RUNNING TITLE: Risky Choice in OCD and Hoarding Disorder

Dimensional Analysis of Decision Making Under Risk in Obsessive-Compulsive and Hoarding Disorders

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ABSTRACT

Background: Many important decisions in life, such as consumption and savings decisions, involve risk. Attitudes towards risk are highly consequential in clinical disorders thought to be prone to “risky behavior”, such as substance use disorders, and those commonly associated with excessive risk aversion, such as obsessive-compulsive disorder (OCD) and hoarding disorder (HD). In this study, we investigated the risk preferences of participants with OCD and HD using a novel adaptive task and the prospect theory framework from behavioral economics.

Methods: 39 participants with HD, 39 participants with OCD, and 38 healthy controls (HC) completed clinical assessments and an adaptive risky choice task. Risk aversion and probability weighting parameter values were estimated from choice data.

Results: Participants with OCD and HD showed lower risk aversion than HC. The pattern of risk preferences was similar for OCD and HD and was characterized by an s-shaped probability weighting function (PWF) that contrasted with the classic inverse-s-shape PWF exhibited by HC. Best-fitting probability weighting parameters revealed statistically significant correlations with symptom scales: risk aversion was inversely correlated with depression, hoarding, and compulsion scores. Rationality of risk preferences was inversely correlated with hoarding severity and positively correlated with compulsion severity.

Conclusions: Contrary to expectation, subjects with OCD and HD were less risk averse than HC. Hoarding (compulsion) scores were associated with lower (greater) rationality. Understanding how fundamental risk attitudes relate to specific psychopathology may contribute to our understanding of the cognitive manifestations of psychiatric illnesses and to the development of more precise and effective treatments.
Introduction

It is commonly believed that so-called "risky behavior" is over-represented in mental disorders. Examining attitudes towards risk may be particularly fruitful in psychiatric disorders hypothesized to be characterized by impulsivity, such as substance use disorders (SUD), as well as in those hypothesized to be risk averse, such as obsessive-compulsive disorder (OCD) and hoarding disorder (HD). Current models of OCD and HD assert that both disorders involve impaired decision-making (1–4), and it has been suggested that abnormal risk attitudes play a fundamental role in both (2; 5). For OCD, the most prominent model implicates excessive risk aversion and intolerance of uncertainty (5; 6). For example, Barlow and colleagues (7) suggested that individuals with OCD “overestimate the likelihood…of danger…and are unable to tolerate uncertainty.” Similarly, with respect to HD, Grisham and colleagues posited that “hoarding participants may be risk averse, as demonstrated by their avoidance of discarding because of hypothetical future need” (2).

The few studies examining risk aversion in OCD and HD have predominantly utilized the Iowa Gambling Task (IGT) (8), a measure of impatience and probabilistic learning (9), and have yielded mixed results. Lawrence et al. (10) found evidence of a “link between hoarding and [increased] risky behavior on the IGT,” while the OCD group did not differ from controls. In contrast, neither Grisham and colleagues (2007), nor Tolin and Villavicencio (2011) found that hoarding participants differed from controls on the IGT(3; 11). A large study by Mackin and colleagues found no differences between HD, OCD, or age matched controls on the IGT (12) while Sohn and colleagues (2014) utilized the Balloon Analogue Risk Task (BART) and found lower risk taking in OCD relative to HC (13).
In the current study, we take advantage of tools from behavioral economics that permit a quantitative, dimensional analysis of decision making under risk that goes beyond the group-level summary measures of traditional decision-making experiments. Tools from economics may prove especially useful in the characterization of alternative phenotypes, or endophenotypes, of mental disorders because they target the very cognitive processes thought to be impaired (14–19). Given the potential of such behavioral endophenotypes for transforming the nosology of psychiatry (20), it is not surprising that tools from behavioral economics have been gaining popularity in the study of psychiatric illness (16–18; 21–24). In economics, risk aversion is defined as “a preference for a sure outcome [e.g., $5 guaranteed] over a prospect with equal or greater expected value [e.g., 25% chance of receiving $20 dollars]” (25). An individual’s preferences over outcomes are summarized with a utility function; linear utility functions imply risk-neutrality, concave utility functions imply risk aversion, and convex functions imply risk seeking (26). In seminal work, Tversky and Kahneman demonstrated that participants tend not to have a single characteristic risk attitude (pure risk aversion vs. pure risk-seeking); the most common pattern involves overweighting of small probabilities along with underweighting of high probabilities, a finding that has been well-replicated (27). This pattern has been invoked to explain the popularity of lottery tickets (small probability of large reward), as well as disaster insurance (small probability of large loss), and can account for well-known behavioral findings such as the certainty effect (the overweighting of outcomes that are certain relative to those that are highly probable) (28).

An individual’s risk preferences can be formally described with a “probability weighting function” (PWF) that relates objective probabilities to subjective probability weights. The PWF is a central component of Cumulative Prospect Theory (CPT) (29), the most
popular and empirically successful theory of decision making under risk in behavioral economics. As shown in Figure 1, the case in which subjective probability weights equal objective probabilities corresponds to a linear PWF, which is classically accepted as the standard of rational choice in economics (30). Empirical findings are better accounted for by nonlinear PWFs (31; 32). In CPT, the curvature of the value function (CPT analogue of the classical utility function) and the PWF jointly determine risk attitude (33), affording a more nuanced perspective on the effect of risk on decision making. Given the prevailing view in the clinical literature, we hypothesized that participants with OCD and HD would exhibit greater risk aversion than HC, as well as group differences in the pattern of risk preferences characterized by probability weighting function parameters.

**Methods and Materials**

**Participants**

Individuals ≥18 years of age with OCD (n = 39, 27 female; mean age = 35, SD = 13), HD but not OCD (n = 39, 29 female; mean age = 58, SD = 11), and healthy controls (HC; n=38, 24 women; mean age = 46, SD = 16) participated. The participants were part of a larger study that included a comprehensive clinical assessment, neuropsychological battery, and electrophysiology (EEG) measurements. Psychosis, dementia, intellectual disability, history of head trauma with loss of consciousness, active substance abuse, current use of antipsychotic medications, or any medical conditions known or suspected to affect cognitive function were exclusionary criteria. Diagnosis of OCD, as well as absence of exclusionary psychiatric disorders, was confirmed using the Structured Clinical Interview for DSM-IV (SCID) (34). Subjects with OCD were excluded if they
endorsed significant hoarding symptoms. HD diagnosis was determined according to DSM-V criteria (35). HC participants were excluded if they met criteria for active DSM-IV-TR Axis I diagnoses within the past year. Participants were recruited from mental health clinics, media advertisements, and the Mental Health Association of San Francisco. Written informed consent was obtained from all participants under protocols approved by the Institutional Review Board of the University of California, San Francisco.

Clinical Measures

For the parent study, participants received extensive clinical assessments. We focused on the results of a relevant subset of these measures: the Saving Inventory, Revised (SI-R) (36), the UCLA Hoarding Symptom Scale (UHSS) (37), the Yale Brown Obsessive Compulsive Scale (YBOCS) (38), the Beck Depression Inventory (BDI) (39), and the Beck Anxiety Inventory (BAI; Beck et al. 1988).

Decision Making Task

Each participant completed a sequence of 52 trials in which pairs of probabilistic rewards (gambles) were presented. Each gamble was presented as a “game of chance” that could yield a reward of $25, $350, or $1000, with specified probabilities (See Supplemental Figure S1). In each trial, participants were required to indicate which gamble they preferred by clicking the appropriate box on a computer screen.
The specific probabilities in each trial of each possible reward were determined in real time for each participant using adaptive design optimization (ADO; see Supplemental Materials for details), a machine learning tool designed to improve measurement precision in experimentation (41). Like adaptive testing in educational testing (e.g., GRE), in which sequences of correct answers result in progressively more difficult questions, the principles formalized in ADO result in more precise estimates of the specific risk attitudes of the participant (42). ADO has been utilized to identify best-fitting parameters in delay discounting (Cavagnaro et al., forthcoming), probability-weighting in healthy controls (43), and memory retention (44). Although risk preference parameters are estimated in real-time as part of the ADO process for selecting optimal stimuli, we elected to reanalyze all of the data at the end of the experiment to eliminate any Monte Carlo sampling error that may have built up, and to incorporate the logistic choice function (see Supplemental Information for details).

**Model Fitting**

We fit each participant’s choice data, as well as pooled group data, to the CPT model (29), which is comprised of two component functions: the value function and the PWF (see Supplemental Information for details). Numerous parametric forms have been proposed for the value function, with a one-parameter power function being the most common. We follow Cavagnaro et al. (2013) in using a “parameter free” specification, which is more flexible than a power function (43). The value function has a single free parameter \( \nu \), which measures risk aversion: \( \nu = \frac{1}{3} \) indicates risk neutrality (linear utility), while \( 0 < \nu < \frac{1}{3} \) indicates risk seeking, and \( \frac{1}{3} < \nu < 1 \) indicates risk aversion (Table 1).
Following Prelec (1998) (45), PWF parameter estimates were obtained using the formula
\[
    w(p) = e^{-(\ln p)^r},
\]
where \( p \) is the objective probability and \( r > 0 \) is a free parameter (see Supplemental Information for details). Figure 1 plots the PWF for a few illustrative values of \( r \). When \( r \) is less than one, the curve has the inverse-s shape that is typical of HC, with overweighting of small probabilities and underweighting of large ones. When \( r \) is greater than one, the curve is s-shaped, meaning that small probabilities are underweighted and large probabilities are overweighted.

**Data Analysis**

The CPT model was fitted to each participant’s data using maximum likelihood estimation (MLE), assuming a logistic choice function (see Supplemental Information for details). This yielded separate estimates of \( \nu \) and \( r \) for each participant. We also pooled the data across participants within each group, yielding a single estimate of \( \nu \) and \( r \) for each group. Next, we used the resulting \( \nu \) and \( r \) parameter estimates as variables in statistical analyses related to group membership and clinical scales. These analyses were carried out using the R statistical package, version 3.1.1 (46). Demographic and clinical characteristics were compared across groups using ANOVA. We tested for main effects of group membership on parameter values using ANCOVA (including age as a covariates given group differences), with HD and OCD as a combined patient group and separately. Follow-up pairwise comparisons were estimated using t-tests with pooled
standard deviations. Multivariate regression analyses were used to test whether PWF parameters predicted clinical measures in the relevant samples: OCD symptom severity (YBOCS) was examined in the OCD group; hoarding severity (UHSS, SI-R subscales) was examined in the HD group; as the SI-R measures hoarding symptoms in both HD populations and in non-clinical populations, it was examined in all three groups (HD, OCD, and HC), as was depression severity as measured by the BDI and anxiety severity as measured by the BAI.

**Results**

Table 2 displays demographic characteristics for our participant samples. The groups differed significantly by age (p < 0.01): The HD group was older than the HC group (p < 0.01), which was older than the OCD group (p < 0.01). Mean parameter values are plotted by group in Figure 2. The combined patient group was characterized by a lower \( \nu \) parameter (mean = 0.54, standard error of the mean (SEM) = 0.04; p < 0.05) and a greater \( r \) parameter (mean = 1.15, SEM = 0.07; p < 0.05), relative to HC (\( r \): mean = 0.84, SEM = 0.10; \( \nu \): mean = 0.70, SEM = 0.06), controlling for age. When OCD and HD were separated, a significant main effect of group was observed for the \( \nu \) (p < 0.05) parameter, with a statistical trend for the \( r \) parameter (p = 0.07). Follow-up pairwise comparisons revealed that the \( r \) parameter was smaller for HC relative to HD (mean = 1.13, SEM = 0.10; p = 0.04) and OCD (mean = 1.17, SEM = 0.10; p = 0.03), while the HD and OCD groups were statistically indistinguishable (p = 0.81); the \( \nu \) parameter was greater for HC relative to HD (mean = 0.51, SEM = 0.05; p < 0.05), and OCD (trend) (mean = 0.56, SEM = 0.05; p = 0.09), with no difference between HD and OCD (p = 0.50). The best fitting \( r \) parameter values based on pooled estimates yielded the PWFs
Regression results are displayed in Table 3. The $r$ parameter was a significant predictor of hoarding severity as measured by the UHSS ($p<0.001$) and SI-R ($p<0.05$) in individuals with HD. Both parameters were significant predictors of scores on the Difficulty Discarding subscale of the SI-R in HD ($r$: $p<0.01$; $v$: $p<0.05$), with statistical trends for the Clutter subscale ($r$: $p=0.07$; $v$: $p<0.10$); Acquisition subscale scores were predicted by the $r$ parameter ($p<0.05$). In the OCD group, both parameters were significant predictors of YBOCS compulsion subscores ($r$: $p<0.001$; $v$: $p<0.05$), though not of obsession subscores. The $v$ parameter was a significant predictor of BDI score across all subjects ($p<0.01$), controlling for health status. Associations between PWF parameters and BAI scores were not significant ($r$: $p = 0.65$; $v$: $p = 0.78$).

**Discussion**

In this study, we investigated risk attitudes in OCD and HD samples utilizing a behavioral economic approach paired with a novel adaptive experimental paradigm. We find that our OCD and HD samples exhibited quite different risk attitudes compared to controls, and these patterns of decision making under risk correlated with symptomatology as measured by standard clinical scales.

**Group Differences in PWF Parameters**

Our approach permitted us to examine risk attitudes from several complementary perspectives. The first is the value of the $v$ parameter. Based on this measure, all three...
groups exhibited risk aversion, which is unsurprising given the predominance of risk aversion in the general population \((27; 47)\). However, contrary to the conventional view and our expectation, the HD and OCD groups exhibited less risk aversion than HC.

The PWF provides additional insight into decision making. There are several prominent interpretations of the shape of the PWF, one of which is that portions of the curve that lie above (below) the diagonal imply risk seeking (aversion) over that particular range of the probability interval \((27)\). As expected, the risk preferences of the HC sample were best described by the classic inverse-s-shape (Figure 3). In contrast, both the OCD and HD samples exhibited an s-shape PWF. This result implies that individuals with either OCD or HD should be much less interested in lottery tickets, disaster insurance, and would be less likely to show the certainty effect, compared to HC.

A second, complementary interpretation highlights the behavior of the PWF near the endpoints of the probability interval \((29; 32)\). It is instructive to consider the extreme values of the \(r\) parameter. Figure 1 shows an inverse-s-shape PWF, which approximates a step function \((r = 0.1)\). The decision maker is essentially indifferent to any change in probability unless it occurs near the extremes of certainty and impossibility; all probability values away from the endpoints are discounted essentially equally, as if they belong to a homogenous category that could reasonably be referred to as “possible.” The extreme case of the s-shape (Figure 1, \(r = 10\)) is flat near the endpoints and steep towards the middle of the interval, implying that changes in probability near the endpoints have little impact on behavior. Prospects are either “probable” or “improbable.” For example, a 90\% probability of occurrence and a 60\% chance of occurrence are both equally “probable.” Hence, in contrast to HC, individuals with HD or OCD would be less focused on certainty and impossibility, and have a
greater tendency to consider prospects in binary, “probable” vs. “improbable”, terms.

A third interpretation of the PWF holds that portions of the curve that lie above (below) the diagonal imply optimism (pessimism) (48; 49). It has been argued that the apparent risk-seeking preferences of entrepreneurs actually reflect excessive optimism, rather than a true difference in risk attitude (50). On this interpretation, the PWF has less to do with preferences than with outlook. Underweighting (overweighting) implies that one is more pessimistic (optimistic) than is warranted by the stated objective probability of occurrence. Relative to HC, individuals with HD or OCD would therefore be expected to be more pessimistic about their chance of winning the lottery (low probability), and more optimistic than controls about their chance of obtaining high probability prospects.

Finally, linear probability weighting is a widely accepted standard for rational choice in economics, and it has been suggested that the curvature parameter of the PWF, $r$, may be treated as an index of rationality with respect to risky choices, in which case $r = 1$ defines rationality and greater departures from $r = 1$ imply less rational choices (30). In our study, all three groups were equally irrational in that the average departures from $r = 1$ were statistically indistinguishable for the 3 groups, though in the opposite direction for HC.

**Relationship Between PWF Parameters and Clinical Measures**

Our findings suggest that risk attitudes may be related to specific patterns of symptomatology. Greater $v$ parameter values (greater risk aversion) were associated with lower BDI, implying an inverse relationship between depressive symptoms and risk aversion, at least in the case of individuals with OCD or HD. It is worth noting that
previous studies of decision making under risk utilizing the IGT in MDD samples have yielded mixed results, with some studies finding greater levels of risk aversion in depressed participants relative to HC, while other studies found the opposite (17; 51–53). For participants with OCD, greater values of both parameters predicted lower YBOCS Compulsion scores. Hence, our results suggest that greater compulsion is associated with more rational probability weighting and lower risk aversion.

Within the HD group, greater values of the $r$ parameter were associated with higher UHSS and SI-R scores, suggesting that hoarding symptoms correlate with less rational probability weighting. Analysis of SI-R subscales revealed that difficulty discarding and acquisitiveness, and not clutter scores, are likely responsible for the association. Given that $r$ parameter values were positively correlated with hoarding symptoms, but inversely correlated with compulsion, it appears that OCD and HD may share certain dimensions of risk attitude (lower risk aversion), but differ with respect to others (rationality of risk preferences).

Thus, the findings of the current study are not consistent with the conventional view of elevated risk aversion in OCD and HD. One plausible explanation for the apparent discrepancy would be that risk preferences do not exhibit trait-like homogeneity. They may be domain-specific, such that individuals appear comparatively more risk averse in certain domains (e.g. physical safety) and less risk averse in others (e.g. monetary gains). This hypothesis has yet to be studied extensively but compelling support has been documented (50). One study found that an anxiogenic intervention led to increased risk aversion in healthy individuals, suggesting that risk preferences may be state-dependent (18; 54). There is also evidence for significant framing effects (27; 55). Furthermore, economists distinguish risky prospects, in which the relevant probabilities
are known or are predictable, from uncertain, or ambiguous, prospects, and there is clear evidence that people often exhibit ambiguity aversion (56–58). Hence, individuals with OCD and/or HD may yet exhibit comparatively elevated risk aversion in particular domains, in the context of particular emotional states, in response to alternative framing, and/or when faced with greater ambiguity. It seems clear to us that a greater understanding of how fundamental risk attitudes relate to specific psychopathology will contribute to our understanding of the cognitive manifestations of psychiatric illnesses, and, ultimately, to the development of more precise and effective treatments.

Finally, we believe that the results of the current study reinforce the idea that psychiatric research will be improved by the adoption of dimensional, transdiagnostic paradigms, such as the behavioral economic approach utilized here, which permit the identification of endophenotypes that may structure the search for genomic and neural correlates, as well as enhance our ability to identify personalized treatment targets.
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None to report.
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Table 1
Dimensions risk preference captured by parameters of the CPT model

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Parameter</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk aversion</td>
<td>$v$</td>
<td>$v &lt; \frac{1}{3} \rightarrow$ risk seeking</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$v &gt; \frac{1}{3} \rightarrow$ risk averse</td>
</tr>
<tr>
<td>Probability</td>
<td>$r$</td>
<td>$r &lt; 1 \rightarrow$ inverse s shape</td>
</tr>
<tr>
<td>weighting</td>
<td></td>
<td>$r &gt; 1 \rightarrow$ s shape</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$r = 1 \rightarrow$ linear (&quot;rational&quot;)</td>
</tr>
</tbody>
</table>
Table 2
Demographic data by participant group

<table>
<thead>
<tr>
<th>Demographic Variables</th>
<th>HC Mean±SD</th>
<th>OCD Mean±SD</th>
<th>HD Mean±SD</th>
</tr>
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<tbody>
<tr>
<td>N</td>
<td>28</td>
<td>29</td>
<td>28</td>
</tr>
<tr>
<td>Age (years)</td>
<td>46.3±16.1</td>
<td>35.1±12.8</td>
<td>57.8±10.6</td>
</tr>
<tr>
<td>Gender (%male)</td>
<td>50</td>
<td>48</td>
<td>37</td>
</tr>
<tr>
<td>Education (years)</td>
<td>15.9±2.2</td>
<td>16.1±2.0</td>
<td>15.4±1.9</td>
</tr>
</tbody>
</table>

Note: HC = Healthy Controls; OCD = Obsessive Compulsive Disorder; HD = Hoarding Disorder
### Table 3
Multivariate regression models predicting clinical measures

<table>
<thead>
<tr>
<th>Predictors</th>
<th>BDI</th>
<th>YBOCS&lt;sup&gt;1&lt;/sup&gt;</th>
<th>UHSS&lt;sup&gt;2&lt;/sup&gt;</th>
<th>SI-R&lt;sup&gt;2&lt;/sup&gt;</th>
<th>SI-R&lt;sup&gt;2,a&lt;/sup&gt;</th>
<th>SI-R&lt;sup&gt;2,b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>r</td>
<td>-0.11</td>
<td>-0.84***</td>
<td>0.62***</td>
<td>0.51*</td>
<td>0.46**</td>
<td>0.39*</td>
</tr>
<tr>
<td>v</td>
<td>-0.28**</td>
<td>-0.47*</td>
<td>-0.42*</td>
<td>-0.46*</td>
<td>-0.35*</td>
<td>-0.20</td>
</tr>
<tr>
<td>HC</td>
<td>-0.87***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R²</td>
<td>0.30</td>
<td>0.52</td>
<td>0.50</td>
<td>0.38</td>
<td>0.32</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Standardized beta coefficients; *p<0.05, **p<0.01, ***p<0.001
BDI: Beck Depression Inventory; YBOCS: Yale Brown Obsessive Compulsive Scale, Compulsion subscale; UHSS: UCLA Hoarding Symptom Scale; SI-R: Saving Inventory, Revised
HC: Dummy variable identifying healthy controls; <sup>1</sup>OCD group; <sup>2</sup>HD group; <sup>a</sup>Difficulty discarding subscale of SI-R; <sup>b</sup>Acquisition subscale of SI-R
Figure 1. Plots of the probability weighting function for various values of the $r$ parameter. $p$: objective probability; $w(p)$: probability weight transformation.
Figure 2. A, Mean plot of $v$ parameter estimates by group. Larger values of $v$ correspond to greater degrees of risk aversion. B, Mean plot of $r$ parameter estimates by group. $r = 1$ corresponds to linear ("rational") probability weighting; error bars represent S.E.M.
Figure 3. Probability weighting function plots for the three participant groups based on pooled estimates. green = HC, red = OCD, blue = HD, dashed = linear (“rational”) weighting.
Figure 1

The graph illustrates the function $w(p)$ for different values of $r$:

- $r = 1.0$ (dotted line)
- $r = 0.1$ (solid blue line)
- $r = 0.5$ (dashed blue line)
- $r = 2.0$ (solid red line)
- $r = 10.0$ (dotted red line)

The x-axis represents $p$, and the y-axis represents $w(p)$. The curves show how $w(p)$ changes with $p$ for each value of $r$.
Figure 2

A

B

Group

HC OCD HD

Group

HC OCD HD
Figure 3

The figure shows the cumulative distribution functions for different groups labeled as HC, OCD, and HD. The y-axis represents the cumulative probability, w(p), and the x-axis represents the p value. Each group is represented by a different line:

- Green line for HC
- Red line for OCD
- Blue line for HD

The shape of each line indicates the distribution characteristics of the corresponding group.