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Dopamine and risk choices in different domains: Findings among serious tournament bridge players

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Abstract We explore how risk-taking in the card game contract bridge, and in a financial gamble, correlate with variation in the dopamine receptor D4 gene (*DRD4*) among serious tournament bridge players. In bridge risk-taking, we find significant interactions between genetic predisposition and skill. Among men with the 7-repeat allele of *DRD4*, namely 7R+ men, those with more bridge skill take more *good* risks and fewer *bad* risks, while the opposite is found for less-expert 7R+ men. Conversely, skill does not predict risk-taking among men without the 7R+ allele. Consistent with some prior studies, we also find that 7R+ men take more risk in the financial gamble. We find no relationship between 7R+ and either risk measure among our female subjects. Our results suggest that the dopamine system plays an important role in individual differences in risk-taking among men, and is the first to distinguish between advantageous and disadvantageous risk-taking.

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Many important decisions in life require choices among options that vary in their level of risk, as formalized by the variance in the values of the possible outcomes once an option is chosen. Risk preferences vary substantially across individuals, with women and older individuals typically being more risk averse than men and younger individuals (Barsky et al. 1997; Byrnes et al. 1999; Croson and Gneezy 2009; Dohmen et al. forthcoming). Some of this observed variation has been associated with biological factors; for example, twin studies on Swedish and Chinese twins suggest that genetic differences account for a sizeable fraction of individual differences in risk preferences (Cesarini et al. 2009, 2010; Zhong et al. 2009a).

Relatively little is known about the specific genetic determinants of individual variation in risk preferences. Genetic loci involved in chemical signaling in the brain (neurotransmission) are promising candidates for helping to explain economic behavior. The neurotransmitter dopamine has received particular attention due to its relation with reward processing in the brain. Activation of the dopaminergic reward pathways, and thus the release of dopamine neurotransmitters, can generate feelings of pleasure and well-being that become associated with the behaviors that triggered the activation. This makes dopamine a major player in reinforcement of behaviors that are associated with the anticipation of rewards.

Of the genetic markers for dopaminergic function, the dopamine receptor D4 gene (*DRD4*) has been identified as a candidate for explaining variation in economic behavior (Benjamin et al. 2008), and has received most of the attention in the literature thus far.[1] As with other genes, *DRD4* comes in various versions ("alleles"), which differ across individuals. There is a specific region of the gene that contains a repeated sequence of DNA base pairs. In different individuals, this sequence is repeated a different number of times (typically 2–11 times) on each of the two relevant chromosomes. The multiple versions of the gene are frequently divided into two dichotomous classes, those with fewer than 7 repeats on both chromosomes (7R−) and those with 7 or more repeats on at least one chromosome (7R+) (Ding et al. 2002). Functionally, individuals with the 7R+ genotype are putatively less sensitive to dopamine uptake, and so require higher levels of dopamine to produce a response of similar magnitude. Therefore, in order for 7R+ individuals to achieve a comparably satiating response in the brain's corticomesolimbic dopamine reward pathway, they may engage in more stimulating behaviors than 7R− individuals. Such genetic variation in response to dopamine may thus contribute to individual differences in those personality and behavioral traits that are associated with the dopamine system. Such traits include novelty seeking (Ebstein et al. 1996; though see Munafo et al.

[1] See Appendix 1 for more information on *DRD4* as well as the genotyping.

2008), pathological gambling (Perez de Castro et al. 1997), attention deficit/hyperactivity disorder (Li et al. 2006), alcoholism (Laucht et al. 2007), impulsivity (Eisenberg et al. 2007; Congdon et al. 2008; though see Munafo et al. 2008), sexual promiscuity (Garcia et al. 2010), and many other behaviors. Such activities all involve some mode of risk-taking. Therefore risk-taking in economic domains might also be influenced by the dopamine system. The goal of this study is to explore this relationship.

A potential concern in genetic analyses relates to multiple testing. If one was to test for relationships between a behavior and a large enough number of genes, some (spuriously) significant positive associations would be sure to emerge due to chance. In order to address this issue, we employ a "candidate gene" approach: based on previous research, we hypothesize that *DRD4* will influence economic risk-taking, and then analyze only this single gene.

In addition to overall risk-taking, we are also interested in distinguishing between two different forms of risk. Riskier (i.e., higher variance) options often offer a higher expected return than safe alternatives. Thus such positive expected value risks can be considered "good" risks in an actuarial sense, as on average they result in gains.[2] Examples of such risks are investing in illiquid securities, or farmers growing a cash crop rather than a subsistence crop. However there are also unequivocally "bad" risks, which offer higher variance together with a negative expected return. Gambling on roulette at a casino is such a risk, since the house takes a cut. Exploring differences between good and bad risk-taking is an issue that merits study, since both arise often in real life. Successful retailers, for example, are always gambling on small risks: an item offering a generous markup if sold on a timely basis may have to be sold at a loss if sales do not materialize. Judging which risks to take is a key to success in many arenas.

In this study, we investigate the effect of variation in *DRD4* on good and bad risky decisions in a field setting where effective risk-taking is a critical component of success, namely the game of contract bridge. As Warren Buffett observed: "Bridge is about weighing gain/loss ratios. You're doing calculations all the time" (Alger 1997). Not surprisingly, bridge has been considered as a sufficiently good model for financial decision making that skill in bridge has been used as part of hiring criteria for investment bankers (Cohan 2009).

Bridge is an ideal setting in which to measure risk preferences experimentally for a few reasons: (1) the outcomes of risk-taking in bridge have quantifiable consequences; (2) risk can be identified as either good or bad in character; (3) potential subjects have had substantial experience outside of the experimental setting with the types of questions required to elicit risk preferences; and (4) variation across subjects in skill and experience within the decision setting can be quantified in the form of bridge "masterpoints" (masterpoints are accumulated through success in certified bridge tournaments, with higher placements and larger and more important tournaments offering higher awards; the number of masterpoints won presumably reflects a combination of ability and experience, and we frequently use the term "skill" to capture all these factors). In short, bridge presents an attractive tool for

[2] Obviously, further elaboration is required if these positive expected value risks are correlated with one another.

studying risk preferences, since it enables us to look at risk-taking among experienced risk takers in a non-laboratory yet controlled setting, with objective measures for both the quantity and quality of the risks taken. In addition, it offers a measure of past decision making success.

Based on previous associations between the 7R+ allele of *DRD4* and risk-taking (see below), we predict that 7R+ subjects will make riskier bids in an incentivized bridge quiz. We also expect that masterpoints will interact with genotype to determine the *type* of risks taken. To be a successful bridge player, one must be able to distinguish between good and bad risks, and selectively take the good risks. Less successful bridge players should differentiate less effectively between quality of risks. Therefore we predict a positive interaction between 7R+ and masterpoints when predicting good risk-taking. We predict a negative interaction between 7R+ and masterpoints when predicting bad risk-taking.

In addition to exploring the relationship between *DRD4* and risk-taking in bridge, we also examine economic risk-taking in a financial gamble. We do so to add a replication to results from four recent papers.[3] In a study of 94 young men, Dreber et al. (2009) find that 7R+ men put significantly more money into a positive-expected value risky investment than do 7R− men; and similarly Kuhnen and Chiao (2009) find a positive relationship between the 7R+ genotype and risk preferences in a laboratory risk measure with positive expected value using a sample of 65 men and women. Carpenter et al. (2011) find that the effect of 7R+ varies depending on the details of the task in a laboratory study of 140 men and women. They find a marginally significant *negative* relationship between 7R+ and risk-taking in a task where the expected value was usually, but not always, increasing with variance and where winning probabilities were known with certainty. But they find that 7R+ subjects are *more* risk-taking when the probabilities are uncertain, or when the task is framed in the domain of losses rather than gains. Eisenegger et al. (2010) find no association between 7R+ and risk in a laboratory task where the expected value of the risk varies across decisions, and do not control for expected value in their analysis. However they do find that when exogenously administering the dopaminergic precursor drug L-dihydroxyphenyalanine (L-DOPA), 7R+ men become more risk-taking than 7R- men. These results are thus somewhat mixed, particularly with respect to positive-expected value risks with known possibilities, and so it is valuable to contribute another set of data using a subject pool with extensive experience in risk-taking, albeit in a domain where bridge success rather than economic return is the payoff. Based on the majority of the previous evidence, however, we predict a positive association between 7R+ and investment in a risky financial gamble with positive expected value.

We find that 7R+ men take more risk in the financial gamble than 7R− men. When it comes to risk-taking in bridge, we find the following significant interactions between genetic predisposition and skill. Among men with high masterpoints, 7R+ men take more good risks and fewer bad risks than 7R− men. The opposite is true among less skilled men. Furthermore, among 7R+ men, those with more master-points take more good risks and fewer bad risks. There is no relationship between masterpoints and either good or bad risk-taking among 7R− men. Similarly, we find

[3] Some of these studies also look at other genes.

no relationship between 7R+ and either bridge risk-taking or economic risk-taking among our female subjects.

1 Experimental design and procedure

See Appendix 2 Table 5 for definitions of all experimental variables.

1.1 The location and setup

This field study recruited 237 participants[4] from the Fall 2008 North American Bridge Championship in Boston, Massachusetts. This major event lasted 10 days, with two 26-hand sessions per day, and more than 42,000 player sessions in total. Almost all of the participants were serious tournament bridge players who play many dozens of sessions per year.[5] Tables for data collection were placed outside the major national championship game rooms one day and outside a secondary championship game room the following day. After reviewing and signing an informed consent form, participants provided a DNA sample by swishing 10 ml of Scope® mouthwash from cheek to cheek for 45 sec and spitting it back into a sterile 15 ml collection tube (buccal wash). They then completed a bridge quiz and a questionnaire. The study was approved by Harvard University's institutional review board, and all genotyping procedures were additionally approved by Binghamton University's Human Subjects Research Review Committee. See Appendix 2 Table 6 for more information on the participants.

1.2 The tasks

Each participant first solved an incentivized bridge quiz that tested both their skill and risk-taking propensity in bridge contexts. After this, participants took part in a risky gamble involving real financial payoffs. They then filled out a short questionnaire which included their masterpoint holding and demographics. Age was reported in discrete intervals of 10 years.

1.2.1 Bridge risk-taking

Each subject was given 10 min to make potentially risky decisions on 8 bridge hands. The hands were presented in the form of an incentivized bridge quiz.[6] Such quizzes are a common format for teaching bridge and for assessing bridge skill, and are designed to reproduce frequently encountered bridge situations. They are

[4] Out of these 237 participants, 209 completed both risk measures and indicated their masterpoints, age and gender, and 175 of these were successfully genotyped. As described in the results section, our analysis only considers these 175 subjects for whom we have all information.

[5] 300+ masterpoints, with an additional requirement that some fraction of them be won in regional or national championships, qualifies one to be a Life Master in competitive bridge. 79% of our participants have 300+ masterpoints.

[6] Our bridge quiz and answers are available by request, and are also posted online by the reference to this paper at http://www.hks.harvard.edu/fs/rzeckhau/biblio.htm

regularly featured in bridge journals and are a staple of bridge books, and were thus familiar to the participants.

In pairs championships at bridge tournaments, all pairs play the same hand, and each hand is scored individually by comparing the different pairs' scores. On a hand, a pair gets 1 point each time its score is better than another pair, 1/2 point when it ties another, and 0 points when it is worse than another pair. To illustrate, with n pairs playing a hand, a pair that outscored all others would receive n-1 points, since it beat n-1 pairs on that hand. Bridge contests, such as those in the leading journals, tend to imitate this system, with leading experts assessing on an expected value basis what percentage of pairs would be defeated or tied if a particular bid is made. Thus, with all scoring normalized to 100 points, a bid of 3 spades on a hand might be awarded an 80, a bid of 4 spades a 60, and a bid of pass only 20.

Our quiz, created by Michael Rosenberg, a world renowned expert, followed this system to rate players' absolute performance. A second expert, Michael Becker, the problem editor of *The Bridge World*, America's leading bridge journal, provided answers to the quiz independently. Each question in the quiz presented the subject with a hand of cards, and in some cases the prior bids of some other players. Subjects were asked to choose which of several bids they preferred,[7] and were then awarded a score based on the rating their choice received from the bridge expert. To incentivize the quiz, subjects were informed that the highest total scorer over the eight hands in each of four masterpoint categories would receive a $250 cash prize.

This paper is about risk-taking, so we needed risk-taking scores in addition to performance scores. Some bridge bids are much riskier than others, in terms of having larger anticipated variance in outcomes. For example, doubling the opponents' final contract—which effectively magnifies the stakes on a hand—makes it more likely one will get a very high or very low score. To assess risk, we asked the creator of the quiz and our second expert to assess the variance in scores each bid was likely to receive. These scores were then normalized on a 0 to 1 scale, with 1 being most risky. Adding up these scores indicated how risky a player's bids were overall, since the variance of the sum of independent variables—the risk scores on individual hands—is the sum of the variances. Thus both the performance scores and the risk scores had concrete underpinnings; their units were cardinal values that would be observed in a real bridge contest. Concurrence between the two experts was high, and an average of their scores was used for both performance and risk.

The bridge quiz was designed in such a way that for some questions, riskier answers earned higher scores ("good risk" questions), while in other questions riskier answers earned lower scores ("bad risk" questions). Each subject's level of good risk-taking was calculated by summing the risk value of each answer for which the subject received a higher than average performance score, weighted by that performance score minus the average performance score on that question. Bad risk-taking was computed equivalently, by summing over the low performance questions, weighted by −1 times the performance score received for each question minus the average score.

[7] For certain hands, participants were also asked to indicate which bid they liked least. This data is not included in our analysis, as it is unclear how dislike translates into a risk preference.

For example, imagine a subject who for a particular question received a risk value of 0.85 and a performance score of 75, while the average performance score for that question was 50. This question would therefore be included in the subject's good risk score and not in her bad risk score (her performance score of 75 was greater than the average of 50), and would be worth 0.85 * (75–50)=21.25. Alternatively, imagine that the subject instead had received a performance score of 25 (while still receiving a risk score of 0.85, and the average performance score for that question again being 50). This question would not be included in the subject's good risk score (her performance score of 25 was worse than the average of 50), but would be included in the bad risk score, worth −1 * 0.85 * (25–50)=21.25.

1.2.2 Economic risk-taking

Participants chose how to allocate money in an incentivized financial investment task, a measure introduced by Gneezy and Potters (1997) and subsequently modified by Charness and Gneezy (2010). The same task was used in Dreber et al. (2009), where a positive relationship was found between the amount invested and the presence of the 7R+ genotype in a sample of male college students. Apicella et al. (2008) also found a positive relationship between risk-taking in the same task and both circulating testosterone and a proxy of pubertal testosterone exposure (facial masculinity) in the same male sample as Dreber et al. (2009).

In the investment task, participants started with $250, of which they could choose an amount $X to devote to a risky investment. The outcome of the risky investment was decided by a coin flip. If successful, the amount X was multiplied by 2.5; if unsuccessful, the amount X was lost. The remainder ($250–$X), the "safe investment" was kept regardless of the outcome of the coin flip. Thus if the coin flip was successful, participants ended up with $250+$1.5X; otherwise $250-$X. Participants were informed that after everyone had made an investment decision, three individuals would be randomly selected to play for real money, bound by the investment amount they had indicated. Investing in this actuarially highly favorable gamble increases both the expected value and variance (risk) of the outcome. Hence, participants had to weigh the two factors in determining their value for X. An individual's choice of X provides our measure of economic risk-taking.

2 Data analysis and results

We report the results of linear regressions (OLS) with robust standard errors, using two-tailed test statistics throughout. Basic demographics are presented in Appendix 2 Table 6. To preserve a constant number of data points across analyses, we exclude from all analyses any of the 237 total participants for whom data was missing (i.e., subjects who did not fully complete one or both risk measures and/or did not indicate their masterpoints, gender or age).

Of the 209 participants with complete data, 175 were successfully analyzed for variation in the *DRD4* gene.[8] Genotype frequencies in our sample are as follows.

[8] All subsequent analysis considers these 175 participants only.

Among the 98 men for whom *DRD4* data was obtained, 16 were 7R+ (16.3%). Among the 77 women successfully genotyped, only 6 were 7R+ (7.8%). These two frequencies are marginally significantly different (chi^2 test: p=0.091).[9] This irregularity is surprising, as there is no previous evidence for the population frequency of 7R+ varying with gender. It may suggest a bias in the propensities of the women, compared to men, who are drawn to competitive bridge, which could also lead to systematic differences in the effect of the 7R+ genotype between men and women in our study. Therefore we examine a gender-by-7R+ interaction term in our analyses. When the interaction is significant, we also analyze men and women separately. We find no significant differences in 7R+/− frequency based on age or masterpoints. In the subsequent regressions, we use a binary 7R+ variable that takes the value 1 if an individual is 7R+ and 0 if 7R−.

2.1 Correlation among risk measures

Dohmen et al. (forthcoming) and Roe et al. (2009) find only limited associations among risk measures from different domains. Here we correlate the different risk measures with each other, expecting positive associations in a simple correlation analysis (see Appendix 2 Table 7). We find that economic risk-taking in the financial gamble is not correlated with any of the bridge measures (p>0.10 for all). Within the bridge measures, we find that overall risk-taking on the bridge quiz is positively correlated with both good and bad risk-taking, while good and bad risk-taking are negatively correlated with each other (all correlations significant at the p<0.01 level). This last fact leads to our most intriguing bridge result: a cluster of factors positively predicts good risk-taking but negatively predicts bad risk-taking.

2.2 Bridge risk-taking

First, we evaluate the prediction that 7R+ individuals take more overall risk in bridge than other individuals (see Table 1). We find no significant main effect of 7R+ on overall bridge risk (with or without controls). We do, however, find a marginally significant negative interaction between 7R+ and being female (coeff=−1.11, p=0.055), as well as a marginally significant positive main effect of 7R+ (coeff=0.51, p=0.086) when this interaction term and control variables are included. Thus we perform an analysis of men and women separately. We find that 7R+ men are marginally significantly more risk-taking in bridge than 7R− men (coeff=0.49, p=0.088). This coefficient indicates that on our bridge risk scale (mean=3.70, std=1.27 among men), 7R+ men take roughly half a point more risk, that is 13.7% more risk, than 7R− men on average (when including control variables). There is no effect of 7R+ on overall bridge risk in our sample of women.

Next we evaluate our second prediction—that there is a positive interaction between 7R+ and masterpoints (reflecting a combination of skill and experience) when predicting good risk-taking in bridge (see Table 2), and a negative interaction when predicting bad risk-taking in bridge (see Table 3). Given the gender interaction

[9] This difference becomes stronger when including subjects with missing demographic information (chi^2 test, p=0.025)

Table 1 Overall bridge risk-taking. All observations (columns 1–3), men only (columns 4–5), women only (columns 6–7)

	All observations			Men		Women	
7R+	0.0834	0.182	0.505*	0.467	0.494*	−0.693	−0.572
	(0.261)	(0.273)	(0.292)	(0.293)	(0.287)	(0.503)	(0.532)
$L_{10}MP$		0.0867	0.0767		0.192		−0.0276
		(0.135)	(0.132)		(0.173)		(0.183)
Age		0.0141	0.0138		0.00322		0.0304**
		(0.0090)	(0.0089)		(0.0120)		(0.0147)
Female		0.183	0.293				
		(0.230)	(0.241)				
Female X 7R+			−1.111*				
			(0.575)				
Constant	3.790***	2.618***	2.610***	3.626***	2.818***	3.979***	2.151**
	(0.107)	(0.621)	(0.610)	(0.145)	(0.788)	(0.157)	(0.995)
Observations	175	175	175	98	98	77	77
R-squared	0.000	0.032	0.049	0.019	0.032	0.020	0.092

Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

we observed for overall bridge risk, we analyze men and women separately here as well.[10]

First we consider the men in our sample. For good risk-taking in bridge, we find a significant positive interaction between 7R+ and masterpoints (coeff=9.69, $p<0.001$) together with a significant negative main effect of 7R+ (coeff=−29.34, $p<0.001$). This indicates that among more accomplished men, those who are 7R+ take more good risk than those who are 7R−, while among the less accomplished, 7R+ men take less good risk than 7R− men. Here "accomplished" indicates participants with more past bridge success as measured by masterpoints. The net coefficient which is the sum of the coefficient on masterpoints and the interaction variable is highly significant ($p<0.0001$) and positive.[11] This indicates that more accomplished 7R+ men also take significantly more good risk in bridge than less accomplished 7R+ men. The magnitude of the interaction coefficient indicates that among 7R+ men, the level of good risk-taking in bridge (mean=11.81, std=8.61 among 7R+ men) increases by roughly 10 points on average for each ten-fold increase in masterpoints. Conversely, there is no main effect of masterpoints when the interaction between 7R+ and masterpoints is included. This indicates that not all more accomplished men take more good risk, only those that are 7R+.

Considering bad risk-taking in bridge among men, we find the opposite pattern: a significant negative interaction between 7R+ and masterpoints (coeff=−29.39, $p=0.021$)

[10] In a regression with all the data, there is a significant three-way interaction between 7R+, being female and masterpoints, for both good and bad risk. This suggests that the effect of 7R+ and masterpoints is dramatically different in men and women.

[11] To get the net predicted effect for any particular player we must multiply the interaction coefficient by his log10(masterpoints+1) and add to the main effect coefficient.

Table 2 Good risk-taking in bridge. Men only (columns 1–3), women only (columns 4–6)

	Men			Women		
7R+	1.457	1.608	−29.34***	0.861	0.804	2.244
	(2.201)	(2.071)	(6.651)	(2.910)	(2.836)	(4.202)
L_{10}MP		1.686*	0.455		−0.974	−0.889
		(0.914)	(0.793)		(1.012)	(1.163)
Age		−0.0130	−0.0423		0.0677	0.0690
		(0.0403)	(0.0405)		(0.0750)	(0.0765)
L_{10}MP X 7R+			9.686***			−0.588
			(2.068)			(1.630)
Constant	10.36***	5.543	11.20***	10.81***	9.242*	8.929
	(0.642)	(3.499)	(3.327)	(0.823)	(5.232)	(5.712)
Observations	98	98	98	77	77	77
R-squared	0.007	0.040	0.173	0.001	0.024	0.024

Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

with a significant positive main effect of 7R+ (coeff=96.30, $p=0.028$). The net coefficient of masterpoints and the interaction variable is significant and negative ($p=0.032$), while there is no significant main effect of masterpoints, indicating the more accomplished men take fewer bad risks, but only if they are 7R+.[12] The negative interaction coefficient indicates that among 7R+ men, the level of bad risk-taking in bridge (mean=36.16, std=32.47 among 7R+ men) decreases by roughly 30 points on average for each ten-fold increase in masterpoints.

These results are portrayed in Fig. 1. Figure 1a shows the strong relationship between masterpoints and good risk-taking in bridge among 7R+ men. Figure 1b, by contrast, shows almost no relation between masterpoints and good risk-taking among 7R− men. As shown in Fig. 1c, more accomplished 7R+ men take less bad risk than less accomplished 7R+ men; while Fig. 1d shows little relation between masterpoints and bad risk-taking among 7R− men.

When considering the women in our sample, we find no significant effect of 7R+, and no significant interaction between 7R+ and masterpoints for either good or bad risk-taking. However, the number of 7R+ women in our sample is very small; thus the analysis is not particularly informative.

2.3 Economic risk-taking

Our dependent variable for economic risk-taking is the amount of money participants put at risk in our 2.5 to 1 gamble on a coin flip. The distribution of investment amounts is shown in Appendix 2 Fig. 3.

We regress economic risk-taking on the 7R+ binary variable (see Table 4). We find that 7R+ individuals (both genders combined) take marginally significantly

[12] This result is only slightly surprising. Positing that 7R+ men take more risk, they could only have achieved significant success (masterpoints) if they were highly skilled at distinguishing between good and bad risks.

Table 3 Bad risk-taking in bridge. Men only (columns 1–3), women only (columns 4–6)

	Men			Women		
7R+	2.560	2.416	96.30**	−11.53	−9.592	−8.311
	(8.487)	(8.309)	(43.09)	(7.556)	(8.375)	(10.65)
L_{10}MP		−0.365	3.369		0.783	0.859
		(3.803)	(3.777)		(2.563)	(2.945)
Age		−0.0500	0.0390		0.389	0.390
		(0.200)	(0.199)		(0.272)	(0.277)
L_{10}MP X 7R+			−29.39**			−0.523
			(12.48)			(4.269)
Constant	33.60***	37.56**	20.39	34.23***	7.747	7.469
	(2.993)	(16.18)	(15.44)	(2.910)	(15.94)	(17.30)
Observations	98	98	98	77	77	77
R-squared	0.001	0.002	0.065	0.017	0.055	0.055

Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

more risk than 7R− individuals (coeff=34.31, $p=0.077$), although this difference becomes non-significant when we control for age and masterpoints (coeff=18.24, $p=0.244$). Importantly, as was the case for bridge risk, we again find a marginally significant interaction between gender and 7R+ (coeff=−65.86, $p=0.077$). This result indicates that 7R+ may have different effects on economic risk-taking in men and women in our sample, and we therefore continue to analyze men and women separately. Also, we find that women in general take less economic risk, regardless of their *DRD4* genotype (gender main effect: coeff=−67.45, $p<0.001$).

Considering the males in our sample, we find that 7R+ men take significantly more risk than their 7R− counterparts with (coeff=37.36, $p=0.013$) or without (coeff=38.80, $p=0.011$) controls for age and masterpoints (Fig. 2). The effect is sizeable: 7R+ men invest almost $39 more out of a possible $250 (mean=$197.22, std=$80.13 among men) into the risky investment compared to 7R− men. In other words, the average investment among 7R+ men is 19.5% larger than that of 7R− men, when including control variables. Looking at women only, the effect of 7R+ is non-significant.[13] It is interesting to note, however, that the sign of the effect of the 7R+ genotype on economic risk-taking is negative in the female sample, the opposite of what is observed in the male sample. Additionally, we find that masterpoints are not significantly related to economic risk-taking for either men or women.

3 Discussion and conclusion

An emerging body of literature explores the potential role of genetic factors in explaining individual variation in economic decision-making. For example, twin

[13] The lack of statistical significance among women is not surprising given the very low number of 7R+ women.

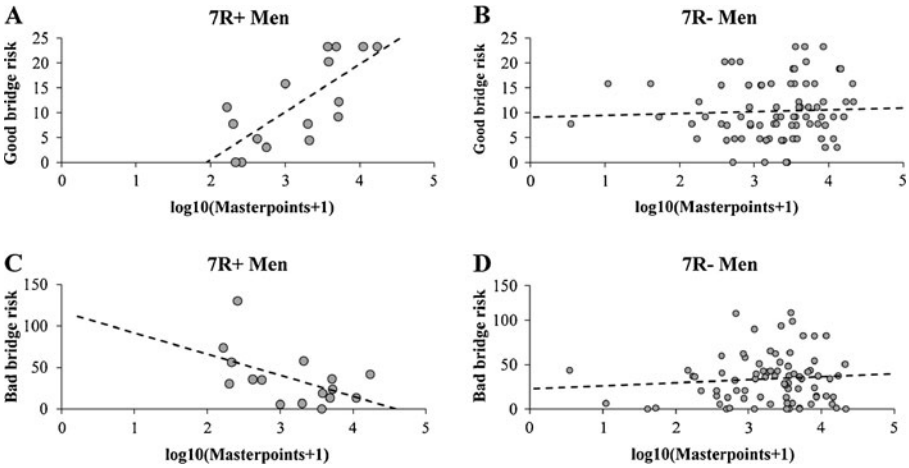

Fig. 1 Good risk-taking (**a**, **b**) and bad risk-taking (**c**, **d**) among men as a function of masterpoints, by DRD4 genotype

studies and molecular genetics studies have been used to address behaviors such as altruism in the dictator game (Knafo et al. 2007; Cesarini et al. 2009; Israel et al. 2009; though see Apicella et al. 2010), rejection behavior in the ultimatum game (Wallace et al. 2007), trust behavior in the trust game (Cesarini et al. 2008), risk preferences (Cesarini et al. 2009; Crisan et al. 2009; Dreber et al. 2009; Kuhnen and Chiao 2009; Roe et al. 2009; Zhong et al. 2009a; b; c; Barnea et al. 2010; Calvet and Sodini 2010; Cesarini et al. 2010; Eisenegger et al. 2010; Carpenter et al. 2011), sensitivity to the framing effect (Crisan et al. 2009; Roiser et al. 2009) and

Table 4 Economic risk-taking. All observations (columns 1–3), men only (columns 4–5), women only (columns 6–7)

	All observations			Men		Women	
7R+	34.31*	18.24	37.36**	38.80**	37.36**	−26.07	−28.47
	(19.26)	(15.60)	(14.54)	(14.90)	(14.69)	(34.64)	(32.64)
$L_{10}MP$		3.986	3.392		7.342		−0.0812
		(9.580)	(9.782)		(12.73)		(14.59)
Age		−0.836	−0.849		−1.046		−0.555
		(0.530)	(0.526)		(0.690)		(0.851)
Female		−67.45***	−60.92***				
		(15.27)	(15.96)				
Female X 7R+			−65.85*				
			(36.98)				
Constant	158.9***	227.1***	226.7***	190.9***	224.6***	121.9***	156.8***
	(7.542)	(37.81)	(38.68)	(9.292)	(48.12)	(10.74)	(59.05)
Observations	175	175	175	98	98	77	77
R-squared	0.015	0.191	0.202	0.032	0.062	0.006	0.011

Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

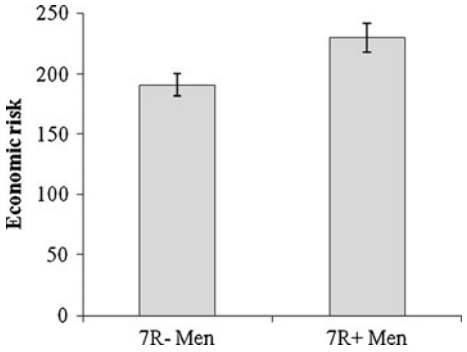

Fig. 2 Amount invested (out of $250) in a risky financial gamble among men. Error bars indicate standard error of the mean

behavioral aggression in an economic game (McDermott et al. 2009). This literature suggests that genetic contributions to individual (biological) differences have substantial implications for economic and behavioral studies. Further, genetic inheritance is a potentially important mechanism to consider when interpreting correlations in preferences between parents and offspring, and when considering determinants of preferences more generally. This is not to say that heritable genetic factors fully determine behavior; experience and environment clearly matter. But the addition of genetic factors to economic models is highly likely to improve our understanding of behavior, thereby improving our models and increasing their predictive power.

The focus of this study is on risk-taking. The vast literature on this topic reports significant heterogeneity in levels of risk aversion across individuals and populations (Barsky et al. 1997; Donkers et al. 2001; Halek and Eisenhauer 2001; Dohmen et al. forthcoming). Determining the sources of this heterogeneity is of great importance for understanding and predicting economic decision-making. Among many other factors, genetics may play an important role in determining an individual's risk preferences. Our study explores this issue, focusing particularly on variation in the dopamine receptor gene *DRD4*. This gene has previously been related to risk preferences in the economic domain, though with somewhat inconsistent results. Our analysis seeks to deepen the field's understanding of the 7R+ genotype's relationship to risk-taking by looking at risk-taking in the field setting of contract bridge at the tournament level, as well as looking at economic risk-taking in a laboratory measure.

We find some evidence of variation in *DRD4* explaining the individual variation we observe in overall risk-taking in bridge, but only in men. 7R+ men take marginally significantly more overall risk in bridge than other men. More intriguing, our results emphasize the importance of interactions between genetic predispositions and skill/experience. Particularly, we examine skill in a setting where the subjects have had a great deal of training in critical reasoning, as illustrated by decision-making by the participants in a national bridge championship. We find a gene-skill interaction in men, where more accomplished 7R+ men take more good risk and less bad risk in bridge than other individuals, where good and bad risks are defined in terms of their expected value. Moreover, less skilled 7R+ men take significantly less good risk and more bad risk than other men. This

disparity could be due to a "bounded awareness" (Bazerman and Chugh 2005; Chugh and Bazerman 2007) whereby less skilled bridge players have access to the same information as more skilled players, but are focusing on a misleading subset. Alternatively, they may indeed be less capable at disentangling the probabilities and outcomes, closer to a state of ignorance (as per Hogarth and Kunreuther 1995).[14] Either way, our results provide evidence of the importance of interactions between genetic predispositions and life experience in explaining variation in behavior among individuals.

In the domain of economic risk-taking, we find that 7R+ men take more economic risk than 7R− men. These results are in line with Dreber et al. (2009), who use the same economic risk measure in a sample containing men only. Among women, there is a non-significant but trending negative relationship. This finding, as well as the result on overall risk-taking in bridge, lends some support to the possibility that there may be systematic differences in the types of men and women in our sample, something that is further supported by the fact that the difference in frequency of the 7R+ genotype between men and women is marginally significant. This difference across genders remains a puzzle to be disentangled in future studies. While nothing (to our knowledge) has been reported on the 7R+ genotype acting differently in men and women in general, or in the other two studies on *DRD4* and economic risk-taking that include both genders, our sample was chosen to be far from representative. It seems quite plausible that systematic differences exist in the types of men versus women attracted to serious bridge tournaments, or that extensive experience with risk-taking in bridge alters the behavior of female bridge players, and that these differences explain the gender differences in both the frequency of the 7R+ genotype and its effects that we observe. Alternatively, it is entirely possible that the negative trend in women is a statistical anomaly arising from the extremely small number of 7R+ women. It is interesting to note that the frequency of the 7R+ genotype in our study is low for both men and women compared to previous studies (e.g., Kuhnen and Chiao 2009; Carpenter et al. 2011). It is also conceivable that the observed effect of the 7R+ genotype in men is a false positive, but this seems unlikely given the size of the sample and other replications of this finding (Dreber et al. 2009; Kuhnen and Chiao 2009). Additionally, the economic risk-taking measure that we used in this study only entails good risk, since the expected value of taking risk always is significantly greater than for the riskless option. Thus, it is important to explore in a future study to what extent experience with economic risk-taking interacts with 7R+ when looking at both good and bad risk-taking on a pure monetary basis.

Risk preferences are of great practical importance given their relationship with economically significant behaviors such as competitiveness, career choice, savings behavior, and pension choice, among many others. We are only beginning to understand the potential role of variation in specific genes, such as the dopamine gene *DRD4*, in contexts involving risk preferences. This implies

[14] Similarly, following Johnson et al. (1993), perhaps less skilled 7R+ men are more biased in their probability assessments than skilled 7R+ men are, and as one gains more experience, either skills are honed or the worst risk takers are weeded out.

that more studies on *DRD4* are merited, and other genes should be identified that may influence risk preferences in the domain of economic games, psychological measures, and human behavior in the field. Understanding risk preferences is essential for understanding economic behavior, and incorporating the role of genetics into that understanding is a central interdisciplinary challenge in the study of human behavior.

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Appendix 1

Background on *DRD4*

The human *DRD4* gene on chromosome 11 contains a 48 bp variable number tandem repeat (VNTR) polymorphism (variation) in exon 3 and consists of 2–11 repeats (Ding et al. 2002), likely involved in modulating expression of the gene (Schoots and Van Tol 2003). There is generally a trimodal distribution of 2, 4 and 7 repeat alleles (2R, 4R and 7R) in most populations (Ding et al. 2002).

Genotyping

Genotyping was performed at the Laboratory of Evolutionary Anthropology and Health at Binghamton University, New York. Each participant was given a 15 ml centrifuge tube containing approximately 10 ml of Scope® mouthwash (Feigelson et al. 2001). Participants gently swirled the mouthwash from cheek to cheek for 45 sec, to collect buccal cells. Using a sterile straw, participants were instructed to spit the sample back into the same centrifuge tube. Samples were later centrifuged and prepared for DNA extraction using the Maxwell® 16 System (Promega).

Sufficient DNA for *DRD4* Polymerase Chain Reaction (PCR) amplification was extracted from 86% (203/237) of the buccal cell samples. Genotyping was only performed for the one candidate gene *DRD4*. Previous studies have highlighted problems associated with consistent genotyping of the *DRD4* VNTR region (Eisenberg et al. 2008), suggesting multiple PCR runs for each sample to control for allelic dropout. Thus, the PCR reaction was modified to reflect the high content of G and C nucleotides, and all samples that were initially scored as homozygotes were reanalyzed two additional times with different starting template concen-

trations to confirm genotypes. The PCR reaction consisted of 1× Q-Solution (Qiagen), 1× Buffer (Qiagen), 1 μM Primer 1 (5' GCGACTACGTGGTCTACTCG 3'), 1 μM Primer 2 (5' AGGACCCTCATGGCCTTG 3'), 200 μM dATP, 200 μM dTTP, 200 μM dCTP, 100 μM dITP, 100 μM dGTP, 0.3 units HotStar Taq (Qiagen), and 1 μl of DNA template, in a total volume of 10 μl. The PCR profile began with 15 min at 95°C for enzyme activation and denaturing of template DNA followed by 40 cycles consisting of 1 min denaturation at 94°C, 1 min annealing at 55°C, 1.5 min extension at 72°C, and finished with a 10 min extension at 72°C. Amplicons were electrophoresed through 1.4–2.0% agarose gels containing ethidium bromide and genotypes were determined by comparison with a 100 bp ladder. Participants were then scored as either 7R+ (at least one allele of at least 7-repeats or more) or 7R− (both alleles less than 7-repeats).

Population stratification can be an issue in this type of candidate gene study (see Hamer and Sirota 2000). Population stratification in this case could lead to biased results due to allele frequency similarities amongst subpopulations with homogeneous ancestry. In the sample studied here, an overwhelming majority of participants self-reported Caucasian race, hence we believe these legitimate concerns to be minimal for our particular results.

Appendix 2

Table 5 Variable description

Variable	Description
7R+	Takes the value 1 if at least one of two DRD4 alleles is 7R and 0 otherwise
Masterpoints	Masterpoints are earned by successful play in bridge tournaments, and therefore represent a combination of skill and experience
L_{10}MP [log10(masterpoints+1)]	Log-transformed masterpoints, with 1 added to the masterpoints rating of each subject because of the presence of 0s
Age	Reported in discrete intervals of 10 years, using the value of the mid-point of the interval
Overall bridge risk	Riskiness of bids in bridge quiz, summed over all questions (risk scores for each bid assigned by two bridge experts)
Good bridge risk	Riskiness of bids in bridge quiz, summed over questions in which the subject earned a higher-than-average performance score, and weighted by the difference between the subjects' performance score and the average performance score (performance scores for each bid assigned by two bridge experts)
Bad bridge risk	Riskiness of bids in bridge quiz, summed over questions in which the subject earned a lower-than-average performance score, and weighted by the difference between the average performance score and the subject's performance score
Economic risk	This variable is an incentivized gamble, where a higher number indicates more risk-taking

Table 6 Summary statistics for genotyped participants

Variable	All	Men	Women
7R+	N=175, M=0.13, SD=0.33	N=98, M=0.16, SD=0.37	N=77, M=0.08, SD=0.27
Overall bridge risk (0 to 8)	N=175, M=3.80, SD=1.29	N=98, M=3.70, SD=1.27	N=77, M=3.93, SD=1.31
Good bridge risk	N=175, M=10.72, SD=6.55	N=98, M=10.60, SD=6.30	N=77, M=10.88, SD=6.88
Bad bridge risk	N=175, M=33.71, SD=26.15	N=98, M=34.01, SD=27.79	N=77, M=33.33, SD=24.07
Masterpoints	N=175, M=3079.3, SD=4187.6	N=98, M=4142.8, SD=4764.1	N=77, M=1725.8, SD=2804.6
L_{10}MP [log10(masterpoints+1)]	N=175, M=3.02, SD=0.81	N=98, M=3.26, SD=0.70	N=77, M=2.71, SD=0.85
Economic risk (0 to 250)	N=175, M=163.2, SD=92.5	N=98, M=197.2, SD=80.1	N=77, M=119.9, SD=89.5
Age (9 categories)	N=175, M=58.14, SD=13.12	N=98, M=54.90, SD=13.28	N=77, M=62.27, SD=11.77

Table 7 Correlation matrix for overall bridge risk-taking, good bridge risk-taking, bad bridge risk-taking, and economic risk-taking. *** p<0.01

	Overall	Good	Bad	Econ
Overall bridge	1.0000			
Good bridge	0.2171***	1.0000		
Bad bridge	0.5609***	−0.3942***	1.0000	
Econ risk	−0.0127	0.0749	−0.0247	1.0000

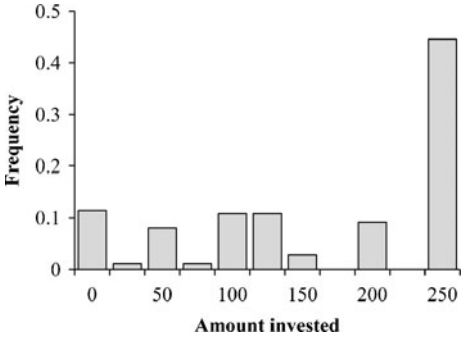

Fig. 3 Distribution of investment amounts (out of 250) in the risky financial gamble

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