 2010, 2011a, 2011b).

1.2. Parkinson's disease

Parkinson's disease (PD) involves a selective deterioration of dopamine cells in the nigro-striatal and mesolimbic systems resulting in severe dopamine depletion in the striatum, prefrontal cortex (PFC), and parietal cortices (McNamara, 2011). This dopamine deficiency leads to major motor deficits, such as resting tremor, rigidity, bradykinesia, and gait dysfunction, as well as non-motor symptoms such as mood disorders, autonomic dysfunction, and cognitive impairments, including heightened impulsivity (McNamara, 2011; McNamara and Durso, 2006). This heightened impulsivity can emerge as one form of impulse control disorders (ICD) that have been found to affect anywhere from 6% to 15.5% of individuals with PD (Callesen et al., 2013). There is building evidence that ICDs may be induced by medication, particularly D2/D3 agonists, with one large study finding nearly a three-fold increase in ICDs associated with dopamine agonist use (Weintraub et al., 2010). Neurologically, the subthalamic nucleus and the nucleus accumbens are likely to be regions of interest in ICDs (Callesen et al., 2013).

Initial investigations into temporal discounting in patients with PD found that individuals with PD have steeper discounting curves (Milenkova et al., 2011). Following the pattern of ICDs more generally this heightened impulsivity has been found to occur primarily within those individuals taking D2/D3 agonists (Pine et al., 2010; Voon et al., 2010), which may excite responses to rewards and impair the control of these impulses (Kassubek et al., 2011). But, other investigations have found that only those individuals with PD and comorbid behavioral addictions exhibit these elevated discounting rates (Averbeck et al., 2013; Voon et al., 2010). Given the fact that those systems impacted by PD closely overlap those involved in the neuro-cognitive model of intertemporal discounting, it would be surprising not to see some relationship between the disease and discounting behaviors.

The degradation of dopamine neurons within PD has also been found to impact access to religious cognition. Researchers found that the right-hemispheric deficits associated with left-onset PD lead to a dampened ability to access religious cognitions (Butler et al., 2010). These deficits were subsequently corroborated by further investigations (Butler et al., 2011a, 2011b). We therefore predict that these differences in accessing religious cognition will result in differing effectiveness of the religious semantic primes in modulating responses to the intertemporal discounting task.

1.3. Present study and hypotheses

The current study investigates the effects of religious semantic priming on discounting rates among individuals with Parkinson's disease and neurotypical controls. Given past research and the background covered above, we had a series of 4 hypotheses:

1) Within our sample of older adults, religious individuals will have reliably lower discounting rates than their non-religious counterparts.
2) Discounting rates will be lower under the religious priming condition compared to rates under the neutral primes.
   a. This effect will be stronger among neurotypical participants than individuals with Parkinson's disease.
3) Individuals will respond more quickly under the religious primes than the neutral primes.
   a. Again, this effect will be stronger among neurotypical participants, and weakened or absent among those with Parkinson's disease even after controlling for severity of motor deficit.
4) The magnitude of response to religious primes will be correlated with functional connectivity of networks extending from the NAcc to areas in the dorsal and ventral mPFC, which mediates prospection and executive control (Spreng et al., 2008, 2010; Zheng et al., 2014).

2. Materials and methods

73 participants were recruited through the Veterans Affairs medical system along with various PD support groups, and flyers. Participants were compensated $10 an hour for their time. For participation in the rsfMRI, participants were compensated $50. This research was approved by the Veterans Affairs, Boston, Institutional Review Board. Our approval number is Veterans Affairs, Boston, Institutional Review Board #2722. Written informed consent was obtained from all participants as specified by the approved protocol.

2.1. Intertemporal discounting task

Using E-Prime 2.0 (Psychology Software Tools, Inc, USA) we used a set of 48 temporal discounting choices developed by Paglieri et al. (2013) as an expanded version of the Monetary Choice Questionnaire (Kirby and Maraković, 1996). Within this set, the monetary rewards range from $15 to $85 and the largest delay is 200 days (See Appendix A for the full set). In four blocks of 24, each choice was randomly shown twice: preceded once by a religious prime and once by a neutral prime. Primes were presented near the subliminal threshold, at 35 ms (Holender, 1986).

By tracking individual preference reversals, the test is designed to yield two mean total discounting rates for each participant: one for the set that was preceded by religious primes and one for the set that followed the presentation of a neutral prime. There is substantial evidence (Odum, 2011) that temporal discounting of future value can be modeled through Mazur's hyperbolic formula: $V = A/(1 + kD)$, where V is the present value of a delayed reward, A is the delayed amount, D is the temporal difference in days, and k is the subjective discounting rate (Mazur, 1987). Since our hypotheses are primarily concerned with priming effects, we assume hyperbolic discounting curves.

In addition to the overall discounting rate, represented by k, this test also yields three discounting rates for choices of varying magnitude. Numerous studies have confirmed a magnitude effect on intertemporal discounting: individuals tend to be more willing to wait for larger rewards and therefore show lower discounting rates as the delayed amount increases (Green et al., 1999; Kirby and Maraković, 1996). Therefore, from the discounting task we have multiple variables for each individual. An individual's overall discounting rate, and discounting rates for small, medium, and large magnitudes are given for each priming condition.

Following established guidelines (Paglieri et al., 2013), individuals who answered smaller sooner or larger later for all trials, or within any reward magnitude, were excluded from the analysis since they could not be assigned a parameter value ($n = 5$).

This procedure also yields a Mean Consistency Score (MCS) for each individual, which represents the percentage of choices that are consistent with the discounting rate estimate (Paglieri et al., 2013). The MCS ensures the internal consistency of the measure for each individual. For neurotypical adults and participants with PD respectively, the MCS were: 92.5% and 91% for overall discounting rate estimates; 97% and 94.4% for small magnitude estimates; 95.4% and 95% for medium magnitude estimates; and 94.1% and 93.8% for large estimates. These high consistency scores support the accuracy of our parameter estimation.

2.2. Religious primes

To construct semantic primes, a group of consenting participants blinded to purpose of the study ($n = 32$) rated 120 words on perceived religiosity and likability on a Likert scale from 1 to 7. From the set we choose the twelve words most consistently rated religious (mean $= 6.29$, sd $= 0.40$): Bible, Nun, Prayer, Monk, Temple, Saint, Angel, Heaven, Sin, Hell, Demon, Devil. We also choose the twelve least religious words (mean $= 1.17$, sd $= 0.14$): Hospital, Axe, Civil, Jolt, Jungle, Lard, Blink, Chisel, Hut, Lodge, Block, Pepper.

The samples were matched for likability (Religious: mean $= 4.1$, sd $= 1.1$; Neutral: mean $= 4.2$, sd $= 0.56$; t-test, $p = 0.717$) and using ratings from the MRC Psycholinguistic Database (Coltheart, 1981), the sets were also matched on familiarity (Religious: mean $= 480$, sd $= 49$; Neutral: mean 485, sd $= 48$; t-test, $p = 0.81$), length (Religious: mean $= 4.8$, sd $= 1.1$; Neutral: mean $= 4.9$, sd $= 1.4$; t-test, $p = 0.71$), Kucera-Francis written frequency (Religious: mean $= 33.5$, sd $= 26$; Neutral: mean $= 32.9$, sd $= 36.9$; t-test $p = 0.96$), and imagibility (Religious: mean $= 519$, sd $= 71$; Neutral: mean $= 506$, sd $= 83$; t-test, $p = 0.64$).

While these religious primes may seem biased toward a Christian worldview, “Bible” and “Sin” are the only uniquely Judeo-Christian concepts. Furthermore, among our sample, all of which live in the larger Metro-Boston area, these words will still likely be recognized as religious in significance, as indicated by our rating system. This association with religiosity is all that is required to activate the associated semantic network.

2.3. Neuropsychological assessments

We administered the standard mini-mental state examination (MMSE) (Nazem et al., 2009), and the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005) to control for cognitive deficits within our sample. Furthermore, interference scores from the Stroop color and word test (Golden, 1978) were used as an assessment of inhibitory control.

2.4. Brief multidimensional measure of religiousness/spirituality (BMMRS)

The BMMRS (Fetzer Institute and National Institute on Aging Working Group, 1999) was developed in a collaborative effort between the Fetzer Institute and the US National Institute on Aging, to provide a self-report measure of different facets of religiosity and spirituality with specific relevance to health outcomes. Given the relationship between impulsivity, self-control, and various health outcomes (McCullough and Willoughby, 2009), we selected this measure of religiosity as the most relevant to delayed discounting outcomes.

The BMMRS consists of ten specific dimensions: daily spiritual experiences, values/beliefs, forgiveness, private religious practices, religious and spiritual coping, religious support, religious/spiritual history, commitment, organizational religiosity, and religious identification. In addition to these dimensions, the scale also includes an overall self-ranking of religiousness and spirituality, assessed by two items each ranked 1–4: "To what extent do you consider yourself a religious person?" and "To what extent do you consider yourself a spiritual person?" These two items are summed and reverse scored, as per the measure design, to give an overall measure of R/S ranging from 2 (not at all religious or spiritual) – 8 (very religious and very spiritual).

Construct validity for the BMMRS has been supported by various studies (Masters et al., 2009; Neff, 2006), with some suggesting that high correlation among the sub-dimensions indicates that they should be treated as facets of a unified phenomenon rather than distinct dimensions (Piedmont et al., 2007). Whether multi-faceted or multidimensional, this measure of religiosity will permit analysis into the aspects of religiosity that relate to impulsivity, beyond affiliation and belief.

2.5. rsfMRI procedures

A sub-sample of thirty-one participants underwent resting state fMRI (rsfMRI); twenty-one of whom had PD. Given the severe motor problems encountered when off medication, all participants with PD were tested on medication. Recent findings have suggested that dopaminergic medication can impact resting state activation by normalizing functional patterns that would otherwise register as abnormal (Tahmasian et al., 2015). However, our hypotheses depend upon behavioral differences while participants with PD are on medication. Therefore, to assess blood oxygenation level dependent (BOLD) signal correlations with these behavioral differences, individuals were imaged while on medication.

MRI scans were obtained using a Siemens TIM Trio 3 T MRI with a 12-channel head coil at the VA Boston Healthcare System in Jamaica Plain, Boston, MA, USA. During each scan, two T1-weighted neuroanatomical images were acquired using an MPRAGE (magnetization-prepared rapid acquired gradient echo) pulse sequence [specifications: 176 slices, TR: 2530 m.s., TE 3.3 m.s. FOV: 256 m.m., flip angle 7°, gaps skip 0.50, with a voxel size of 1*1*1 m.m.] for a total of 6:02 min for each full head scan. Additionally, three sets of T2*-weighted functional images of resting state were acquired for each participant using an Echo Planar image (EPI) sequence with a sensitivity to BOLD (blood oxygen level-dependent) contrast (specifications: 38 slices per full head volume, TR: 3000 m.s., TE: 30 m.s., FOV: 192 m.m., flip angle 90°, 3 m.m. gaps skip 0.8, voxel size 3*3*3.75 m.m.) for a total of 120 volumes and lasting approximately 6:08 min for each run. All participants were instructed to keep their eyes open during this time (Van Dijk et al., 2010).

Image processing was performed in the FreeSurfer processing suite (http://surfer.nmr.mgh.harvard.edu/). Surface models were reconstructed from two T1-weighted scans using automated segmentation of anatomical images. Resting state fMRI scans, per subject, were processed using a standard stream as outlined by Robinson and et al. (2015; motion correction, time shifting, concatenation of scans, motion regressed from the time series, regression of the average time course from the white matter and ventricles, band pass filtering between 0.01 and 0.1 Hz). Sessions, runs, and time points with excessive motion were excluded (30TRs/session; 20TRs/run; 0.5 mm/TR; 0.4 mm/motion threshold). The data were smoothed by a surface based procedure with FWHM of 12mm, and each brain was mapped to Freesurfer's fsaverage template brain. Seed regions were taken from subcortical segmentations of the bilateral NAcc as outlined by Fischl et al. (1999). Vertex-wise partial correlation to the seeds were used for group-level analyses.

2.6. Statistical analysis

Group comparisons of continuous variables were assessed by independent-samples *t*-tests. Relationships between continuous variables were assessed using the Pearson correlation coefficient.

We also compared groups using multivariable mixed effects methods controlling for age, education, gender, and motor severity among those participants with PD. We used a random intercept to account for multiple observations from the same subject. One advantage of using mixed effects models is that the problem of multiple comparisons is removed when viewed from these models (Gelman et al., 2012). Moreover, these multivariate models provide higher power for detecting small but clinically important differences compared to independent regression models for each outcome (Goldstein, 2010).

For imaging analysis, the bilateral NAcc was defined individually per subject in the Control (n=10) and the PD (n=21) groups with FreeSurfer's *selxavg3-sess* utility. Both within-group and between-group analyses were run with FreeSurfer's *mri_glmfit* utility with no covariates, age as a covariate, DRT scores as a covariate, and both age and DRT scores as covariates. Multiple comparisons corrections (MCC) followed Freesurfer's GLM methods utilizing *mri_glmfit-sim* with a voxel-wise threshold of $p < 0.005$ and a cluster-wise threshold of $p < 0.05$ in a 10,000 repetition Monte-Carlo simulation in the final group analysis.

3. Results

35 neurotypical adults and 33 participants with PD participated in our study. A neurologist (author R.D.) specializing in movement disorders confirmed the diagnosis in all patients using clinical criteria from the United Kingdom Parkinson's Disease Society Brain Bank (Hughes et al., 1992). All participants were screened for dementia using the criteria of the Diagnostic and Statistical Manual of Mental Disorders, 4th ed. text revision (American Psychiatric Association, 2000). Our sample was religiously diverse including: 22 Catholics, 21 Protestants, 4 Jews, 2 Buddhists, 1 Mormon, 1 Eastern Orthodox, and 15 non-affiliated individuals.

Among our participants with PD: mean age was 69 (sd=9.2); mean years of education was 15.3 (sd=2.7); and standardized scores on the MMSE were 46 (sd=13.1). The mean disease duration was 6.9 years (sd=5) and the Unified Parkinson's Disease Rating Scale motor scores averaged 30.6 (sd=14.9) with mean Hoehn-Yahr scores 2.4 (sd=0.7). All participants with PD were tested on their medication. 11 participants were taking D2/D3 agonists and 22 were only taking levodopa; the mean levodopa equivalency daily dosage (Tomlinson et al., 2010) averaged 555.5 mg (sd=372.2 mg).

Among our neurotypical adults: mean age was 58 (sd=12); mean years of education was 15.35 (sd =3.9); mean MMSE standardized scores were 51 (sd=11.0). 19 participants were female and of that group, 4 had PD. Given the differences in age and gender between our groups, we controlled for this variable in our analyses comparing the two groups.

Between our neurotypical adults and participants with PD, there were no statistically significant differences for MMSE scores, $t(55)=-1.32$, $p=0.192$, or for MoCA scores, $t(54)=-1.10$, $p=0.274$, as assessed by independent samples, 2-tailed, *t*-tests. Furthermore neurotypical adults did not significantly differ from participants with PD on the Stroop test as assessed with an independent sample, 2-tailed, *t*-test, $t(55)=0.74$, $p=0.464$. These comparisons indicate that the group of neurotypical adults was appropriately matched with participants with PD.

Given past research indicating the potential medication effects on impulsivity (Kassubek et al., 2011; Pine et al., 2010; Voon et al., 2010) we examined group differences in discounting rates between those participants on D2/D3 agonists (n=11) to those only taking levodopa (n=22). There were no significant differences in discounting rates as assessed by independent sample, 2-tailed, *t*-tests: $p>0.500$ for all magnitudes. Using levodopa equivalency dosages, which provide a standardized comparison across the variety of dopamine replacement therapies (Tomlinson et al., 2010), we found no significant correlations between medication and discounting rates, reaction times, or individual religiosity.

The sub-sample of participants willing and able to undergo the rsfMRI (n =31) was relatively representative of the overall group: mean age was 61 years old (sd =12), mean education was 15.7 years in school (sd =3.0), mean standardized scores on the MMSE were 45.9 (sd =13.1). Discounting rates, differences in reaction times, and religiosity did not significantly differ between those individuals in the rsfMRI subsample and those not including the rsfMRI analysis, as assessed by independent sample, 2-tailed, *t*-tests: overall discounting rate $t(55)=0.89$, $p=0.377$; small $t(55)=1.32$, $p=0.190$; medium $t(55)=1.44$, $p=0.153$; large $t(55)=.29$, $p=0.770$; differences in reaction time $t(55)=1.07$, $p=0.287$; and religiosity $t(55)=.21$, $p=0.833$. Only three women were able to participant in the rsfMRI analysis, 2 of which had PD. This limits the generalizability of our findings, but does not severely undermine their validity since on cognitive, demographic, and other major variables the sub-sample is representative.

3.1. Hypothesis 1

Testing our first hypothesis, we used the two-item overall religiosity and spiritual score (R/S) from the BMMRS and discounting rates from the neutral priming condition. Among our entire sample (n=68) Pearson correlations comparing R/S with discounting rates found a significant moderate positive relationship between religiosity and impulsivity: for overall discounting rate ($r=0.331$, $p=0.006$), small magnitude rewards ($r=0.337$, $p=0.005$), medium magnitude rewards ($r=0.307$, $p=0.011$), and large magnitude rewards ($r=0.350$, $p=0.003$). Within this sample of older adults, the more religious an individual, the higher their discounting rate. See Fig. 1 for a scatterplot of this relationship.

The relationship between R/S and discounting rates held over and above age and education, both of which also influenced discounting rates. In a hierarchical multiple regression, for which all assumptions were met, age and education significantly predicted discounting rates with $R=0.352$, $R^2=0.124$, $F(1, 65)=4.20$, $p=0.044$. The addition of religiosity/spirituality to the model led to a statistically significant increase in R^2 of 0.073, $F(1, 64)=5.82$, $p=0.019$, with the resulting $R=0.444$. Therefore, within our sample of older adults, higher levels of religiosity and spirituality significantly predicted higher discounting rates.

3.2. Hypothesis 2

With regard to our second hypothesis (religious primes would reduce discounting rates relative to neutral primes), a mixed effects regression model revealed no significant effects of the religious semantic primes on discounting rates for either Controls or PDs (see Table 1).

For both groups, all estimates within the model were negative, ranging from −0.22 to −0.02, indicating that the religious primes

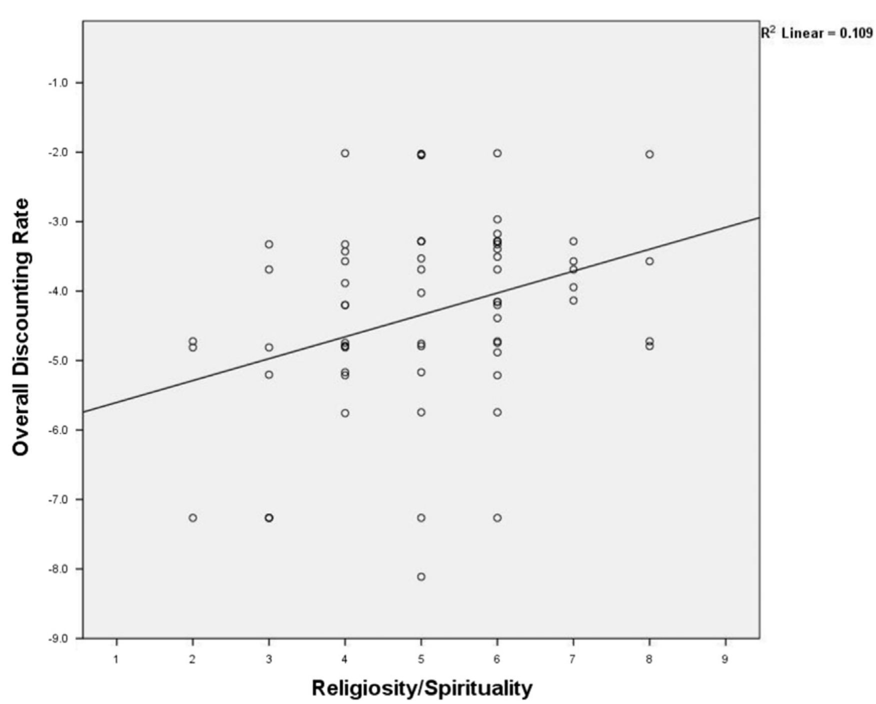

Fig. 1. Correlation between Discounting Rate and Individual Religiosity/Spirituality. Overall Discounting Rate values are log-transformed; higher numbers indicate a higher discounting rate. The Religiosity/Spirituality variable is the two-item overall score from the BMMRS, such that higher values indicate higher levels of religiosity.

Table 1
Comparison of Discounting Rates under the Religious versus the Neutral Priming conditions.

	Controls (n=35)				PD (n=33)			
Discounting magnitude	**Estimate**	**Standard error**	***t*-value**	***p*-value**	**Estimate**	**Standard error**	***t*-value**	***p*-value**
Overall	−0.070	0.135	−0.52	0.602	−0.094	0.142	−0.66	0.509
Small	−0.062	0.135	−0.46	0.643	−0.110	0.142	−0.77	0.439
Medium	−0.101	0.135	−0.75	0.454	−0.223	0.142	−1.56	0.118
Large	−0.023	0.135	−0.17	0.866	−0.189	0.142	−1.32	0.186

were trending towards lower discounting rates than those under the neutral priming condition. But none of these differences reached significance, with $p > 0.10$ for all values. Thus, contrary to our second hypothesis, the religious semantic primes did not significantly alter individual discounting rates in comparison with the neutral priming condition.

Given the recent meta-analysis (Shariff et al., 2015) suggesting that religious primes are primarily effective among religious individuals, we modeled the influence of R/S on differences in discounting rates under the two priming conditions, again controlling for age, education, gender, and motor severity among those participants with Parkinson's disease. The interaction effects between R/S and religious semantic priming for both controls and participants with PD are reported in Table 2.

This multivariate mixed effects model suggests there was no significant influence of individual religiosity on differences in discounting rates under the two priming conditions for either controls or participants with PDs. The positive estimates among Controls indicate some influence, but this interaction was not robust enough to yield significance.

3.3. *Hypothesis 3*

To test hypothesis three (that relative to neutral primes, religious primes would reduce reaction times on discounting decisions), we compared reaction times, milliseconds from choice presentation to response, under the neutral primes and the religious primes. Given the motor impairment of PD, we expect participants with PD to respond more slowly under all priming conditions. Therefore, all analyses used differences within each individual's reaction time: modeled by the variable DRT =(RT under the neutral condition) – (RT under the religious priming condition), to measure the impact of the religious semantic primes on reaction times for each participant regardless of relative slowness.

Again, using multivariate mixed effects methods, we built a model to assess the influence of religiosity on these differences in reaction times under the two priming conditions while controlling for age, education, gender, and motor severity among those participants with Parkinson's disease. These interaction effects are reported in Table 3.

There was no reliable influence of religiosity/spirituality on DRT for either controls or participants with PD. But, there was a reliable dissociation effect between the two groups, reflected here by the positive estimates among controls and the negative estimates among individuals with PD. Positive estimates within the model indicate that the greater the religiosity, the greater the difference in reaction times, while negative estimates within the model suggest that differences in reaction time were not influenced by religiosity.

For controls, mean DRT=347.8 ms (sd=1051.4). While for participants with PD mean DRT=−297.4, (sd=1274.7). This suggests that not only does religiosity exert a greater influence on differences in reaction time among the controls, but these participants are, on average, answering more quickly under the religious priming condition than the neutral condition.

To test the significance of this dissociation effect, we compared the interaction effects of religiosity and DRT, as reported in Table 3, between controls and participants with PD through a multivariate mixed effects model, again controlling for demographic factors. These results are reported in Table 4.

Religious semantic primes led to significantly divergent effects in Controls compared to PDs. This was true across all magnitudes and was statistically significant for overall discounting rates and choices involving small magnitudes, and marginally significant for medium and large magnitude choices. This significant dissociation effect suggests that reaction times under the religious priming condition reliably sped up in relation to religiosity among controls, while the participants with PD were unaffected in their reaction times by the religious semantic primes.

3.4. *Hypothesis 4*

To assess the neural structures related to these behavioral differences in response times to religious versus neutral primes, we conducted rsfMRI analysis. Bilateral NAcc seed-analysis revealed widespread regions of positive correlations with the seed for both the Control and PD groups in the rsfMRI acquisition. BOLD correlations with the seed were significantly greater ($p < 0.005$) in the Control group when compared to the group with PD in regions spreading across the bilateral superior temporal, precuneus, and anterior cingulate regions. BOLD correlations were also greater in the Control group in the left rostral middle frontal ($p < 0.05$), left postcentral, left posterior cingulate, right superior frontal, and right supramarginal regions ($p < 0.005$).

Group analysis investigating the interaction between groups and their DRT scores found significant differences in BOLD correlations in a number of regions in both hemispheres. When compared against one another, increasing correlations to the NAcc were explained by increasing DRT scores in the Control group for the right dorsolateral prefrontal cortex (DLPFC), paracentral cortex (PARC), subcentral gyrus

Table 2
The Effect of Religiosity on Differences in Discounting Rates under the Religious and Neutral Priming Conditions.

	Controls (n=35)				PD (n=33)			
Discounting magnitude	**Estimate**	**Std Error**	***t*-value**	***p*-value**	**Estimate**	**Std error**	***t*-value**	***p*-value**
Overall	0.173	0.20	0.86	0.400	−0.144	0.16	−0.92	0.369
Small	0.265	0.21	1.25	0.223	0.116	0.17	0.67	0.509
Medium	0.230	0.21	1.12	0.275	−0.002	0.16	−0.01	0.993
Large	0.257	0.22	1.19	0.244	−0.176	0.15	−1.18	0.369

Table 3
The Effect of Religiosity on Differences in Reaction Time Under the Religious and Neutral Priming Condition.

	Controls (n=35)				PD (n=33)			
Discounting magnitude	**Estimate**	**Std error**	***t*-value**	***p*-value**	**Estimate**	**Std error**	***t*-value**	***p*-value**
Overall	179.54	146.0	1.25	0.217	−170.93	139.2	−1.23	0.224
Small	180.60	145.2	1.24	0.218	−180.71	145.3	−1.24	0.218
Medium	189.99	145.2	1.31	0.195	−158.40	145.3	−1.09	0.280
Large	168.57	145.2	1.16	0.250	−174.20	145.3	−1.20	0.235

Table 4
Group Differences in the Effect of Religiosity on Differences in Reaction Times: PDs versus Controls.

Discounting magnitude	Estimate	Standard error	DF	*t*-value	*p*-value
Overall	−141.40	61.24	131	−2.31	0.023*
Small	−152.03	74.93	131	−2.03	0.045*
Medium	−139.11	74.93	131	−1.86	0.066
Large	−133.49	74.93	131	−1.78	0.077

* $p < .05$.

(SCg) and the left central sulcus, transverse temporal gyrus (TTG), posterior superior temporal lobule and caudal anterior cingulate cortex (cACC) as shown in Fig. 2.

These regions were not significantly correlated with changes in DRT scores in the PD group when compared against the Control group; however, within-group analysis revealed the medial post-central gyrus of the PD group to have reduced correlation to the NAcc with increasing DRT scores.

4. Discussion

Our results suggest that religiosity is indeed related to discounting rates; yet contrary to previous studies with young adults (Carter et al., 2012; Kim-Spoon et al., 2014; Paglieri et al., 2013), the more religious our older adult participants were, the larger their discounting rates. As reviewed in the introduction, religiosity likely impacts intertemporal discounting rates by modulating valence attributed to rewards and by altering temporal perception processes that impact calculations concerning the time horizon in discounting decisions.

In adolescents and young adults, religion appears to support decisions in favor of delayed gratification given their longer time horizons and the valence assigned to monetary rewards (Carter et al., 2012; Kim-Spoon et al., 2014; Paglieri et al., 2013). For older adults, however, the time horizon is more restricted (Read and Read, 2004) and the valence attached to monetary rewards has diminished, shifting importance to other values (Rademacher et al., 2013). Thus older age leads to steeper discounting curves for monetary rewards as it becomes advantageous and rational to select rewards now rather than

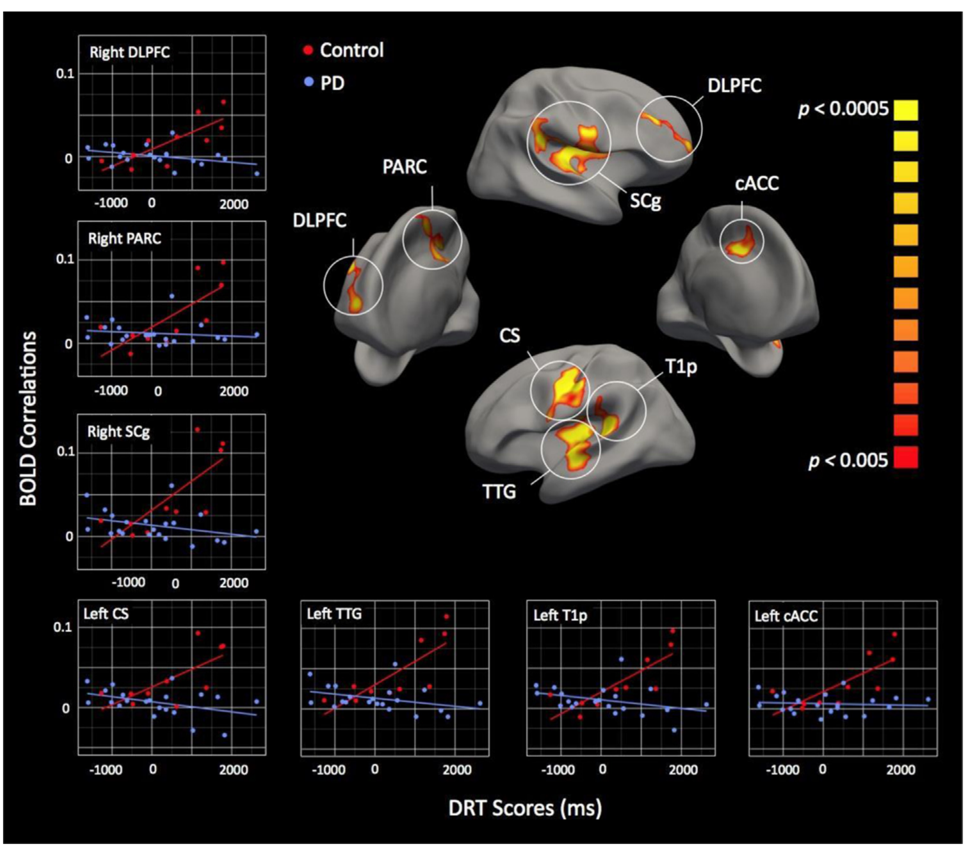

Fig. 2. ROIs of significant correlation to the NAcc seed for right hemisphere (top & left) and left hemisphere (bottom & right) in relation to Differences in Reaction Time (DRT) under the religious versus neutral priming condition. Using Differences in Reaction time under the religious and neutral priming conditions as a regressor, controls expressed increasing BOLD correlations (unitless) to the NAcc seed for every region compared to the PD group, which did not show a significant trend. DLPFC, dorsolateral prefrontal cortex; PARC, paracentral cortex; SCg, subcentral gyrus; CS, central sulcus; TTG, transverse temporal gyrus; T1p, posterior superior temporal lobule; cACC, caudal anterior cingulated cortex.

wait (Green et al., 1999; Read and Read, 2004). Supporting this interpretation, we found a linear positive relationship between age and discounting when investigating hypothesis 1. Thus, while our results could be interpreted as linking religiosity with impulsive decision-making, it may be that religiosity, in both the young and old, flexibly supports rational decision making around rewards for any relevant time horizon.

The flexible decision making process supported by religiosity can be described through the de-centering model of religious cognition (McNamara, 2009). Recall that the decentering model suggests religious cognition supports a decoupling from a current self-model and a striving for and linking up to a future hoped for or ideal self-model supported by the contextually relevant religious culture. The values embedded within a prospective ideal self will shift throughout a lifetime. For a religious adolescent, this ideal self may be one of self-restraint, patience, and responsibility (Kim-Spoon et al., 2014), leading to habits of delaying gratification. Yet for a religious older adult, research from the psychology of religion suggests that the ideal may be oriented around traits such as gratitude, humility (McFadden, 2013), and self-reflective meaning-making (Hood et al., 2009). Practiced association with these values could accelerate the steepening discounting rates that naturally occur with age by fostering an acceptance of what is given and a realistic assessment of the temporal horizon. In both cases, religious individuals, through a prospective focus on the ideal self (McNamara, 2009), would develop action control habits supporting rational decision making within a given temporal horizon and value landscape.

Similarly, previous studies have found reliable effects of religious priming on delay of gratification behaviors (Rounding et al., 2012) while others have failed to replicate these effects (Harrison and McKay, 2013), both using college students. Within our study, the religious semantic primes did not reliably influence participants' discounting rates. While our experimental design was novel, the priming technique has been successfully used in previous samples (Butler et al., 2010, 2011b), and within our sample the primes did influence reaction times. Therefore it seems unlikely that the lack of statistical significance in hypothesis 2 was due simply to a failure of the experimental paradigm.

Instead, this too is more coherently explained by shifting salience of monetary rewards within the changing values and temporal perspective of age. Shariff et al.'s (2015) meta-analysis showed that religious priming is mostly effective among the religiously affiliated. Within our sample, the religious participants had higher discounting rates than their less religious peers, as discussed above. Therefore, those who were most likely to be influenced by the religious primes were also those that had the highest discounting rates and the least value attached to monetary rewards. Furthermore, if religious participation accelerated this reduction in salience assigned to money, then religious primes are unlikely to lead to a shift in preferences already given. The lack of religious semantic priming effects on discounting rates fits the overall trend among our religious participants towards reduced salience attached to money.

Rather than causing participants in this study to choose the smaller sooner choice more often, it would seem that the religious semantic primes did lead to diverging effects for reaction times between neurotypical adults and participants with Parkinson's disease. The more religious our neurotypical controls were, the more quickly they responded under the religious priming condition than the neutral condition, while the participants with Parkinson's disease showed no significant interactions between their religiosity and differences in reaction times under the two priming conditions. Past research has found magnitude effects in response time differences, such that participants responded more quickly to larger magnitude rewards than smaller rewards (Paglieri et al., 2013). The explanation given for this difference relates to the ease of distinguishing larger magnitudes, while the same proportions in smaller magnitudes were more difficult to determine, thus slowing the process.

The ease of decision-making in relation to perceived value can also help explain our results. Cognitively, this dissociation effect between neurotypical adults and participants with Parkinson's disease could be modeled in terms of access to religious semantic networks with their embedded values. Past research has suggested that individuals with PD have impaired access to the neural networks supporting religious cognition (Butler et al., 2010, 2011a, 2011b). Therefore, this neural impairment associated with Parkinson's disease may explain the diverging effects between our two groups, but it alone does not explain the how religious semantic primes would facilitate quicker responses among the religious controls.

Our rsfMRI analysis found significant correlations between BOLD signals in the NAcc and multiple regions: right dorsolateral prefrontal cortex (DLPFC), paracentral cortex (PARC), subcentral gyrus (SCg) and the left central sulcus, transverse temporal gyrus (TTG), posterior superior temporal lobule and caudal anterior cingulate cortex (cACC). The functional connectivity within these networks increased in relation to faster reaction times in response to the religious semantic prime as compared to responses under the neutral priming condition. This relationship between functional connectivity and DRT was present for controls, but absent for participants with PD whose responses were not influenced by the religious primes.

In the right hemisphere, connectivity associated with faster responses under the religious priming condition, included networks between the NAcc and the right DLPFC regions, specifically the fronto-polar Brodmann areas 10 and 46. These areas are densely interconnected with the ventromedial PFC and the limbic system. They are crucial for executive processing, cognitive branching, working memory, decision making, multi-tasking, and specifically play a role in prospective processing (Spreng et al., 2008, 2010; Zheng et al., 2014). Past studies have also implicated the right lateral PFC in religious cognition (Butler et al., 2010, 2011a, 2011b; Han et al., 2008), with Kapogiannis et al. (2014) suggesting the role of these regions in how beliefs may guide behavior. Therefore, the suggestion that prospection plays a crucial role in the capacity of religious primes to quicken responses to intertemporal decisions is supported by this associated connectivity between the NAcc and DLPFC.

In the left hemisphere, the primary region of interest is the cACC, which has been attributed with error detection (Bush et al., 2002) and conflict monitoring (Holroyd et al., 2004; Luu and Pederson, 2004). Importantly, this interpretation has also been incorporated within research suggesting the essential role of the ACC in reward-based decision-making circuits (Bush et al., 2002). The ACC is sensitive to value and salience of rewards, while also integrated with motor networks, allowing for modulation of behavior in the midst of decision processes involving rewards (Bush et al., 2002). Given this role in reward networks, it is no surprise that connectivity between the NAcc and the cACC was associated with the influence of religious priming on responses to discounting choices.

Other regions of interest include the PARC, SCg, the left central sulcus, the TTG, and posterior superior temporal lobule. These regions are variously associated with complex motor and action programming and control functions, auditory and language processing (Spitsyna et al., 2006), and social cognitive processing (Bigler et al., 2007). Correlated BOLD activity between the bilateral NAcc and these regions likely represent integrated networks for timed responses to complex language-based decisions and for enacting a behavioral plan associated with prospection and valuation.

Collectively this neurological evidence supports a cognitive interpretation for faster responses under the religious primes among neurotypical adults. Religious semantic primes, activating a prospective ideal self among religious controls, with reduced valence assigned to monetary rewards, lead to faster decision-making processes but these effects were not present among neurally impaired patients with PD. Past studies have found that religious cognition is impaired within individuals with Parkinson's disease (Butler et al., 2010, 2011a, 2011b), especially within left-onset disease, which further implicates the dopaminergic networks of the right hemisphere (Butler et al., 2011a). Our rsfMRI data supports these previous findings by suggesting regions within the right PFC that are particularly associated with responses to religious semantic primes. These regions are integrated bilaterally with other networks to produce a behavioral difference.

Clinically, these results suggest that neural degradation may disrupt or slow access to religious semantic networks and their associated meanings. Past research has found that nearly 45% of older adults use religious coping strategies (Koenig et al., 1988). While the degradation of the dopaminergic system itself may not lead to difficulty in delaying gratification, it may hinder access to other cognitive networks that can be drawn in to support intertemporal decision making. These results should help clinicians be broadly aware of the complex cognitive disruptions that can occur in the midst of PD. But, importantly, this slowed access to religious semantic networks did not ultimately change our participants' choice selection. Therefore, it would seem that even with slowed access, individuals with PD find new resources and routes within their decision making processes.

4.1. Limitations and future directions

One limitation of the current study is the age difference between our control sample and our group of participants with PD. Given this difference we controlled for age within all analyses comparing the two groups. Nevertheless, a more closely matched comparison may helpfully yield stronger effect sizes in the differences observed. Furthermore, our sample did not include a fully balanced number of females with Parkinson's disease, largely due to our recruitment through the VA hospital system. To extend our results, future research will need to include an equal proportion of men and women in their samples. Although we had an acceptable number of participants for a neuroimaging study, a larger sample would allow a greater generalizability of our rsfMRI results. The neuro-cognitive model asserted here is one possible explanation for the effects observed; however, future research will be necessary to refine the model given the complex nature of religious cognition and decision processes concerning intertemporal discounting.

As our study has found age-related differences in the relationship between religiosity and discounting behaviors, a promising future direction for research on this relationship would include more age-diverse samples. Furthermore, as young adults have shown an association between lower discounting rates and higher levels of religiosity, we would predict that a repetition of the study among a younger sample would lead not only to increased reaction times but to a corresponding decrease in discounting rates.

Despite the constraints of our sampling limitations, this study nevertheless offers insight into the complex ways religiosity may modulate perceptions of value and prospection processes to influence discounting behavior. Furthermore, our results suggest that religious cognition may aid discounting decision-making processes by activating prospective ideal selves, shaped by the relevant religious context, and corresponding action control habits. These cognitive mechanisms were evidenced by neurological differences between those participants who responded more quickly under the religious priming condition and those whose reaction times did not significantly alter. Given the ways dopamine replacement therapies can normalize aberrant functional connectivity patterns (Tahmasian et al., 2015), future research may examine these cognitive and neurological differences with participants off medication. But, our results showed significant differences, even while individuals were on medication. These neurological differences suggest that dopaminergic networks extending from meso-limbic system to the right DLPFC and left cACC play a central role in the relationship between religiosity and intertemporal discounting by mediating valuation and prospection processes.

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Appendix A. Intertemporal Discounting Task

See Table A1.

Table A1
Intertemporal Discounting Task choices.[a]

Rewards and Delays	Magnitude	Hyperbolic Discounting Rate
$29 today or $30 in 110 days	Small	0.0003
$35 in 200 days or $33 today	Small	0.0003
$53 today or $55 in 125 days	Medium	0.0003
$60 in 114 days or $58 today	Medium	0.0003
$78 today or $80 in 85 days	Large	0.0003
$85 in 121 days or $82 today	Large	0.0003
$34 today or $35 in 43 days	Small	0.0007
$30 in 50 days or $29 today	Small	0.0007
$53 today or $55 in 55 days	Medium	0.0007
$60 in 49 days or $58 today	Medium	0.0007
$83 today or $85 in 35 days	Large	0.0007
$75 in 39 days or $73 today	Large	0.0007
$27 today or $30 in 35 days	Small	0.0032
$35 in 40 days or $31 today	Small	0.0032
$48 today or $55 in 45 days	Medium	0.0032
$60 in 35 days or $54 today	Medium	0.0032
$65 today or $75 in 50 days	Large	0.0031
$80 in 41 days or $71 today	Large	0.0031
$21 today or $30 in 75 days	Small	0.0057
$35 in 23 days or $31 today	Small	0.0055
$47 today or $60 in 50 days	Medium	0.0055
$60 today or $70 in 31 days	Large	0.0054
$30 today or $35 in 20 days	Small	0.0083
$30 in 25 days or $25 today	Small	0.008
$65 in 70 days or $40 today	Medium	0.0089
$43 today or $55 in 35 days	Medium	0.008
$60 in 49 days or $43 today	Medium	0.0081
$85 in 35 days or $67 today	Large	0.0077
$50 today or $80 in 70 days	Large	0.0086
$75 in 61 days or $49 today	Large	0.0087
$25 today or $35 in 25 days	Small	0.016
$30 in 36 days or $19 today	Small	0.016
$40 today or $55 in 25 days	Medium	0.015
$60 in 20 days or $46 today	Medium	0.0152
$45 today or $70 in 35 days	Large	0.0159
$75 in 30 days or $51 today	Large	0.0157
$16 today or $30 in 35 days	Small	0.025
$35 in 40 days or $16 today	Small	0.03
$32 today or $55 in 20 days	Medium	0.0359
$60 in 15 days or $43 today	Medium	0.0264
$40 today or $70 in 20 days	Large	0.0375
$75 in 35 days or $37 today	Large	0.0293
$15 today or $35 in 10 days	Small	0.1333
$30 in 10 days or $13 today	Small	0.131
$24 today or $55 in 10 days	Medium	0.1292
$60 in 14 days or $21 today	Medium	0.1333
$30 today or $85 in 14 days	Large	0.131
$80 in 11 days or $33 today	Large	0.1295

[a] All reward sizes and delays were those developed and used by Paglieri et al. (2013). The only adjustment made was to replace euros (€) with dollars ($).

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