



Review

A review of risky decision-making in psychosis-spectrum disorders

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ABSTRACT

The investigation of risky decision-making has a prominent place in clinical science, with sundry behavioral tasks aimed at empirically quantifying the psychological construct of risk-taking. However, use of differing behavioral tasks has resulted in lack of agreement on risky decision-making within psychosis-spectrum disorders, as findings fail to converge upon the typical, binary conceptualization of increased risk-seeking or risk-aversion. The current review synthesizes the behavioral, risky decision-making literature to elucidate how specific task parameters may contribute to differences in task performance, and their associations with psychosis symptomatology and cognitive functioning. A paring of the literature suggests that: 1) Explicit risk-taking may be characterized by risk imperception, evidenced by less discrimination between choices of varying degrees of risk, potentially secondary to cognitive deficits. 2) Ambiguous risk-taking findings are inconclusive with few published studies. 3) Uncertain risk-taking findings, consistently interpreted as more risk-averse, have not parsed risk attitudes from confounding processes that may impact decision-making (e.g. risk imperception, reward processing, motivation). Thus, overgeneralized interpretations of task-specific risk-seeking/aversion should be curtailed, as they may fail to appropriately characterize decision-making phenomena. Future research in psychosis-spectrum disorders would benefit from empirically isolating contributions of specific processes during risky decision-making, including the newly hypothesized risk imperception.

1. Introduction

“...taking a risk is not the same as having poor judgement and impaired decision-making” - Bechara, Damasio, and Damasio (2000)

Psychotic disorders such as schizophrenia (SZ) and schizoaffective disorder (SZA) are often characterized by pervasive cognitive impairment, hallucinations, unusual beliefs, atypical affectivity, and decreased goal pursuit. Despite extensive literature investigating risky decision-making, there is no consensus as to whether psychotic disorders are associated with increased or decreased risk-taking on behavioral, laboratory tasks. This is particularly troublesome when conflicting interpretations are applied to understanding ecological phenomena or formulating recommendations for treatment. The present review synthesizes findings across three categories of risky decision-making tasks (explicit, ambiguous, and uncertain risk). It is posited that during explicit risk-taking psychotic disorders are not characterized by greater risk-averse nor risk-seeking attitudes, but rather risk imperception,

defined as decreased ability to perceive and integrate risk-relevant information to properly discriminate between options and optimize decision-making. Risk imperception may also impact ambiguous or uncertain risky decision-making, but further investigation is necessary to identify specificity of potential deficits and rule out confounding processes. While the current review outlines descriptive support for risk imperception in psychosis by interpreting findings in the literature, the hypothesis warrants further, direct testing via targeted behavioral tasks.

During decision-making, evidence is accumulated from the environment and integrated with prior beliefs (Sterzer et al., 2018). Previous findings in psychosis have implicated a general deficit in this integration process, resulting in aberrant decision inferences that may not be well-adjusted by option values (Gold, Waltz, Prentice, Morris, & Heerey, 2008; Sterzer, Voss, Schlagenhauf, & Heinz, 2019). Poorer decision-making in psychosis has manifested as disrupted reinforcement learning, reduced effort allocation, indiscriminate probabilistic reversal learning, and jumping to conclusions, with many studies identifying an association between cognitive functioning and decision-making quality

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(Barch et al., 2017; Culbreth, Moran, & Barch, 2018; Reddy, Waltz, Green, Wynn, & Horan, 2016; Tripoli et al., 2020). Social, financial decision-making tasks in psychosis similarly reveal poorer choices in the forms of accepting unfair offers, rejecting fair offers, and other forms of maladjustment to a partner's performance (for review see Robson, Repetto, Gountouna, & Nicodemus, 2020). The present review suggests that this decision-making deficit, while not differential (i.e. not uniquely isolated to risky decision-making; MacDonald, 2014), extends into risk-taking tasks. Though the hypothesized risk imperception is likely secondary to a more general deficit (Fig. 1), it offers novel, process-oriented insight into evidence integration in psychosis, as many risky decision-making tasks do not rely on decision-outcome evaluation or learning. Thus, the current review is a departure from, and extension of, the extensive reinforcement and reward learning literature (Deserno, Schlagenhauf, & Heinz, 2016; Pratt et al., 2020).

Risk as a psychological experience can be conceptualized as the construal of future events with potentially undesirable consequences (Sjöberg, 2000). However, risk in behavioral tasks can be broken down into sub-components that differently influence decision-making (Fukunaga, Purcell, & Brown, 2018; Schonberg, Fox, & Poldrack, 2011). Behavioral tasks have investigated decision-making along various psychological and mathematical forms of risk, assessed in the laboratory using probabilistic gambles for gains, losses, or null outcomes. Such tasks have been purported to measure "risk attitude", or the amount of risk one will endure for a potential benefit (Kahneman & Tversky, 2013). Risk attitude is typically described as risk seeking or risk averse, based on decisions relative to gamble parameters such as potential gain probability, gain amount, loss amount,¹ loss probability, variance, entropy, framing effects, and expected value (EV;² Herrnstein, 1970; Slovic & Lichtenstein, 1968). Differing methods of analyzing these parameters can determine the isolated or relative impact of specific forms or facets of risk on choice behavior^{3,4}

However, risk attitudes are importantly shaped by "risk perception", or the initial cognitive processes by which information is integrated to formulate understanding of risk (Weber & Milliman, 1997). Rather than being driven primarily by gamble parameters, Sjöberg (2000) reflects that, "Risk perception is all about thoughts, beliefs and constructs". Given the far-reaching cognitive dysfunction, atypical beliefs, and faulty information integration found in psychosis (Garety, Bebbington, Fowler, Freeman, & Kuipers, 2007; Lee & Park, 2005; Velthorst et al., 2021), it is vital to elucidate whether risky decision-making deficits may be better attributed to differences in risk perception (Fig. 2), rather than risk attitude.

¹ One form of risk, 'loss aversion' is prominently discussed in psychosis literature. Loss aversion is the premise that "a loss of \$X is more aversive than a gain of \$X is attractive", thus potential gain amounts must outweigh potential loss amounts to incentivize risk-taking in a gamble with equal probabilities (Tversky & Kahneman, 1992). Loss aversion is not the same as the impact of losses on decisions, as the former includes the relative impact of gains while the latter does not. The latter, less precise use of this term permeates psychosis literature. The only stringent report of loss aversion in SZ thus far was found using a social, financial decision-making task (Currie et al., 2017).

² EV is the sum of all potential outcome amounts multiplied by the probabilistic likelihood of their occurrence. Decreased ability to adjust choices based on EV is also a prominent theory in the psychosis literature.

³ For example, the impact of a gamble's potential rewards on decisions may be isolated to gain probability, gain amount, a combination of both, or any of these parameters relative to others. Additionally, the mathematical models used to determine 'impact of gains on risk-taking' can vary considerably in terms of formulae and parameters (e.g. Albrecht et al., 2016).

⁴ Choice behavior can also be impacted by numerous psychological factors that violate standard decision-making theories and concepts, such as affect (e.g. frustration, boredom, regret) and familiarity, which impact the perception of risk and potential benefits (Kilg, Van Tilburg, & Igou, 2020; Weber, 2010; Yakobi & Danckert, 2021).

2. Article search protocol, eligibility, and ineligibility

Authors searched for articles using Google Scholar without a specified range of publication years, yielding publications ranging from 2002 to 2021. A final search of the literature was performed on October 10, 2021. To find studies relating to psychosis-spectrum disorders, the following search terms were used "psychotic", "schizophrenia", "schizo*", "psychosis", along with search terms related to risky decision-making, including "decision", "decision-making", "risk-taking", "risky decision", "uncertainty", "uncertain decision", "ambigu* decision", "gambl*". Inclusion criteria included: (1) empirical research published following peer review, (2) written in English, (3) clinical subjects along the psychosis spectrum (e.g. SZ, SZA, schizophreniform, schizotypy), (4) non-clinical subjects with familial risk for psychosis, (5) non-clinical subjects with measures of schizotypy related to risky behavioral task measures, (6) inclusion of behavioral risk, ambiguous, or uncertain decision-making task.

The current review identifies three categories of such tasks: (1) "Explicit risk tasks" in which all gamble parameters (outcome probabilities, gain/loss amounts) are explicitly provided. These tasks sidestep learning, unlike reinforcement or procedural learning tasks, as they do not require associations to be formed between stimuli and outcomes, nor the active maintenance and comparison of previous outcomes. Additionally, some of these tasks do not provide subjects with the outcomes of their choices (Table 1). (2) "Ambiguous risk tasks" in which some gamble parameters are either fully or partially concealed. Such tasks parse the impact of limited information on decision-making without allowing for learning across trials, as none provide choice outcomes. (3) "Uncertain risk tasks", in which subjects discern whether to pursue risky rewards while learning the probability distribution of choice outcomes via trial and error (De Groot & Thuri, 2018; Mousavi & Gigerenzer, 2014). The two uncertain tasks included in this review differ from other tasks, as they involve both learning across trials and cumulative, sequential risk within trials, such that choosing a risky option begets further opportunities to pursue risk (Pleskac, 2008; Schürmann, Frey, & Pleskac, 2019). However, these tasks were included as each offers an obvious choice between taking greater risk for potential larger reward or avoiding risk for a lesser reward. This characteristic differentiates uncertain risk tasks from reinforcement learning tasks, in which no option is designated to subjects as more or less risky (e.g. Iowa Gambling Task, IGT; Betz et al., 2019; Gold et al., 2008).

Exclusion criteria included (1) social decision-making tasks in which participants believed to be completing tasks with another person or digital avatar, (2) tasks better classified as reward/reinforcement-learning/reversal learning tasks due to no explicit information about reward amounts and outcome probabilities (e.g. IGT; Probabilistic Reward Learning), (3) tasks better classified as jumping-to-conclusions or disconfirmatory-evidence tasks (e.g. Beads Task, BADE Task, Box Task; Bronstein, Pennycook, Joormann, Corlett, & Cannon, 2019; Moritz et al., 2020), (4) one study investigating "endowment effects" rather than risky decision-making, which is further described below. Our search yielded results from 34 investigations across 29 publications, outlined in Tables 1 and 2.

3. Behavioral tasks

3.1. Explicit risk tasks

3.1.1. Cambridge Gambling Task (CGT)

The CGT yields several behavioral measures of decision-making and allows subjects to make independent decisions regarding gamble probabilities and amounts wagered across two stages within each trial (Rogers et al. 1999). Trials begin by displaying 10 squares of two colors, representing the probability of a gamble outcome (i.e. 4 red squares = 40%, 6 blue squares = 60%). A token is hidden under 1 square, and in the first decision stage subjects choose which color they believe the

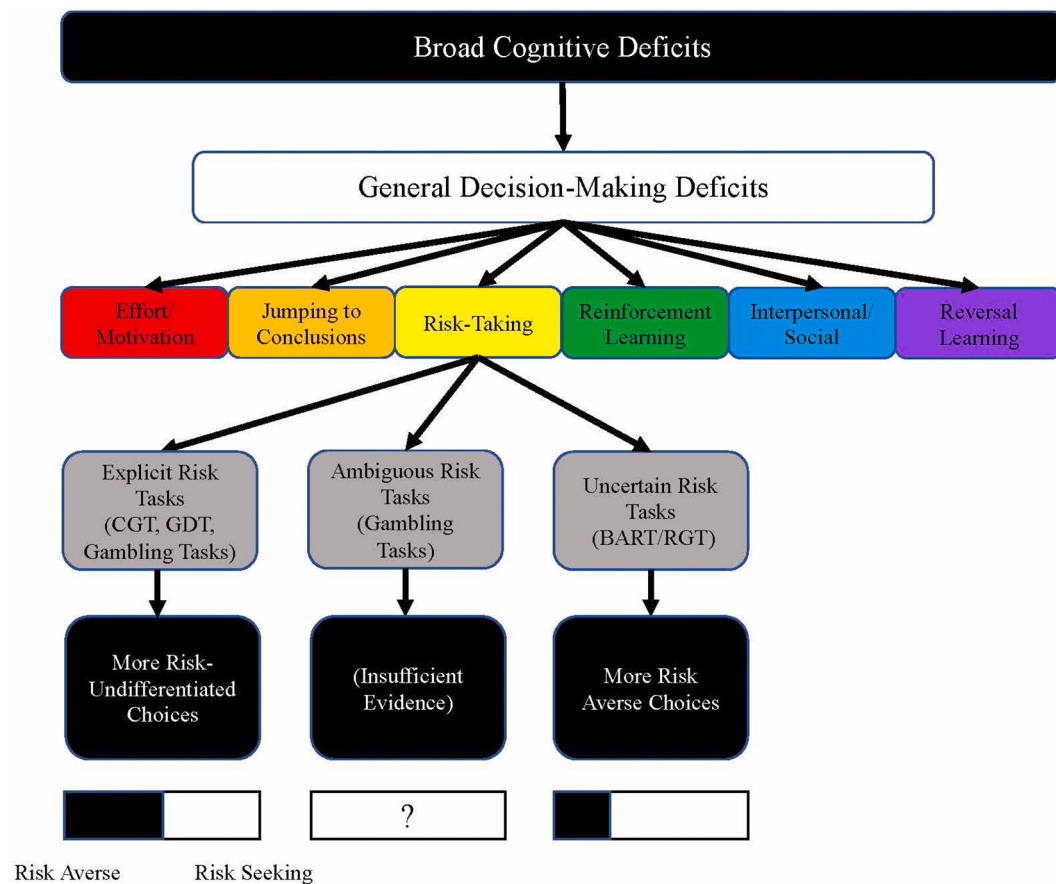


Fig. 1. Theorized relationship between cognitive functioning and risk-taking in psychosis-spectrum disorders. Cognitive processes underlying various decision-making task categories are not mutually exclusive. Theorized risk imperception results in choices that are risk-undifferentiated on explicit risk tasks, but not necessarily more or less risk averse/seeking. Ambiguous risk tasks have insufficient evidence as only three published works with inconsistent results were found. Uncertain risk tasks suggest greater risk-aversion, though further research is warranted to parse whether this may be attributed to risk imperception, risk sensitivity, motivation, or reward/reinforcement-related processes.

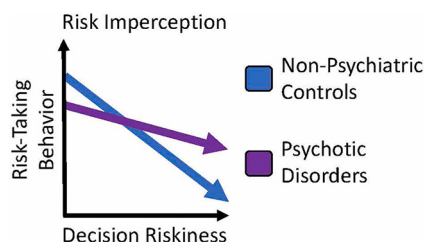


Fig. 2. Simplified illustration of risk imperception in psychosis-spectrum disorders relative to non-psychiatric controls.

token is under. The proportion of trials in which the higher probability color is chosen is referred to as “quality of choice”. After choosing a color, subjects enter a second decision stage in which they wager a proportion (5%, 25%, 50%, 75%, 95%; subjects each have 100 points on the first trial) of their running total presented serially across time as point amounts. Thus, subjects must wait to place a wager, which will result in a gain or loss. Two conditions are included to investigate “speed of decision-making”, to parse temporal impulsivity (regularly choosing wagers presented early) from risk-taking (regularly choosing larger wagers). In an ascending condition, the wager option starts at 5% and serially increases over time, with the descending condition starting at 95% and decreasing. Most pertinent to this review are, quality of choice and “risk-adjustment”, the propensity to wager an optimal proportion of points relative to the probability of each gamble. Additionally, “risk-taking” has been isolated as the proportions wagered after choosing the

highest probability gamble.

Subjects with chronic and first-episode (FE) SZ have demonstrated less risk adjustment on the CGT (Hutton et al., 2002), wagering similar proportions of points irrespective of probabilistic risk. This results in risk-aversion in low-risk contexts and risk-seeking in high-risk contexts, an effect that was more robust in chronic than FE SZ. Chronic SZ, but not FE SZ, was also associated with poorer quality of choice. These findings have replicated, with additional analyses revealing no differences in proportions of points wagered after choosing the highest probability gamble, nor proportion of points gambled across all trials (Martin, Mowry, Reutens, & Robinson, 2015). Taken together, the CGT implicates risk imperception in psychosis, as subjects: (1) less frequently choose higher probability gambles, even before wagering points; (2) wager amounts that are not as well-adjusted to gamble probability; and (3) do not consistently wager larger or smaller proportions of points (i.e. not more risk-averse/seeking with wager amounts) compared to controls.

Differences in CGT task performance have not been found in children born of at least one parent with a psychosis-spectrum, bipolar, or neither disorder (Hemager et al., 2021), nor in non-clinical samples of college students with high schizotypal personality questionnaire scores (Li et al., 2016). However, psychosis symptom prevalence has been associated with worse quality of decision-making and risk adjustment in adolescents and young adults of parents with severe mental illness (MacKenzie et al., 2017). These findings may suggest the CGT performance deficits coincide with psychosis symptomatology but not necessarily schizotypal traits or familial risk.

The CGT is often included within a cognitive battery that allows for

Table 1
Study characteristics and findings in risky decision-making in psychosis-spectrum disorders.

Citation	Final sample	Matched	Cog. match?	Between group sig results	Between group non-sig results	B?	O?
Cambridge Gambling Task (CGT)							
Hemager et al., 2021	FHR-SZ (197), CTL (190)	Age, Sex	N	N/R	Quality of Decision-Making; Risk-Taking; Risk Adjustment; Deliberation Time; Delay Aversion; Overall Proportion Bet	N	Y
Hutton et al., 2002	C-SZ (22), FE-SZ (28), SZ-CTL (26), FE-CTL (30)	Age	Y (NART)	Deliberation Time; Quality of Decision-Making; Risk Adjustment	Delay Aversion	N	Y
Li et al., 2016	High SPQ (44), Low SPQ (22)	Age, Sex, Edu.y	Y (DS, LNS, WAIS-CV)	Deliberation Time	Quality of Decision-Making; Risk Adjustment; Delay Aversion	N	Y
MacKenzie et al., 2017	FHR + Psy (69), FHR-Psy (87)	Age, Sex	Y (WASI-F)	Between-group results N/R	Between-group results N/R	N	Y
Martin et al., 2015	SZ (43), CTL (45)	Age, Sex	Y (NART)	Deliberation Time; Quality of Decision-Making; Risk Adjustment	Risk-Taking; Overall Proportion Bet	N	Y
Game of Dice Task (GDT)							
Fond et al., 2013	P-SZ (40), CTL (67)	Age	N (f-NART covariate)	Net Score; Gamble 1	Gambles 2–4	N	Y
Lee et al., 2007	S-SZ (23), CTL* (28)	Age, Sex, Edu.y	Y (measure N/R)	N/R	Net Score; Gambles 1–4	N	Y
Li et al., 2021	AO-SZ-IO (71), CTL (53)	Age, Sex, Edu.y	N	Net Score; Gamble 1, 3; Points earned; Negative Feedback Use	Gambles 2,4; Positive Feedback Use	N	Y
Pedersen et al., 2017	SZ-I (38), CTL (38)	Age, Sex, Edu.y	Y (WAIS Vocab)	Net Score; Gamble 1; Risky Choice Odds; Negative Feedback Use (29 SZ; 22 CTL)	Gambles 2–4	N	Y
Runyon and Buelow, 2019	Undergraduates (102)	N/A	N/A	N/R	Net Score	N	Y
Zhang et al., 2015	FE-SZ-I (46), CTL (80)	Age, Sex	Y (RPM)	Net Score; Gamble 1	Gambles 2–4; Positive Feedback Use (44 FE-SZ; 76 CTL); Negative Feedback Use (41 FE-SZ; 76 CTL)	N	Y
Risky Two-Choice Gambling Tasks (Two-Armed Bandits)							
Albrecht et al., 2016	SZ + SZA (44), CTL (30)	Age, Sex, P-Ed.	N	EV discrimination slope steepness (λ , Sharp Model); Probability information in Model (M)4 and M5	Bias toward gamble with highest reward probability (k, Sharp model). Magnitude Sensitivity (M4; M5; M6)	Y- T	Y
Baker et al., 2019 (Risk/Ambiguity Task)	SZ + SZA + SZPH (24), CTL (21)	Age, Sex, Race, P-SES	Y (LNS)	N/R	Risk Aversion (α); Ambiguity aversion (β) on Tymula Task	Y- R	N
Baker et al., 2019 (Loss Aversion Task)	SZ + SZA + SZPH (24), CTL (21)	Age, Sex, Race, P-SES	Y (LNS)	N/R	Amount of potential gain (β gain); Amount of potential loss (β loss); Loss Aversion (λ ; β loss/ β gain) on Tom Task	Y- R	N
Benke et al., 2021	SZ-I (28), CTL (30)	Age, Sex, Edu.o	N	Lowest Probability Gamble; Shifting to gamble with greater gain probability; Gambling during “keep frames” on DeMartino Task	Three higher probability gambles; Shifting to gamble with greater loss probability; Frequency of gambles with 20/–20 “safe option”; Total winning amount	N/ R	Y
Brown et al., 2013 (Framing Effects Task)	SZ (34), CTL (31)	Age, Sex, Race	N	Amount of potential gain (β gain); Amount of potential loss (β loss) on Tom Task	Gambling during “loss frames” on DeMartino Task	Y- B	N
Brown et al., 2013 (Loss Aversion Task)	SZ (34), CTL (31)	Age, Sex, Race	N	Amount of potential gain (β gain); Amount of potential loss (β loss) on Tom Task	Loss Aversion (λ = $-\beta$ loss/ β gain) on Tom Task (28 SZ, 31 CTL)	Y- B	N
Fujino et al., 2016	SZ (21), CTL (30)	Age, Sex, Edu.o	Yes (JART)	Ambiguous Choices	Risky Choices; Gain amount on risk-taking; Gain probability on risk-taking; Gain amount on ambiguous choice; Ambiguity level on ambiguous choice	N	N
Hart et al., 2019	SZ (33) + SZA (18), CTL (88)	Sex, Race	N	Preference for less-risky option (HDM; 34 SZ/SZA, 83 CTL)	Preference for less-risky option (AUC; full sample)	N	N
Heerey et al., 2008	C-SZ (37), CTL (26)	Age, Sex, Race, P-Ed.	N	Loss value (β_2) on choice; Proportion of optimal choices	Gain value (β_1) on choice; Ambiguity (β_3) on choice; Mean EV to switch gamble choice; Proportion of gambles chosen; Gamble choice reversal	N	N
Larquet et al., 2010	SZ (21), CTL (20)	Age	N	N/R	Regret Emotion Ratings	Y- R	Y
Martinelli et al., 2018b	SZ (20), CT (22)	Age, Sex	N	Absolute value of impact of high/low gamble preference; Absolute value of attractiveness of reward variance (α)	% of gambles; gambling across low/high amount contexts; Difference between high-low value context gambles multiplied by impact of high/low gamble preference; Attractiveness of reward variance (α); Baseline propensity to gamble (μ); Normalization of the trial amount associated with the high-value context (τ); Impact of previous trial outcome; Previous trial EV	Y- R	Y
Yu et al., 2017 (Risk Aversion Task)	SZ + MDE-SZA (40), SZ-Rel (31), CTL (39)	Age, Sex, Edu.y, P-Ed.	N	N/R	Risk Aversion (α) on Gambling Task	Y- R	N
Yu et al., 2017 (Loss Aversion Task)	SZ + MDE-SZA (44), SZ-Rel (33), CTL (37)	Age, Sex, Edu.y, P-Ed.	N	N/R	Loss Aversion (λ) on Tom Task	Y- R	N
Risky Gains Task (RGT)							
Cheng et al., 2012	SZ (25), CTL (25)	Age, Sex, Edu.y	N	% safe responses; % risky responses	% safe responses after loss; % risky responses after loss	N/ R	Y

(continued on next page)

Table 1 (continued)

Citation	Final sample	Matched	Cog. match?	Between group sig results	Between group non-sig results	B?	O?
Luk et al., 2019	FEP (33; [23 SZ, 1 SZPH, 5 BPsyD, 3 DD, 1 PsyNOS], CTL (32)	Age, Sex, Edu.y	N	% safe responses; % risky responses; % safe responses after gain; % risky response after gain	% safe responses after loss; % risky responses after loss	N/ R	Y
Balloon Analogue Risk Task (BART)							
Boka et al., 2020	SZ + SZA (46), CTL (16)	Sex, Race, Ed.o	N/R	Explosion Number; Points (\$)	Reaction Time	N/ R	Y
Brown et al., 2015	SZ (49) + SZA (10), CTL (43)	Age, Sex	N	Earned; Average Inflation; Adjusted Pumps; Explosion Number; Points (\$)	Points (\$)	Y- N	Y
Cheng et al., 2012	SZ-IO (25), CTL (25)	Age, Sex, Ed.y	N	Adjusted Pumps; Explosion Rate; Reaction Time	N/R	N	Y
Dominguez, 2011	SZ (28) + SZA (4), CTL (10)	Age, Sex	Not measured	Adjusted Pumps; Explosion Number; Points (\$)	Points (\$)	N	Y
Fischer et al., 2015	SZ (24), CTL (24), SZ-Can (18)	Race.NW	N	Adjusted Pumps; Explosion Number	Points (\$)	Y- N	Y
Luk et al., 2019	FEP (33; 23 SZ, 1 SZPH, 5 BPsyD, 3 DD, 1 PsyNOS], CTL (32)	Age, Sex, Edu.y	N	Adjusted Pumps; Explosion Rate	Points (\$)	N	Y
Reddy et al., 2014	SZ (38), CTL (36)	Age, Sex, P-Ed.	N	Adjusted Pumps; Explosion Number; Points (\$)	Task Duration (seconds)	Y- T	Y
Tikász et al., 2019	SZ (34) + SZA (12) + SZPH (1), CTL (23)	Age, Sex-M, Race. NW	N	Explosion Number	Points (\$)	N	Y

Column Headers: B? = Did subjects receive bonus payments for task performance?; Cog. Match = Subjects matched on cognitive measure(s); Final Sample = Sample size of only psychosis-spectrum subject and controls after exclusion of some subjects; Matched = Demographic features on which groups were matched; O=Did subjects see the outcomes of each of their decisions?; Sig = Significant.

Clinical Groups: AO-SZ-IO = Adolescent-onset in-patient and out-patient schizophrenia (Ages 13–18) within 3-years of diagnosis; BPsyD = Brief psychotic disorder; C-SZ = Chronic Schizophrenia; CTL* = Hospital staff only assessed for substance abuse; CTL = Controls; DD = Delusional disorder; FE-CTL = First-episode sample controls; FE-SZ-I = unmedicated first-episode inpatients with schizophrenia; FE-SZ = First-episode schizophrenia; FEP = First episode psychosis; FHR-Psy = Familial high risk for severe mental illness without current psychosis symptoms (Ages 7–24); FHR-SZ = Familial high risk for schizophrenia-spectrum disorder (Age 7); FHR + Psy = Familial high risk for severe mental illness with at least 1 current psychosis symptom (Ages 7–24); High PDI = Peters delusion inventory >9.5 via median split; High SPQ = Schizotypal personality questionnaire score > 36; Low PDI = Peters delusion inventory <9.5 via median split; Low SPQ = Schizotypal personality questionnaire score < 17; MDE-SZA = Unipolar schizoaffective disorder with major depressive episodes; P-SZ = Paranoid schizophrenia; PsyNOS = Psychosis not otherwise specified; S-SZ = “Stable” SZ (i.e. “no florid psychotic features at the time of testing”); SZ-CTL = Schizophrenia sample controls; SZ-I = inpatient schizophrenia subjects; SZ-IO = group includes both inpatient and outpatient schizophrenia subjects; SZ-Rel = Unaffected subjects with a first-degree relative with psychosis; SZ + Can = Schizophrenia with cannabis use disorder; SZ = Schizophrenia; SZA = Schizoaffective disorder; SZPH = Schizophreniform disorder.

Matched Variables: E.o = Education ordinarily evaluated; E.y = Education in years; P-Ed. = Parental education; P-SES = Parental socio-economic status; Race.NW = Matched groups on % of white and non-white subjects; Sex-M = All subjects were men.

Cognitive Measures: Comp = Composite score of letter-number span, digital symbol coding, logical memory, and letter cancellation; DS = Digit span; f-NART = French version of the national adult reading test; JART = Japanese version of the national adult reading test short form; LNS = Letter-number sequencing; NART = National adult reading test; RPM = Raven’s progressive matrices; Vocab = Vocabulary; WAIS = Wechsler adult intelligence scale; WAIS-CV = Wechsler adult intelligence scale - Chinese version short form; WASI-F = Wechsler abbreviated scale of intelligence full.

Miscellaneous Abbreviations: AUC = Area under the curve analysis; HDM = Hyperbolic discounting model analysis; N=No; N/A = Not applicable; N/R = Not reported; Y=Yes; Y-A = Yes, subjects were paid an average across all trials; Y-B = Yes, subjects were just told they would be paid a bonus based on performance; Y-N = Yes, subjects were paid a bonus, but the payment schedule not indicated in the text; Y-R = Yes, subjects were paid the amount won in a random trial; Y-T = Yes, subjects were given the total amount of money earned.

comparison with other tasks and uniform, digital administration across large samples. Most studies have also matched psychosis and control groups on at least one measure of cognitive functioning. Despite this, groups have differed on various other cognitive tasks with results remaining after accounting for some cognitive measures (WASI; Mackenzie et al., 2017; Table 2) but not others (Matrix Reasoning; Martin et al., 2015). There are downsides to this battery administration; symptom interviews and self-reports have been largely omitted, offering few insights into how psychosis symptomatology relates to decision choices. Additionally, task performance has not been incentivized by offering bonus payment, leaving the impact of monetary motivation unaddressed.⁵

3.1.2. Game of Dice Task (GDT)

Originally used to investigate executive functioning in Korsakoff

syndrome, the GDT was designed to gauge explicit risk-taking, counter to the reinforcement learning format of the IGT, by providing gamble probabilities consistently paired with wager amounts (Brand et al., 2005). Each trial presents 4 differing categories of gambles, depicted as combinations of a die roll. Across 18 trials, subjects choose gambles that will gain or lose amounts of money with probabilities that can be determined by adding up die roll outcome probabilities (i.e. 2/6 or 33% chance of either a one or two being rolled). The gambles include chances of winning paired with wagers: 1/6 chance of winning 1000€, 2/6 chance of 500€, 3/6 chance of 200€, or 4/6 chance of 100€. Frequency of choosing each gamble is used to assess risk-taking, with an additional “net score” derived by subtracting the number of disadvantageous/risky (gamble 1 + gamble 2) from non-risky/advantageous options (gamble 3 + gamble 4).⁶

At first glance, GDT results in SZ suggest increased risk-taking, as subjects consistently earn less-positive net scores. Comparing frequency

⁵ Risk-taking behavior and brain activity have been impacted by payment method (Charness, Gneezy, & Halladay, 2016; Schmidt et al., 2019; Schmidt & Hewig, 2015; Xu, Wang, & Wang, 2020). Future research should determine whether payment may differentially impact risky decision-making, as it has impacted SZ subject performance in some tasks (Hellman, Kern, Neilson, & Green, 1998; Horan, Johnson, & Green, 2017).

⁶ While gambles 1–4 are ordinally different in riskiness, on a ratio scale they are very disproportionate. An EV approach reveals that the first two gambles have an expected value of –4000€ and –500€ respectively, with the third gamble breaking even (i.e. 0€), and only the fourth yielding a positive EV of 100€. Thus, choosing the third gamble, while less risky than the first and second, may not necessarily indicate risk-seeking/aversion.

Table 2

Clinical and cognitive associations with risky decision-making task performance in psychosis-spectrum disorders.

Citation	Cognitive measures	Sig. cognitive associations	Cognitive covariate	Psychosis symptom measures	Sig. symptom associations	Non-Sig. symptom associations
Cambridge Gambling Task (CGT)						
Hemager et al., 2021	RIST, RVP, SOC, SRM, SS, SWM, WISC-IV,	Neg. between SS and quality of decision-making; Pos. between SWM and quality of decision-making	N	None	N/A	N/A
Hutton et al., 2002	NART, MMSE	N/R	N	None	N/A	N/A
Li et al., 2016	DS.b, DS.f, LNS, WAIS-CV	N/R	N	SPQ	N/R	N/R
MacKenzie et al., 2017	SWM, WASI-F	◊Neg. between SWM and CGT measures; Pos. between WASI-F and CGT measures	Y (SWM; WASI-F) effects remained	K-SADS-PL, FFI, SIPS, SPI-CY	†Neg. between psychosis symptoms (aggregated across measures) and risk adjustment and quality of decision-making	†Psychosis symptoms (aggregated across measures) and delay aversions, deliberation, risk-taking
Martin et al., 2015	DS.b, DS.f, HSCT, L. Flue, NART, PAL, PRM, RAVLT, S. Flue, SD, SMR, Stroop, SWM, Syd. Bat, WASI-F	†Neg. between SWM and risk adjustment	Y (Matrix Reasoning; GTB) effects nullified	None	N/A	N/A
Game of Dice Task (GDT)						
Fond et al., 2013	f-HSCT, f-NART, TMT, UMT	Neg. between TMT completion time and total gains	Y (f-NART) effects remained	PANSS (Kay 1987)	None	PANSS-Gen/Neg/Pos/Tot
Lee et al., 2007	IQ (Measure Not Reported), WCST	None with WCST	N	PANSS (Kay 1987)	None	PANSS-Gen/Neg/Pos/Tot
Li et al., 2021	DS.b, DS.f, MoCA, Stroop	None	Y (“cognitive functions”) effects remained	PANSS (Kay 1987)	None	PANSS-Neg/Pos/Tot
Pedersen et al., 2017	WAIS Vocabulary	N/R	N	PANSS (Kay 1987)	Neg. between PANSS-Pos and net score; Pos. between PANSS-Pos and % risky choices following negative feedback	PANSS-Gen/Neg
Runyon and Buelow, 2019	None	N/A	N/A	PDI	None	PDI
Zhang et al., 2015	DS.f, DS.b, RPM, TMT, WCST	Neg. between WCST-PE, TMT-B, TMT-Diff, and net score; Pos. between WCST-Cat and net score	N	PANSS (Kay 1987)	N/R	N/R
Risky Two-Choice Gambling Tasks (Two-Armed Bandits)						
Albrecht et al., 2016	WASI-F WMS.f, WMS.b, WTAR	Pos. between WASI and EV sensitivity (λ) and gamble amount impact averaged across four models; Neg. between WASI and bias for highest reward probability (k)	N	BNSS, BPRS, CAINS, SANS	Neg. between BNSS-EE, BPRS-Neg, SANS [®] -AFB/Alog/Avol and magnitude sensitivity averaged across four models	BPRS-AGD/Dis/RD/Tot; SANS-AA/Tot; BNSS-EE/MP/Tot
Baker et al., 2019 (Loss Aversion Task)	LNS	Pos. between LNS and impact on gain amounts (β_{gain})	N	CAPS, PANSS (Kay 1987), PDI, PSYRATS	None	PANSS-P1/P6; PDI
Baker et al., 2019 (Risk/Ambiguity Task)	LNS	None	N	CAPS, PANSS (Kay 1987), PDI, PSYRATS	None	PANSS-P1/P6; PDI
Benke et al., 2021	CVLT, RWT, TMT	Neg. between CVLT learning (trials 1–5) and frequency choosing lowest probability Gamble	N	PANSS	Neg. between PANSS-Neg/Pos and shifting to gamble with greater gain probability	PANSS-Pos
Brown et al., 2013 (Framing Effects Task)	MDS-WM, RS WASI, WRAT, WTAR	Pos. between RS and WASI and catch trial performance	N	BNSS, BPRS, SANS	None	BNSS, BPRS, SANS
Brown et al., 2013 (Loss Aversion Task)	MDS-WM, RS WASI, WRAT, WTAR	Pos. between WASI and impact of potential loss (β_{loss})	N	BNSS, BPRS, SANS	None	BNSS, BPRS, SANS
Fujino et al., 2016	BACS-J, JART	None for BACS-J; N/R for JART	N	PANSS (Kay 1987)	Pos. between PANSS-Gen/Neg and risk attitude	PANSS-Gen/Neg/Pos and ambiguity

(continued on next page)

Table 2 (continued)

Citation	Cognitive measures	Sig. cognitive associations	Cognitive covariate	Psychosis symptom measures	Sig. symptom associations	Non-Sig. symptom associations
Hart et al., 2019	CNTB, WASI-A	N/R	Y (WASI-A) HDM effects remained	PANSS (Kay 1987)	N/R	attitude; PANSS-Pos and risk attitude N/R
Heerey et al., 2008	HVLT, LNS, SS, WTAR	None	Y (LNS + SS) accounted for group differences in average of gain + loss weight via HMR	BPRS, SANS	None	BPRS, SANS
Larquet et al., 2010	L.Flue, S.Flue, Stroop, TMT, WAIS, WCST (None done in controls)	None	N	PANSS (Kay 1987), RPAS, RSAS, SDS	N/R	RAS-P, RAS-S
Martinelli et al., 2018b	DS, WASI-A	Pos. between DS, and WASI-A(trending)* and absolute value of preference for gambling with high or low amounts	N	ASI, PANSS (Kay 1987)	Neg. between ASI and absolute value of preference for gambling with high or low amounts	PANSS-Neg/Pos
Yu et al., 2017 (Loss Aversion Task)	PCNB	None	N	CAINS, RAS-P, RAS-S, SANS, SAPS	None	CAINS, RAS-P, RAS-S, SANS, SAPS
Yu et al., 2017 (Risk Aversion Task)	PCNB	None	N	CAINS, RAS-P, RAS-S, SANS, SAPS	Pos. between SAPS and risk aversion (α);	CAINS, RAS-P, RAS-S, SANS
Risky Gains Task (RGT)						
Cheng et al., 2012	RPM	None	N	PANSS (Kay 1987)	None	PANSS-Gen/Neg/Pos
Luk et al., 2019	D.Sym, L.can, LNS, LogMem	Pos. between LogMem and risky response rate following punishment and reward; Neg. between LogMem and safe response rate after reward	N	PANSS (Emsley 2003), SANS	None	PANSS-Dis/Pos; SANS-Amot/DE/Tot
Balloon Analogue Risk Task (BART)						
Boka et al., 2020	WAIS	N/R	N	PANSS (Kay 1987)	Pos. between individual item (emotional withdrawal, excitement, poor rapport, and uncooperativeness) and “average inflations” Neg. between BPRS-Dis and adjusted pumps, explosions, and money earned; Pos. between SANS-AFB/AL and adjusted pumps (due to outlier)	PANSS-Gen/Neg/Pos
Brown et al., 2015	WASI-F, RBANS, dSym, LNS,	None	N	SANS, BPRS		BPRS-neg/psychosis; SANS-AA/RF
Cheng et al., 2012	RPM	None	N	PANSS (Kay 1987)	None	PANSS-Gen/Neg/Pos
Dominguez, 2011	None	N/A	N	PANSS (Van den Oord 2006)	Neg. between PANSS-Pos and adjusted pumps, explosions, and money earned	N/R
Fischer et al., 2015	WTAR, RBANS	N/R	N	BPRS	N/R	N/R
Luk et al., 2019	LNS, LogMem., dSym, Lcan	Pos. between Comp-Cog. and adjusted pumps and total points; Pos. between LNS and adjusted pumps, explosion rate, and total points; Pos. between LogMem and total points	N	PANSS (Emsley 2003), SANS	Pos. between PANSS-Pos and adjusted pumps and explosion rate	PANSS-Dis; SANS-Amot/DE/Tot
Reddy et al., 2014	MCCB	Pos. between CPT and adjusted pumps	N	BPRS	Pos. between BPRS-Neg and adjusted pumps	BPRS-Pos/Tot
Tikász et al., 2019	WASI	N/R	N	PANSS (Lindenmayer 1995)	N/R	N/R

General: EV = Expected value; HDM = Hyperbolic discounting model analysis; HMR = Hierarchical multiple regression; N = No; N/A = Not applicable; Neg. = Negative; NR = Not reported; Pos. = Positive; Y = Yes.

Cognitive Measures: BACS-J = Brief assessment of cognition in schizophrenia, Japanese version; CNTB = Cambridge neuropsychological test automated battery including spatial working memory, attention switching task, paired-associates learning, and stop signal task; Comp. Cog = Composite score of letter-number span, digital symbol coding, logical memory, and letter cancellation; CPT = Continuous performance test—identical pairs version; CVLT = California Verbal Learning Test; D.Sym = Digit symbol; DS.b = Digit span backwards; DS.f = Digit span forwards; DS = Digit span; f-HSCT = Hayling sentence completion task French version; f-NART

= French version of the national adult reading test; GTB = General test battery, a composite of recognition score from RAVLT, digit-span forwards, and block design and similarities from WASI; HSCT = Hayling sentence completion task; HVLTL = Hopkins verbal learning test; JART = Japanese version of the national adult reading test short form; L.can = Letter cancellation; L.Flue = Letter fluency; LNS = Letter-number sequencing; LogMem = Logical memory; MCCB = MATRICS (Measurement and treatment research to improve cognition in schizophrenia) consensus cognitive battery; MDS-WM = MATRICS domain score—working memory; MMSE = Mini-mental state examination; MoCA = Montreal cognitive assessment; NART = National adult reading test; PAL = Paired associates learning test; PCNB = Penn computerized neurocognitive battery; PRM = Pattern recognition memory test; RBANS = Repeatable battery for the assessment of neuropsychological status; RIST = Reynolds intellectual screening test; RPM = Raven's progressive matrices; RS = Reading score is mean score of WRAT and WTAR; RVP = Rapid visual information processing; RWT = Regensburger word fluency test ("animals" & "S-words"); S.Flue = Semantic fluency; SD = Symbol-digit modalities test; SOC = Stockings of Cambridge; SRM = Spatial recognition memory test; SS = Spatial span; SWM = Spatial working memory; Syd.Bat = Sydney language battery; TMT = Trail making test (-B = time to complete Trail-Making test B; -Diff = Difference between time taken to complete trail-making test A and B); UMT = Updating memory task; WAIS-CV = Wechsler adult intelligence scale-Chinese version short form; WAIS = Wechsler adult intelligence scale; WASI-A = Wechsler abbreviated scale of intelligence abbreviated (2 tests); WASI-F=Wechsler abbreviated scale of intelligence full (4 tests); WCST = Wisconsin card sort task (-PE = Perseverative errors; -Cat = Number of categories completed); WISC-IV = Wechsler intelligence scale for children – fourth edition; WMS.f, & WMS.b = digit span forwards and backwards from the WAIS; WRAT = Wide ranging achievement test; WTAR = Wechsler test of adult reading.

Psychosis Symptom Measures: ASI = Aberrant salience inventory; BNSS = Brief negative symptom scale (-EE = Emotional expressivity; -MP = Motivation and pleasure; -Tot = Total); BPRS = Brief Psychiatric Rating Scale (-AGD = name not reported in the article; -Dis = Disorganization; -Neg = Negative; -Pos = Positive; -RD = Reality distortion; -Tot = Total); CAINS = Clinical assessment interview of negative systems. CAPS = Cardiff anomalous perceptions scale; FFI = Funny feelings interview; K-SADS-PL = Kiddie schedule for affective disorders and schizophrenia, present and lifetime version; PANSS = Positive and negative syndrome scale (-Dis = Disorganization factor; Gen = General psychopathology factor; -Neg = Negative factor; -P1 = Delusion item; -P6 = Suspiciousness/Persecution item; -Pos = Positive factor; -Tot = Total score); PDI = Peters delusion inventory; PSYRATS = Psychotic symptoms rating scale; RAS = Revised chapman anhedonia scale (-S = Social; -P = Physical); SANS = Scale for assessment of negative symptoms (-AA = Anhedonia asociality; -AFB = Affective blunting; -Alog = Alogia; -Amot = Amotivation; -DE = Diminished expression; -RF = Role functioning); SAPS = Scale for assessment of positive symptoms; SDS = Schedule for the deficit syndrome; SIPS = Structured interview for prodromal syndromes; SPI-CY = Schizophrenia proneness instrument - child and youth version; SPQ = Schizotypal personality questionnaire.

◇ *Correlations are weak and moderate. They include all subjects (youth at familial risk for severe mental illness with and without psychosis symptoms). For specific CGT and SWS measures see MacKenzie et al. (2017).*

‡ *Other GDT correlations not directly related to risk taking (e.g. delay, deliberation) reported in Martin et al. (2015) supplement.*

† *Regression results are from a generalized linear latent and mixed model adjusted for age, sex, family history of psychotic symptoms, and familial clustering. They include all subjects (youth at familial risk for severe mental illness with and without psychosis symptoms).*

* *Correlations in Martinelli et al., 2018b were only reported for the combined schizophrenia and control sample. Within-group correlations were not reported.*

⊕ *The main text of Albrecht et al., 2016 reports these SANS subscale correlations as significant, however it is unclear due to the lack of reported statistics and lack of bolded notation in Table 2 of the original publication.*

of choosing each gamble, SZ (in inpatient and outpatient settings) and hospitalized, never-antipsychotic-medicated FE-SZ, has been associated with choosing only the riskiest, first gamble more than controls (Fond et al., 2013; Pedersen, Göder, Tomczyk, & Ohrmann, 2017; Zhang et al., 2015). A combined group of adolescents with SZ from inpatient and outpatient settings have chosen the first and third gambles more frequently than controls (Li et al., 2021). Conversely, Lee et al. (2007) did not find any gamble choice differences in a sample of "stable" outpatient SZ subjects without "florid psychotic features", suggesting more normative performance in subjects with less active symptoms. Additional analyses have found that adolescent and adult SZ subjects were less likely than controls to be deterred from risk-taking following a negative outcome from risky gamble choices (Li et al., 2021; Pedersen et al., 2017); however, no differences in choices following negative or positive outcomes were observed in hospitalized, never-antipsychotic-medicated FE-SZ (Zhang et al., 2015). Taken together, current psychosis symptom severity may relate to overall gamble choices but not necessarily decision updating following negative outcomes.

While these metrics have traditionally be interpreted as increased risk-taking attitude in SZ, risk-imperception offers another interpretation: namely that SZ is associated with less differentiation between gamble riskiness. Since the riskiest gamble is largely avoided and the least-risky gamble is exploited by controls, there is a disparity between net scores. Thus, in SZ all four gambles are sampled from more equally irrespective of risk. This interpretation is bolstered by SZ subjects more frequently choosing lower-probability gambles even before wagering points on the CGT. "Risk-taking" in the GDT combines gamble amounts and probabilities, but we posit that in psychosis, there is less discrimination between each gamble's probabilistic risk. While this behavior may be described as "more frequently choosing the riskiest gamble", it is more aptly described as "choosing each gamble with more similar frequency irrespective of risk". This theory is complemented by recent findings that psychosis is associated with increased exploratory behavior and decreased exploitation of more rewarding choices in reinforcement learning (Cathomas et al., 2021; Martinelli, Rigoli, Averbeck, Shergill 2018a).

Though GDT performance has not consistently correlated with general intelligence in non-clinical samples, it has been associated with executive functioning, and intellectual ability which has moderated mathematical strategy use (Brand, Heinze, Labudda, & Markowitsch, 2008; Brand, Laier, Pawlikowski, & Markowitsch, 2009). Performance also improved when non-clinical subjects were instructed to calculate gamble probabilities, gains, and losses (Pertl, Zamarian, & Delazer, 2017). Additionally, while the GDT was designed to isolate risky choices from gamble properties, subjects perform better from versions of the task that include choice outcomes, suggesting some role of outcome learning (Brand et al., 2009). Though most clinical studies matched groups on single-modality, estimated measures of IQ (e.g. RPM, f-NART, WAIS-Vocab; Table 1), associations with cognitive functioning within psychosis have still been found (Fond et al., 2013; Li et al., 2021; Zhang et al., 2015), while analyses have not been conducted/reported in other studies (Lee et al., 2007; Pedersen et al., 2017). Future research should identify with what frequency clinical subjects utilize mathematical calculation relative to intuition on the GDT, as a greater reliance on the latter may underlie risk imperceptive decision-making.

Whether or not GDT finding relate to specific psychosis symptomatology remains unclear. Though associations between task performance and symptomatology were assessed across all the cited studies, only one found that positive symptoms in an inpatient sample positively correlated with both lower net score and less adjustment following negative outcomes (Pedersen et al., 2017). No correlations were found between delusion proneness, conviction, preoccupation, or distress in a non-clinical undergraduate sample (Runyon & Buelow, 2019).

3.1.3. Risky two-choice gambling tasks (two-armed bandits)

The gambling tasks outlined in this section all require subjects to decide between two options, which take the forms of mixed gambles, skipping trials, and "safe options" (i.e. lower rewards/losses with 100% outcome certainty). While these tasks have been grouped according to prominent risk-related features, other differences such as whether subjects were paid performance-based bonuses exist across studies. Importantly, only a handful of studies presented subjects with outcomes of

their decisions (Table 1), a feature that may impact decision-making, as evidenced by some reinforcement and punishment learning findings (Barron & Erev, 2003; Fervaha, Agid, Foussias, & Remington, 2013; Waltz, Frank, Robinson, & Gold, 2007).

3.1.3.1. Decisions between risky and “safe” choices. Several tasks have investigated preferences for gambles with higher potential reward, rather than a “safe option” alternative with a 100% outcome of a lower gain or loss amount. For example, Yu et al. (2017) investigated choices between lower rewards and mixed gambles (e.g. 50% null outcome or larger reward) and did not find differences in model parameters indicating risky decision-making in SZ or unaffected first-degree relatives. Hart, Brown, Roffman, and Perlis’ (2019) task offered choices between a lower reward or gambles with greater rewards across various outcome probabilities (i.e. 100%, 90%, 75%, 50%, 25%) and null outcomes. A model-free analysis yielded no between-group differences, but after excluding 5 control and 17 psychosis subjects, whose performance failed to meet model-based performance thresholds, the psychosis group exhibited a greater preference for smaller, less risky rewards. Excluded subjects were typically younger and had lower IQs. These results suggest similar risk-taking across the full samples of subjects.

The Probability-Associated Gambling Task (PAG) offers a choice between a safe option (gaining/losing 20 points on differing trials) or a probabilistic (12.5%, 37.5%, 62.5%, 87.5%) gamble for gaining/losing 100 points. Benke, Marksteiner, Ruepp, Weiss, and Zamarian (2021) found that inpatient subjects with SZ chose to gamble in the lowest gain probability (12.5%) condition more frequently than controls, similar to behavior of inpatient subjects on the GDT (Pedersen, Göder, Tomczyk, & Ohrmann, 2017; Zhang et al., 2015). While interpreted as increased risk-taking, SZ subjects did not gamble more often in other conditions, suggesting a lack of greater risk-taking more broadly. Additionally, across all trials SZ subjects did not shift to gambling when there was an increased gain probability, suggesting imperception of when shifting to a risk-taking strategy is more advantageous. This pattern of behavior is consistent with disadvantageous choice on the CGT and other gambling tasks (Brown et al., 2013). Interestingly, there were no group-differences in gambling due to negative or positive safe options. Together, findings may suggest that SZ is not characterized by general, increased risk-taking, but rather inability to differentiate and optimize choice based on relative gamble riskiness. Findings of the PAG are interpreted with caution as the probability information is less visually clear than other tasks.

The Tom Task gives options between skipping trials or pursuing a 50/50 probability gamble of a gain/loss (Tom, Fox, & Poldrack, 2007). In accordance with risk imperception, SZ subjects gambled more indiscriminately to gains and losses (choosing more small gain/large loss, and less large gain/small loss gambles), but did not differ from controls in the impact of potential loss amounts relative to the impact of potential gain amounts (i.e. no differences in loss aversion; Brown et al., 2013). These findings may implicate risk imperception as subjects exhibited less discriminate behavior for potential gains and losses, treating all gambles more similarly irrespective of EV. However, later studies did not find group differences between controls and groups of subjects with SZ and unipolar SZA, psychosis, or unaffected first-degree relatives (Baker, Konova, Daw, & Horga, 2019; Yu et al., 2017). Thus, while there is limited support for risk imperception in SZ (Benke et al., 2021; Brown et al., 2013), other findings suggest no differences in SZ or psychosis when deciding between safe options and risky gambles.

The associations between risk-taking on these tasks and cognition or psychosis symptoms are unclear. Hart et al. (2019) did not find correlations between behavior and symptoms or cognitive functioning in psychosis, but within an adjusted logistic regression model IQ predicted risk-taking (greater IQ associated with more risk-seeking). Episodic memory has been negatively associated with gambling despite high likelihoods of losing (Benke et al., 2021) in an inpatient SZ sample.

Sensitivity to gains and losses on the Tom Task has correlated with cognitive functioning (WASI) and antipsychotic medication dosage (Brown et al., 2013), but cognitive functioning was not assessed in a subsequent study (Baker et al., 2019), or replicated in another (Yu et al., 2017). Associations between risk-taking and symptomatology on these tasks has weak support, only found between shifting to risk-taking according to increased probability of winning and negative/general symptoms (Benke et al., 2013). In a non-clinical sample, Klaus, Chumbley, Seifritz, Kaiser, and Hartmann-Riemer (2020) found greater loss aversion in a small group ($n = 15$) of college students with greater negative symptomatology ascertained via the Community Assessment of Psychic Experiences.

3.1.3.2. Gambling involving choices between gambles. Rather than creating scenarios of “gamble vs no gamble”, other tasks have investigated choices between two risky gambles. Heerey, Bell-Warren, and Gold (2008) used gambles with potential losses, null outcomes, gains, and even ambiguity. When investigating the impact of potential gain amounts on choices, the chronic SZ group made comparable decisions to controls, but potential loss amounts had less impact on decisions. Loss aversion as defined by prospect theory (i.e. decision impact of potential losses relative to potential gains (λ); Tversky & Kahneman, 1992) was not reported. Additionally, while the average EV difference required to shift risky choice behavior was comparable, controls made more optimal decisions based upon EV (for definition see footnote 2). These findings suggest risk imperception as SZ subjects made fewer EV optimizing choices, in addition to altered risk processing specific to decreased impact of loss information.

Investigating preferences for choices between gambles with varying probabilities of rewards and null outcomes, Fujino et al. (2016) did not find differences in SZ. Albrecht, Waltz, Frank, and Gold (2016) found decreased discrimination based upon EV in psychosis using mixed gambles with gains or null outcomes. Using “the best fitting logistic regression model”, no between-group differences emerged across six parameters of EV. However, two simpler models implicated less sensitivity to probabilities, but these should be treated with caution as the results depended on a particular model choice. These findings are consistent with risk imperception as psychosis groups consistently failed to optimize risky decision-making based upon EV of gambles, however the specific task features underpinning this deficit are neither clear nor consistent across studies.

Cognitive functioning has been related to performance on two-choice gambling tasks, which is unsurprising considering the inherent mathematical nature of comparing gambles according to EV. Group differences in valuation parameters have disappeared after accounting for working memory (i.e. spatial span, letter-number sequencing; Heerey et al., 2008) and estimated IQ (WASI) has correlated with EV discrimination and bias for reward probability (Albrecht et al., 2016). Given that cognitive functioning is a poorly controlled variable across most studies, it is imperative for future work to discern whether risk-taking operationalized via EV calculation is a byproduct of lower cognitive functioning rather than a differential, uniquely impaired process in psychosis. Symptom measures have not correlated with EV sensitivity nor most extracted task parameters. One study found the parameter for potential reward amount averaged over three behavioral models correlated with negative symptoms, suggesting greater symptomatology was associated with less sensitivity to rewards; however, correlations were not found with other models (Albrecht et al., 2016).

3.1.3.3. Unique Gambling Parameters

3.1.3.3.1. Gambling tasks with equal expected value options. While most studies have focused on decisions between options of differing risk or value, one found decreased choice adjustment relative to reward amounts in SZ for decisions between smaller, safe rewards or double-or-nothing gambles (i.e. equal EV gambles). Martinelli, Rigoli, Dolan, and

Shergill (2018b) found that groups did not differ in the percent of gambles chosen (~40%), preferences to gamble within contexts of higher or lower amount trials, or preference for gambling relative to across-trial amounts (i.e., “gambling slope”). However, they found that the average of gamble slope absolute values varied, indicating less within-subject differentiation in choice related to gamble amounts in SZ. Thus, there were no differences in propensity to gamble based upon choice amounts (i.e. not more or less risk-seeking), but consistent with risk imperception, gamble amounts had less impact on adjustments in subjects’ behavior in the SZ group. No behavioral differences were attributed to preceding trial outcome, reward variance, trial amount, or baseline gambling propensity. This design created equal EV between certain and risky gambles, thus results are specific to differences in gain amounts rather than value. Despite the reported differences in “value-sensitivity”, these findings more aptly suggest that when faced with equal-value gambles for null outcomes or gains, subjects with SZ are less discriminatory between gain amounts, with less adjusted behavior than controls. No correlations were found between psychosis symptoms, but performance did trend toward a positive correlation with IQ and reached significance with working memory (digit span).

3.1.3.3.2. Gambling tasks comparing gain and loss framing. Brown et al. (2013) investigated framing effects, or the impact of differently describing gamble outcomes with equal EVs, by giving subjects choices between a 100% certain outcome or a gamble. Half of the trials framed both outcomes as “keeping”, while the remaining framed outcomes as “losing”, points. Within-group analyses indicated controls chose to gamble more during trials framed as loss compared to keep, an effect typically found in non-psychiatric subjects (De Martino, Kumaran, Seymour, & Dolan 2006). No such effect was seen within the SZ group. Between-group analyses revealed SZ was associated with greater percent of gambles chosen within trials framed as keeping points and no differences on losing trials, suggesting that gambling behavior in SZ was not more risk averse due to loss framing. No correlations were found between framing effects and social anhedonia, physical anhedonia, or cognitive functioning.

3.1.3.3.3. Gambling tasks evaluating affect and regret. Larquet, Coricelli, Opolczynski, and Thibaut (2010) used mixed gain/loss gambles to investigate affect and regret in risky decision-making by revealing the outcome of chosen gambles on some trials and the outcomes of both gambles on others. Emotion ratings from “extremely sad” to “extremely happy” were collected following outcomes. Surprisingly, no group differences in EV-related choice emerged between SZ and controls, nor differences in emotion responses. However, a lack of regretful feelings was found in a small subset ($n = 7$) of SZ subjects with higher positive symptoms. These findings suggest that decision-making in some subjects with SZ may be associated with a lack of regret, or affective appraisal of outcomes, a phenomenon that may be more aptly related to positive symptomatology or similar to deficits found in subjects with orbitofrontal lesions. Larquet and colleagues’ SZ group mean IQ was a full standard deviation below average ($m = 80.6$, $SD = 16.2$) making the non-significant between-group results curious given that clinical subjects’ IQ has positively correlated with performance in other tasks. However, these results are difficult to further contextualize as the control subject (medical staff and students) IQs were not assessed. No correlations were found between regret and symptoms or cognitive functioning.

3.2. Ambiguous risk tasks

Ambiguous decision-making in psychosis-spectrum disorders is the least-investigated category of risky decision-making covered in this review, with only three published works investigating it using similar tasks with minor, unique features. Differences between risk and ambiguity have been investigated by either fully or partially concealing the probabilities of ambiguous gambles (Becker & Brownson, 1964; Rode, Cosmides, Hell, & Tooby, 1999). Using mixed gambles with gains,

losses, and null outcomes, Heerey et al. (2008) found that chronic SZ was not associated with a difference in the impact of complete ambiguity (i.e. fully concealed) on risky decisions. Using a different design with either 25%, 50%, or 75% concealment of gain or null outcome gambles compared to gambles with displayed probabilities, Fujino et al. (2016) found ambiguous gambles were chosen more frequently in SZ, but this effect was not associated with percentage of concealment. Ambiguity has also been investigated along the psychosis-spectrum, with subjects given gambles for a gain or null outcome at similar percentages, or an alternative safe option guaranteeing \$5 (Baker et al., 2019). No differences in task performance due to ambiguity were reported. Null findings (Heerey 2007; Baker 2019) may suggest that when gamble probabilities are concealed (i.e. task information is limited), subjects with chronic SZ, and psychosis more broadly, are no more risk-seeking nor risk-averse than controls. However, due to the findings of Fujino et al. (2016), and the paucity of literature, further research into ambiguity processing in psychosis-spectrum disorders is warranted. Currently there is insufficient evidence to draw conclusions regarding risk imperception during risk-ambiguous decision-making in psychosis-spectrum disorders. No correlations between risky ambiguous decision-making and clinical measures or cognitive functioning have been found.

3.3. Uncertain risk tasks

Behavior on uncertain risk tasks, which require learning over trials, has consistently been described as more risk averse. However, findings may be caused or impacted by several alternative processes in psychosis. Only two tasks have been used to investigate uncertain risk-taking, the balloon analogue risk task (BART) and risky gains task (RGT).

3.3.1. Balloon Analogue Risk Task (BART)

The BART is an uncertain risk task, originally described as a measure of “actual risky behavior for which...riskiness is rewarded up until a point at which further riskiness results in poorer outcomes” (Lejuez et al., 2002). In each trial, subjects decide between inflating a virtual balloon to increase its value, or “cashing-out” to collect the amount of money the balloon is worth. Each inflation causes the balloon to expand as monetary amounts are added. At an unknown threshold, the balloon explodes, rendering it null. Trials end when the balloon either explodes or is cashed-out. The BART offers a measure of risk-taking that relies upon learning explosion probability across trials and the relative value of potential gains: evaluating null outcome avoidance without the more explicit, mathematical calculation of EV. The gold standard measure of risk-taking is the number of inflations on unexploded balloons (i.e. adjusted pumps), indexing the point at which subjects voluntarily forego greater potential reward presumably due to risk sensitivity.

Poorer performance, with fewer adjusted pumps, fewer explosions, and occasionally, less money earned has been found in psychosis (Boka et al., 2020; Brown et al., 2015; Cheng, Tang, Li, Lau, & Lee, 2012; Dominguez, 2011; Luk et al., 2019; Reddy et al., 2014; Tikász et al., 2019). Interestingly, subjects with psychosis and cannabis dependence or present/history of cocaine use take more advantageous risks than psychotic-disorder-only groups, similar to controls⁷ (Duva, Silverstein, & Spiga, 2011; Fischer et al., 2015). Findings in psychosis indicate preferences for smaller, certain rewards over greater, uncertain rewards. While this may suggest that risk attitude is altered, it could also be a downstream consequence of risk imperceptivity (i.e. risk avoidance due to inability to learn and weigh uncertain outcome probabilities). However, other constructs may impact or contribute to performance. For example, greater anhedonia or avolition in SZ is associated with less willingness to inflate virtual balloons for greater reward in a different

⁷ Interestingly, SZ subjects with comorbid cocaine dependence exhibited greater risk aversion on the 8-trial, Sabater-G.-Georgantzis lottery panel task compared to controls (Sabater-Grande et al., 2020).

effort task (Gold et al., 2013; Strauss et al., 2016). Further investigation is warranted, as the BART has several idiosyncratic features that may make it hard to generalize to other risk-taking tasks (Steiner & Frey, 2021), and performance may be compounded by parallel processes such as reward anticipation, motivation, effort, or defeatist performance beliefs (Gard et al., 2014; Gold et al., 2013; Reddy et al., 2018). While not a solution for inherent task-design elements, computational modeling may help parse the relative contributions of such processes (Lasagna et al., 2021).

No investigations utilizing the BART have matched groups on cognitive functioning, with psychosis groups all exhibiting lower average scores of at least 10-points (t-scores). Some studies did not measure or report cognitive scores, and no studies covaried for IQ. Correlations between IQ and performance are mixed, with mostly null findings, but Luk et al. (2019) found correlations between a composite cognitive measure and adjusted pumps. The use of disparate cognitive or neuropsychological measures and failure to match groups further complicates our understanding of the relationship between BART performance and cognitive functioning. Various inconsistent correlations have been found between BART performance and psychosis symptomatology (Table 2).

3.3.2. Risky Gains Task (RGT)

The RGT evaluates uncertain risk-taking by offering choices between no-risk, low-risk, and high-risk choices (Paulus, Rogalsky, Simmons, Feinstein, & Stein, 2003). Each trial includes the choice between 20 points with 100% certainty or waiting for a subsequent gamble of 40 or – 40, followed by another optional gamble of 80 or – 80 points. Gamble outcome probabilities are unknown to subjects but occur such that there is no net difference between options (i.e. choosing one exclusively would yield the same final score as choosing another exclusively). Since each option has the same net value, the risk in this task is better described as sensitivity to the amounts of potential gains and losses. The RGT traditionally indexes “risk-taking” as choices relative to the preceding trial outcome (i.e., gain vs. loss), though the frequency of choosing +20, ±40, ±80 has also been investigated.

More uncertain, risky options were chosen less frequently in a combined group of hospitalized and not hospitalized SZ, and a group of FE subjects compared to controls (Cheng, Tang, Li, Lau, & Lee, 2012; Luk et al., 2019), interpreted as greater risk-aversion. However, SZ and FE subjects similarly choose safer options following losses, highlighting intact lose-shift behavior. This is an important feature as the lose-shift behavior in reinforcement learning in SZ is mixed (Reddy et al., 2016; Waltz, Frank, Wiecki, & Gold, 2011). Like the BART, these findings cannot be solely attributed to risk attitude and may be impacted by various processes such as risk imperception, reward processing, or motivation. Some correlations between task performance have been found with IQ (Luk et al., 2019) but neither study found any symptom correlations.

3.4. Endowment effects (mug selling task)

One commonly cited study of purported loss aversion in SZ is based upon the value placed on hypothetically selling or buying a mug. This study defined “loss aversion” as the group difference between median amounts of hypothetical money subjects were willing to pay for a mug and the price at which they would sell it (after pretending they owned it; Trémeau et al., 2008). This creative task is meant to mimic the real-world “endowment effect”, rather than loss aversion specifically related to risk-taking, or even broadly defined (Kahneman, Knetsch, & Thaler, 1990; Novemsky & Kahneman, 2005). This investigation deviated from the original research in several key ways, most notably by having subjects “imagine” owning a mug rather than actually endowing them with it. Additionally, results were found in “inpatients with chronic SZ”, and sell amounts correlated with age, duration of illness, and number of months spent hospitalized, suggesting more chronic

illness was associated with poorer performance. Differences in median buy/sell amounts did not correlate with clinical measures. Replicating these effects by literally endowing subjects with an object is required, as well as determining the impact of acute psychotic symptomatology or lack-there-of. While the findings of this study are interesting, the results likely do not generalize to risk-related loss aversion in SZ, as they require value estimation of an object, rather than avoiding choices with potential losses. Thus, the findings from this study should be specifically referenced as “endowment effects” to avoid conflation with the broader construct of loss aversion.

4. Exclusion of clinical subjects

It is standard practice within decision-making research to remove subjects who perform inconsistently with established task parameters based upon expectations for a “rational decision-maker”. These parameters are often established according to non-clinical data, and are presumably helpful in non-psychiatric samples to weed-out subjects who demonstrate poor attention, contradictory behavior, or lack of task engagement. Removing subjects based upon a “lack of model fit” or due to their position as outliers in the data occurred within several papers outlined in this review across seven tasks (n Mean = 8.43, Median = 9, Min = 1, Max = 17).

We caution against this approach to investigating decision-making in psychosis, as choices may be made for reasons that do not neatly fit within prescribed models. Exclusion may sacrifice subjects with particular symptomatology (e.g. odd beliefs, grandiosity, suspiciousness), that may underlie behaviors that seem irrational. As long as task instructions are understood and engagement is satisfactory, including such subjects will make our current model interpretations more nuanced. Alternatives include running analyses with and without subjects who meet thresholds or running secondary analyses that allow for the inclusion of all subjects. These approaches are vital, as findings have disappeared when additional analyses have compared full-samples, rather than a subset that met model-based standards (e.g. Hart et al., 2019).

5. Potential contributions of mathematical competence, strategy, and cognitive functioning

Before concluding that suboptimal behavior is attributable to risk-taking attitudes, it is essential to determine what precise psychological phenomena decision-making tasks are, and are not, quantifying. Subjects with psychotic disorders have exhibited poorer performance on neuropsychological measures of cognitive functioning but have demonstrated intact basic mathematical competency despite poorer working memory (Kiefer, Apel, & Weisbrod, 2002; Nuechterlein et al., 2004; Velthorst et al., 2021). Most of the tasks outlined in this review require integrating mathematical properties into an understanding of risk, such as outcome probabilities and EV, a point that warrants further consideration given that psychosis groups regularly exhibit poorer cognitive functioning. In non-clinical samples the GDT has shown differences in choices based on mathematical competency and reported use of mathematical calculation rather than intuition. Frequency of employing mathematical calculation has also correlated with executive functioning and logical intelligence (Brand et al., 2008, 2009; Pertl et al., 2017). Superior choices between mixed gambles have also been observed in college students with remedial statistics exposure (Schoemaker, 1979), but not in those given descriptions of EV calculation strategies (Lichtenstein, Slovic, & Zink, 1969; Montgomery & Adelbratt, 1982). Alternatively, BART performance has not been associated with mathematical competency nor math-specific anxiety (Buelow & Barnhart, 2017) but has been criticized over asymmetric feedback and uniform explosion probability distribution (Steiner & Frey, 2021). The role of mathematical calculation or computational strategies has not been investigated in the majority of risk-taking tasks nor has it been scrutinized in psychosis. This warrants further investigation in clinical and

non-clinical samples to pinpoint driving factors underlying suboptimal decision-making behavior across tasks.

Studies of risky decision-making in psychosis have largely reported cognitive functioning or IQ scores, but across-study comparison has been weakened by the use of disparate measurement tools, single-measure IQ estimates, and in the worst cases, not assessing IQ in control (or both) groups. Matching clinical and non-clinical groups on cognitive functioning has proven very task-specific, with groups matched in nearly all studies employing the CGT and most employing the GTD. The RGT and miscellaneous gambling tasks have not matched groups (exceptions are Baker et al., 2019; Fujino et al., 2016), despite findings showing cognitive measures have been associated with risk-taking behavior in psychosis (Albrecht et al., 2016; Benke et al., 2021; Brown et al., 2013; Hart et al., 2019; Luk et al., 2019; Martinelli et al., 2018b), and between group differences disappearing after accounting for working memory (Heerey et al., 2008; Martin et al., 2015). One study found that IQ determined by the WASI was moderately correlated with several model coefficients of EV utilization and bias for higher rewards during decision-making in SZ but not controls (Albrecht et al., 2016). No studies of the BART have matched subjects, but only Luk et al. (2019) found correlations between adjusted pumps and IQ in psychosis.

Due to the cognitively demanding nature of risky decision-making tasks, we encourage the use of tasks that make clear distinctions between risky/non-risky choices and rely less on definitions of risk that may be obfuscated by mathematical minutia. This is essential, as psychotic disorders have been associated with a general deficit across decision-making tasks (Sterzer et al., 2019; Fig. 1). This aim is to ensure that task performance better indexes purposeful risk-taking, rather than inability to discern risk (i.e. risk imperception) in psychosis. Though mathematical parameters operationalize risk, future work should translate risk beyond mere mathematical representations, making it an accessible experiential construct, perceivable regardless of cognitive functioning. Additionally, future research may benefit from better matching clinical and control groups on cognitive variables in service of identifying a unique, risk-related explanation for task performance (Green, Horan, & Sugar, 2013). However, such stringent matching may be over-matching, considered by some as throwing out the baby with the bathwater. Indeed, discourse on a general cognitive deficit in SZ or psychosis offers multiple perspectives on whether such deficits are intrinsic (Gold & Dickinson, 2013; Green et al., 2013; Schaefer, Giangrande, Weinberger, & Dickinson, 2013). An alternative solution may be including analyses evaluating contributions of, or associations with, measures of cognitive functioning. Relationships between risk-taking and cognitive measures could be carefully documented within clinical groups.

6. Associations with symptomatology and illness state

Associations between psychosis symptomatology, determined via self-reports and interviews, and risky decision-making task performance have not been consistently found, with some studies even showing conflicting findings (e.g. BPRS, Albrecht et al., 2016; Reddy et al., 2014; PANSS, Dominguez, 2011; Luk et al., 2019; Table 2). Inconclusive findings may reveal a lack of clinical relevance, or reflect a symptom-specific relationship not elucidated by broad or composite scales. For example, Baker et al. (2019) found associations that approached significance between both risk aversion and loss avoidance and delusions, but not other positive symptoms such as suspiciousness/persecution. Across-study comparisons are further complicated by disparate use of symptom measures and within-measure variation in subscale composition (Wallwork, Fortgang, Hashimoto, Weinberger, & Dickinson, 2012). For example, the Positive and Negative Syndrome Scale (PANSS) has four different factor structures utilized across the cited literature, making direct comparisons of “PANSS Positive Symptoms” difficult (Table 2; Emsley & RIS-INT-35 Early Psychosis Global Working Group, 2003; Kay, Fiszbein, & Opler, 1987; Lindenmayer, Grochowski, & Hyman, 1995;

Van den Oord et al., 2006).

Across these risk-taking tasks there is sparse, inconsistent support for existing theories of negative symptomatology (e.g. anhedonia, avolition) relating to poor EV utilization, decreased effort, or diminished reward-seeking (Albrecht et al., 2016; Benke et al., 2021; Brown et al., 2015), and positive symptomatology (e.g. delusional thought content, paranoia) relating to poor belief updating or greater risk-aversion (Dominguez, 2011; Luk et al., 2019; Pedersen, Göder, Tomczyk, & Ohrmann, 2017; Yu et al., 2017). Several studies included multiple measures of such symptomatology and found nothing, while others found only one association with behavior. Thus, risk-taking, within or across tasks, has not consistently been associated with psychosis symptomatology. This may be emblematic of our proposed general deficit underlying poorer decision-making, rather than the existence of symptom-related relationships.

Psychosis illness-state of subjects during experimentation is not clearly or consistently identified across the literature. While the majority of studies reported subjects as “stable”, this designation lacks clarity in observed symptomatology or phenomenology (e.g. “stabilized after an acute psychotic episode with moderate psychopathology scores”, “no changes in housing or hospitalization”, “not show any florid psychotic features”) as well as duration (e.g. “at the time of testing”, “one month”, “three months”). Most cited studies included outpatient subjects, with some recruiting inpatients (Benke et al., 2021; Pedersen et al., 2017; Zhang et al., 2015), or both inpatients and outpatients (Cheng et al., 2012; Li et al., 2021). Several studies did not include in or out-patient status of “stable” subjects (Hutton et al., 2002; Yu et al., 2017), though did report recruitment/referral sources (e.g. “community mental health centers”, “psychiatric hospital”, “physician referrals”; Brown et al., 2015; Larquet et al., 2010; Martin et al., 2015). Despite the differences in illness state across studies, no robust differences in task performance are noted across tasks.

7. Conclusions

Findings from behavioral risk-taking tasks in psychotic disorders have been interpreted in various ways, including greater risk-seeking, greater risk-aversion, comparable risk-taking, and insensitivity to risk. The present critique of the literature reinterprets these findings to assert that explicit risky decision-making in psychosis may be attributed to risk imperception, or less discrimination between choice riskiness. There is currently insufficient evidence to understand this pattern of behavior in ambiguous risk-taking due to few published works. Uncertain risk-taking is consistently described as more risk-averse, but this cannot be deduced due to other confounding processes that may impact decision-making (e.g. risk imperception, reward anticipation, motivation, effort, or defeatist performance beliefs). Thus, future research should test the risk imperception hypothesis directly across each category of risky decision-making in psychosis. Failure to optimize decisions due to aberrant integration of task information and context has been previously posited in select tasks (e.g. Brown et al., 2013; Heerey et al., 2008), but the present review asserts that this risk imperception is more broadly applicable.

Findings from tasks in which risky outcome probabilities are explicitly known, such as CGT and GDT, yield consistent results which may be interpreted as less differentiation between the risk of options in psychosis. Indiscriminate choice behavior is likely better attributed to risk imperception, rather than greater risk-seeking attitude. In the CGT, psychosis is associated with more frequently choosing less probabilistically rewarding options and less adjustment of wager based upon gamble probabilities. In the GDT, risk imperception in psychosis may contribute to more equally sampling among all four options, despite the lowest having very low EV.

Results from two-choice gambling tasks of risk-taking in SZ suggest an inability to properly integrate gamble amount and probability information to utilize EV of gamble choices. While this aligns with risk

imperception, findings are not consistent across all studies, and are sometimes only found in a subset of analyses, or not at all. Results have been explained by, or correlated with, cognitive functioning, suggesting some contribution or association. Formal loss aversion has not been found in any studies of purely financial risk-taking. Ambiguous gambling tasks find mixed results in preferences between risky and concealed gambles in psychosis. Due to an insufficient number of studies, it is currently unclear if risk-imperception is implicated in these tasks or even if there are any differences in choice behavior due to ambiguity.

Behavior on uncertain risk tasks (BART; RGT) may not currently be attributed to a single construct, such as risk imperception or risk attitude, due to the confounding factors of reward anticipation, reinforcement learning, motivation, or effort. These tasks require not only pursuing risk but learning from outcomes and taking cumulative risks for reward within trials to discern optimal risk-taking. However, if risk is not well perceived in psychosis, decreased ability to differentiate between high and low risk may cascade into disadvantageous decision-making. Thus, behavior on these tasks may not be due to risk-averse attitudes according to accurately assessed risk, but rather heavier weighing of less risky options due to inability to discern riskiness. This hypothesis requires further testing to parse the aforementioned parallel, or confounding, processes.

In summary, we hypothesize that risk imperception, defined as an inability to integrate task information and discriminate between the riskiness of choices, may impact risky decision-making behavioral task performance in psychotic disorders. Some researchers have suggested that risky decision-making on such tasks may scale-up to ecological behaviors such as substance use, acts of aggression, medication non-adherence, medical decision-making, or pathological gambling in psychosis. Such relationships and interpretations have not been born from empiricism, and should be tempered unless directly investigated (e.g. Dominguez, 2011). Our hypothesis of risk imperception is specific to experimental tasks, and thus it is unclear how those with psychosis perceive real-world risks. As this is an exciting new area for investigation, we encourage scientists to consider the hundreds of little risks we weigh consistently; Can I catch the bus if I sleep five more minutes? Is this joke appropriate to tell? Should I smoke another cigarette? If people with psychosis demonstrate imperception while processing everyday risks, it may prove to be a novel therapeutic target.

8. Limitations

There are caveats or limitations to the current work, which we hope are reconciled in future research. Firstly, the proposed risk imperception hypothesis is descriptive; gleaned theoretically from interpreting the current findings, but without direct empirical demonstration. Currently used tasks and analyses cannot adequately parse risk-imperception from other constructs. We hope that this review lays the groundwork of theory that precedes practice. Future research should empirically test this hypothesis by parsing risk-perception from risk-attitude. This may be done in several ways, including directly asking subjects about perceived risk or designing experiments that isolate specific parameters to disambiguate these constructs. Self-report measures have already tapped into this by eliciting perceptions, benefits, and likelihoods of engaging in risk-taking (e.g. Blais & Weber, 2006). Secondly, while the current review qualitatively bares differences across the literature (Tables 1 and 2) to invite nuanced reflection on features of task design, participant recruitment/inclusion, symptom measures, and cognitive assessments, the field would additionally benefit from an integrated, quantitative investigation across the literature. To this end, a meta-analytic approach could measure the effect sizes of these phenomenon across studies, quantify associations with cognitive/ symptom measures, and integrate unpublished data.

Consent for publication

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Authors contributions

JRP, ENH, & JM conducted literature search. JRP wrote manuscript draft and produced revisions with substantial contributions and feedback from all authors. JRP created figures and tables, which were confirmed for accuracy by ENH and JM.

Declaration of Competing Interest

The authors declare no conflicts of interest with respect to the authorship or the publication of this article.

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References

- Albrecht, M. A., Waltz, J. A., Frank, M. J., & Gold, J. M. (2016). Probability and magnitude evaluation in schizophrenia. *Schizophrenia Research: Cognition*, 5, 41–46.
- Baker, S. C., Konova, A. B., Daw, N. D., & Horga, G. (2019). A distinct inferential mechanism for delusions in schizophrenia. *Brain*, 142(6), 1797–1812.
- Barch, D. M., Carter, C. S., Gold, J. M., Johnson, S. L., Krings, A. M., MacDonald, A. W., III, Strauss, M. E., ... (2017). Explicit and implicit reinforcement learning across the psychosis spectrum. *Journal of Abnormal Psychology*, 126(5), 694.
- Barron, G., & Erev, I. (2003). Small feedback-based decisions and their limited correspondence to description-based decisions. *Journal of Behavioral Decision Making*, 16(3), 215–233.
- Bechara, A., Damasio, H., & Damasio, A. R. (2000). Emotion, decision making and the orbitofrontal cortex. *Cerebral Cortex*, 10(3), 295–307.
- Becker, S. W., & Brownson, F. O. (1964). What price ambiguity? Or the role of ambiguity in decision-making. *Journal of Political Economy*, 72(1), 62–73.
- Benke, T., Marksteiner, J., Ruepp, B., Weiss, E. M., & Zamarian, L. (2021). Decision making under risk in patients suffering from schizophrenia or depression. *Brain Sciences*, 11(9), 1178.
- Betz, L. T., Brambilla, P., Ilankovic, A., Premkumar, P., Kim, M. S., Raffard, S., Kambeitz, J., ... (2019). Deciphering reward-based decision-making in schizophrenia: A meta-analysis and behavioral modeling of the Iowa gambling task. *Schizophrenia Research*, 204, 7–15.
- Blais, A. R., & Weber, E. U. (2006). A domain-specific risk-taking (DOSPERT) scale for adult populations. *Judgment and Decision making*, 1(1).
- Boka, E., Del Pozzo, J., Goetz, D., Remsen, B., Walsh-Messinger, J., Getz, M., Malaspina, D., ... (2020). Ineffective risk-reward learning in schizophrenia. *Psychiatry Research*, 293, Article 113370.
- Brand, M., Fujiwara, E., Borsutzky, S., Kalbe, E., Kessler, J., & Markowitsch, H. J. (2005). Decision-making deficits of korsakoff patients in a new gambling task with explicit rules: Associations with executive functions. *Neuropsychology*, 19(3), 267.
- Brand, M., Heinze, K., Labudda, K., & Markowitsch, H. J. (2008). The role of strategies in deciding advantageously in ambiguous and risky situations. *Cognitive Processing*, 9(3), 159–173.
- Brand, M., Laier, C., Pawlikowski, M., & Markowitsch, H. J. (2009). Decision making with and without feedback: The role of intelligence, strategies, executive functions, and cognitive styles. *Journal of Clinical and Experimental Neuropsychology*, 31(8), 984–998.
- Bronstein, M. V., Pennycook, G., Joormann, J., Corlett, P. R., & Cannon, T. D. (2019). Dual-process theory, conflict processing, and delusional belief. *Clinical Psychology Review*, 72, Article 101748.
- Brown, J. K., Waltz, J. A., Strauss, G. P., McMahon, R. P., Frank, M. J., & Gold, J. M. (2013). Hypothetical decision making in schizophrenia: The role of expected value computation and “irrational” biases. *Psychiatry Research*, 209(2), 142–149.

- Brown, E. C., Hack, S. M., Gold, J. M., Carpenter, W. T., Jr., Fischer, B. A., Prentice, K. P., & Waltz, J. A. (2015). Integrating frequency and magnitude information in decision-making in schizophrenia: An account of patient performance on the Iowa gambling task. *Journal of Psychiatric Research*, 66, 16–23.
- Buelow, M. T., & Barnhart, W. R. (2017). The influence of math anxiety, math performance, worry, and test anxiety on the Iowa gambling task and balloon analogue risk task. *Assessment*, 24(1), 127–137.
- Cathomas, F., Klaus, F., Guetter, K., Chung, H. K., Beharelle, A. R., Spiller, T. R., & Kaiser, S. (2021). Increased random exploration in schizophrenia is associated with inflammation. *npj Schizophrenia*, 7(1), 1–9.
- Charness, G., Gneezy, U., & Halladay, B. (2016). Experimental methods: Pay one or pay all. *Journal of Economic Behavior & Organization*, 131, 141–150.
- Cheng, G. L., Tang, J. C., Li, F. W., Lau, E. Y., & Lee, T. M. (2012). Schizophrenia and risk-taking: Impaired reward but preserved punishment processing. *Schizophrenia Research*, 136(1–3), 122–127.
- Culbreth, A. J., Moran, E. K., & Barch, D. M. (2018). Effort-based decision-making in schizophrenia. *Current Opinion in Behavioral Sciences*, 22, 1–6.
- Currie, J., Buruju, D., Perrin, J. S., Reid, I. C., Steele, J. D., & Feltoch, N. (2017). Schizophrenia illness severity is associated with reduced loss aversion. *Brain Research*, 1664, 9–16.
- De Groot, K., & Thuri, R. (2018). Disentangling risk and uncertainty: When risk-taking measures are not about risk. *Frontiers in Psychology*, 9, 2194.
- Deserno, L., Schlagenhauf, F., & Heinz, A. (2016). Striatal dopamine, reward, and decision making in schizophrenia. *Dialogues in Clinical Neuroscience*, 18(1), 77.
- Dominguez, G. B. (2011). *The Relationship between Risk-Taking, Substance Abuse and Aggression in Schizophrenia*. Doctoral dissertation, Barnard College.
- Duva, S. M., Silverstein, S. M., & Spiga, R. (2011). Impulsivity and risk-taking in co-occurring psychotic disorders and substance abuse. *Psychiatry Research*, 186(2–3), 351–355.
- Emsley, R., Rabinowitz, & RIS-INT-35 Early Psychosis Global Working Group. (2003). The factor structure for the positive and negative syndrome scale (PANSS) in recent-onset psychosis. *Schizophrenia Research*, 61(1), 47–57.
- Fervaha, G., Agid, O., Fousias, G., & Remington, G. (2013). Impairments in both reward and punishment guided reinforcement learning in schizophrenia. *Schizophrenia Research*, 150(2–3), 592–593.
- Fischer, B. A., McMahon, R. P., Kelly, D. L., Wehring, H. J., Meyer, W. A., Feldman, S., Goretlick, D. A., ... (2015). Risk-taking in schizophrenia and controls with and without cannabis dependence. *Schizophrenia Research*, 161(2–3), 471–477.
- Fond, G., Bayard, S., Capdevielle, D., Del-Monte, J., Mimoun, N., Macgregor, A., Raffard, S., ... (2013). A further evaluation of decision-making under risk and under ambiguity in schizophrenia. *European Archives of Psychiatry and Clinical Neuroscience*, 263(3), 249–257.
- Fujino, J., Hirose, K., Tei, S., Kawada, R., Tsurumi, K., Matsukawa, N., Aso, T., ... (2016). Ambiguity aversion in schizophrenia: An fMRI study of decision-making under risk and ambiguity. *Schizophrenia Research*, 178(1–3), 94–101.
- Fukunaga, R., Purcell, J. R., & Brown, J. W. (2018). Discriminating formal representations of risk in anterior cingulate cortex and inferior frontal gyrus. *Frontiers in Neuroscience*, 12, 553.
- Gard, D. E., Sanchez, A. H., Cooper, K., Fisher, M., Garrett, C., & Vinogradov, S. (2014). Do people with schizophrenia have difficulty anticipating pleasure, engaging in effortful behavior, or both? *Journal of Abnormal Psychology*, 123(4), 771.
- Garety, P. A., Bebbington, P., Fowler, D., Freeman, D., & Kuipers, E. (2007). Implications for neurobiological research of cognitive models of psychosis: A theoretical paper. *Psychological Medicine*, 37(10), 1377.
- Gold, J. M., & Dickinson, D. (2013). “Generalized cognitive deficit” in schizophrenia: Overused or underappreciated? *Schizophrenia Bulletin*, 39(2), 263–265.
- Gold, J. M., Waltz, J. A., Prentice, K. J., Morris, S. E., & Heerey, E. A. (2008). Reward processing in schizophrenia: A deficit in the representation of value. *Schizophrenia Bulletin*, 34(5), 835–847.
- Gold, J. M., Strauss, G. P., Waltz, J. A., Robinson, B. M., Brown, J. K., & Frank, M. J. (2013). Negative symptoms of schizophrenia are associated with abnormal effort-cost computations. *Biological Psychiatry*, 74(2), 130–136.
- Green, M. F., Horan, W. P., & Sugar, C. A. (2013). Has the generalized deficit become the generalized criticism? *Schizophrenia Bulletin*, 39(2), 257–262.
- Hart, K. L., Brown, H. E., Roffman, J. L., & Perlis, R. H. (2019). Risk tolerance measured by probability discounting among individuals with primary mood and psychotic disorders. *Neuropsychology*, 33(3), 417.
- Heerey, E. A., Bell-Warren, K. R., & Gold, J. M. (2008). Decision-making impairments in the context of intact reward sensitivity in schizophrenia. *Biological Psychiatry*, 64(1), 62–69.
- Hellman, S. G., Kern, R. S., Neilson, L. M., & Green, M. F. (1998). Monetary reinforcement and Wisconsin card sorting performance in schizophrenia: Why show me the money? *Schizophrenia Research*, 34(1–2), 67–75.
- Hemager, N., Jepsen, J. R. M., Thorup, A., Christiansi, C., Ellersgaard, D., Spang, K. S., Plessen, K. J., ... (2021). Decision making and its associations to neurocognitive functions, psychopathology, and the home environment in seven-year-old children at familial high risk of schizophrenia or bipolar disorder: The Danish high risk and resilience study VIA 7. *Journal of Affective Disorders*, 281, 609–617.
- Herrnstein, R. J. (1970). On the law of effect 1. *Journal of the Experimental Analysis of Behavior*, 13(2), 243–266.
- Horan, W. P., Johnson, M. W., & Green, M. F. (2017). Altered experiential, but not hypothetical, delay discounting in schizophrenia. *Journal of Abnormal Psychology*, 126(3), 301.
- Hutton, S. B., Murphy, F. C., Joyce, E. M., Rogers, R. D., Cuthbert, I., Barnes, T. R. E., Robbins, T. W., ... (2002). Decision making deficits in patients with first-episode and chronic schizophrenia. *Schizophrenia Research*, 55(3), 249–257.
- Kahneman, D., & Tversky, A. (2013). Choices, values, and frames. In *Handbook of the fundamentals of financial decision making: Part I* (pp. 269–278).
- Kahneman, D., Knetsch, J. L., & Thaler, R. H. (1990). Experimental tests of the endowment effect and the coase theorem. *Journal of Political Economy*, 98(6), 1325–1348.
- Kay, S. R., Fiszbein, A., & Opler, L. A. (1987). The positive and negative syndrome scale (PANSS) for schizophrenia. *Schizophrenia Bulletin*, 13(2), 261.
- Kiefer, M., Apel, A., & Weisbrod, M. (2002). Arithmetic fact retrieval and working memory in schizophrenia. *Schizophrenia Research*, 53(3), 219–227.
- Kılıç, A., Van Tilburg, W. A., & Igou, E. R. (2020). Risk-taking increases under boredom. *Journal of Behavioral Decision Making*, 33(3), 257–269.
- Klaus, F., Chumbley, J. R., Seifritz, E., Kaiser, S., & Hartmann-Riemer, M. (2020). Loss aversion and risk aversion in non-clinical negative symptoms and hypomania. *Frontiers in Psychiatry*, 11.
- Larquet, M., Coricelli, G., Opolczynski, G., & Thibaut, F. (2010). Impaired decision making in schizophrenia and orbitofrontal cortex lesion patients. *Schizophrenia Research*, 116(2–3), 266–273.
- Lasagna, C. A., Pleskac, T. J., Burton, C., McInnis, M. G., Taylor, S. F., & Tso, I. F. (2021). *Mathematical modeling of risk-taking in bipolar disorder: Reductions in behavioral consistency and substance use history-specific alterations to loss aversion*. <https://doi.org/10.31234/osf.io/287sq>. PsyArXiv.
- Lee, J., & Park, S. (2005). Working memory impairments in schizophrenia: A meta-analysis. *Journal of Abnormal Psychology*, 114(4), 599.
- Lee, Y., Kim, Y. T., Seo, E., Park, O., Jeong, S. H., Kim, S. H., & Lee, S. J. (2007). Dissociation of emotional decision-making from cognitive decision-making in chronic schizophrenia. *Psychiatry Research*, 152(2–3), 113–120.
- Lejuez, C. W., Read, J. P., Kahler, C. W., Richards, J. B., Ramsey, S. E., Stuart, G. L., & Brown, R. A. (2002). Evaluation of a behavioral measure of risk taking: The Balloon Analogue Risk Task (BART). *Journal of Experimental Psychology: Applied*, 8(2), 75.
- Li, Z., Shi, Y. F., Parker, G. J., Huang, J., Yan, C., Lui, S. S., Chan, R. C., ... (2016). Devaluation of rewards for the future is associated with schizotypal personality features. *Australian Psychologist*, 51(6), 481–489.
- Li, D., Zhang, F., Wang, L., Zhang, Y., Yang, T., Wang, K., & Zhu, C. (2021). Decision making under ambiguity and risk in adolescent-onset schizophrenia. *BMC Psychiatry*, 21(1), 1–11.
- Lichtenstein, S., Slovic, P., & Zink, D. (1969). Effect of instruction in expected value on optimality of gambling decisions. *Journal of Experimental Psychology*, 79(2p1), 236.
- Lindenmayer, J. P., Grochowski, S., & Hyman, R. B. (1995). Five factor model of schizophrenia: Replication across samples. *Schizophrenia Research*, 14(3), 229–234.
- Luk, M. S. K., Chang, W. C., Chong, C. S. Y., Siu, C. M. W., Chan, S. K. W., Lee, E. M. H., Chen, E. Y. H., ... (2019). Altered risky decision making in patients with early non-affective psychosis. *European Archives of Psychiatry and Clinical Neuroscience*, 1–9.
- MacDonald, A. W., III (2014). Differential deficit. *The Encyclopedia of Clinical Psychology*, 1–5.
- MacKenzie, L. E., Patterson, V. C., Zwicker, A., Drobinin, V., Fisher, H. L., Abidi, S., Uher, R., ... (2017). Hot and cold executive functions in youth with psychotic symptoms. *Psychological Medicine*, 47(16), 2844–2853.
- Martin, A. K., Mowry, B., Reutens, D., & Robinson, G. A. (2015). Executive functioning in schizophrenia: Unique and shared variance with measures of fluid intelligence. *Brain and Cognition*, 99, 57–67.
- Martinelli, C., Rigoli, F., Averbach, B., & Shergill, S. S. (2018a). The value of novelty in schizophrenia. *Schizophrenia Research*, 192, 287–293.
- Martinelli, C., Rigoli, F., Dolan, R. J., & Shergill, S. S. (2018b). Decreased value sensitivity in schizophrenia. *Psychiatry Research*, 259, 295–301.
- Montgomery, H., & Adelbratt, T. (1982). Gambling decisions and information about expected value. *Organizational Behavior and Human Performance*, 29(1), 39–57.
- Moritz, S., Scheunemann, J., Lüdtke, T., Westermann, S., Pfuhl, G., Balzan, R. P., & Andreou, C. (2020). Prolonged rather than hasty decision-making in schizophrenia using the box task. Must we rethink the jumping to conclusions account of paranoia? *Schizophrenia Research*, 222, 202–208.
- Mousavi, S., & Gigerenzer, G. (2014). Risk, uncertainty, and heuristics. *Journal of Business Research*, 67(8), 1671–1678.
- Novemsky, N., & Kahneman, D. (2005). The boundaries of loss aversion. *Journal of Marketing Research*, 42(2), 119–128.
- Nuechterlein, K. H., Barch, D. M., Gold, J. M., Goldberg, T. E., Green, M. F., & Heaton, R. K. (2004). Identification of separable cognitive factors in schizophrenia. *Schizophrenia Research*, 72(1), 29–39.
- Paulus, M. P., Rogalsky, C., Simmons, A., Feinstein, J. S., & Stein, M. B. (2003). Increased activation in the right insula during risk-taking decision making is related to harm avoidance and neuroticism. *NeuroImage*, 19(4), 1439–1448.
- Pedersen, A., Göder, R., Tomczyk, S., & Ohmann, P. (2017). Risky decision-making under risk in schizophrenia: A deliberate choice? *Journal of Behavior Therapy and Experimental Psychiatry*, 56, 57–64.
- Pertl, M. T., Zamarian, L., & Delazer, M. (2017). Reasoning and mathematical skills contribute to normatively superior decision making under risk: Evidence from the game of dice task. *Cognitive Processing*, 18(3), 249–260.
- Pleskac, T. J. (2008). Decision making and learning while taking sequential risks. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 34(1), 167.
- Pratt, D. N., Barch, D. M., Carter, C. S., Gold, J. M., Ragland, J. D., Silverstein, S. M., & MacDonald, A. W. (2020). Reliability and replicability of implicit and explicit reinforcement learning paradigms in people with psychotic disorders. *Schizophrenia Bulletin*, 47(3), 731–739.
- Reddy, L. F., Lee, J., Davis, M. C., Altschuler, L., Glahn, D. C., Miklowitz, D. J., & Green, M. F. (2014). Impulsivity and risk taking in bipolar disorder and schizophrenia. *Neuropsychopharmacology*, 39(2), 456–463.

- Reddy, L. F., Waltz, J. A., Green, M. F., Wynn, J. K., & Horan, W. P. (2016). Probabilistic reversal learning in schizophrenia: Stability of deficits and potential causal mechanisms. *Schizophrenia Bulletin*, 42(4), 942–951.
- Reddy, L. F., Horan, W. P., Barch, D. M., Buchanan, R. W., Gold, J. M., Marder, S. R., Green, M. F., ... (2018). Understanding the association between negative symptoms and performance on effort-based decision-making tasks: The importance of defeatist performance beliefs. *Schizophrenia Bulletin*, 44(6), 1217–1226.
- Robson, S. E., Repetto, L., Gountouna, V. E., & Nicodemus, K. K. (2020). A review of neuroeconomic gameplay in psychiatric disorders. *Molecular Psychiatry*, 25(1), 67–81.
- Rode, C., Cosmides, L., Hell, W., & Tooby, J. (1999). When and why do people avoid unknown probabilities in decisions under uncertainty? Testing some predictions from optimal foraging theory. *Cognition*, 72(3), 269–304.
- Runyon, M., & Buelow, M. T. (2019). Risky decision-making and delusion proneness: An initial examination. *Heliyon*, 5(11), Article e02767.
- Sabater-Grande, G., Haro, G., García-Gallego, A., Georgantzis, N., Herranz-Zaroso, N., & Baquero, A. (2020). Risk-taking and fairness among cocaine-dependent patients in dual diagnoses: Schizophrenia and anti-social personality disorder. *Scientific Reports*, 10(1), 1–13.
- Schaefer, J., Giangrande, E., Weinberger, D. R., & Dickinson, D. (2013). The global cognitive impairment in schizophrenia: Consistent over decades and around the world. *Schizophrenia Research*, 150(1), 42–50.
- Schmidt, B., & Hewig, J. (2015). Paying out one or all trials: A behavioral economic evaluation of payment methods in a prototypical risky decision study. *The Psychological Record*, 65(2), 245–250.
- Schmidt, B., Keßler, L., Hecht, H., Hewig, J., Holroyd, C. B., & Miltner, W. H. (2019). What you give is what you get: Payment of one randomly selected trial induces risk-aversion and decreases brain responses to monetary feedback. *Cognitive, Affective, & Behavioral Neuroscience*, 19(1), 187–196.
- Schoemaker, P. J. (1979). The role of statistical knowledge in gambling decisions: Moment vs risk dimension approaches. *Organizational Behavior and Human Performance*, 24(1), 1–17.
- Schonberg, T., Fox, C. R., & Poldrack, R. A. (2011). Mind the gap: bridging economic and naturalistic risk-taking with cognitive neuroscience. *Trends in Cognitive Sciences*, 15(1), 11–19.
- Schürmann, O., Frey, R., & Pleskac, T. J. (2019). Mapping risk perceptions in dynamic risk-taking environments. *Journal of Behavioral Decision Making*, 32(1), 94–105.
- Sjöberg, L. (2000). The methodology of risk perception research. *Quality and Quantity*, 34(4), 407–418.
- Slovic, P., & Lichtenstein, S. (1968). Importance of variance preferences in gambling decisions. *Journal of Experimental Psychology*, 78(4p1), 646.
- Steiner, M. D., & Frey, R. (2021). Representative design in psychological assessment: A case study using the balloon analogue risk task (BART). *Journal of Experimental Psychology: General*, Advance Online Publication. <https://doi.org/10.1037/xge0001036>
- Sterzer, P., Adams, R. A., Fletcher, P., Frith, C., Lawrie, S. M., Muckli, L., Corlett, P. R., ... (2018). The predictive coding account of psychosis. *Biological Psychiatry*, 84(9), 634–643.
- Sterzer, P., Voss, M., Schlagenhauf, F., & Heinz, A. (2019). Decision-making in schizophrenia: A predictive-coding perspective. *NeuroImage*, 190, 133–143.
- Strauss, G. P., Whearty, K. M., Morra, L. F., Sullivan, S. K., Ossenfort, K. L., & Frost, K. H. (2016). Avolition in schizophrenia is associated with reduced willingness to expend effort for reward on a progressive ratio task. *Schizophrenia Research*, 170(1), 198–204.
- Tikász, A., Dumais, A., Lipp, O., Stip, E., Lalonde, P., Laurelli, M., Potvin, S., ... (2019). Reward-related decision-making in schizophrenia: A multimodal neuroimaging study. *Psychiatry Research: Neuroimaging*, 286, 45–52.
- Tom, S. M., Fox, C. R., & Poldrack, R. A. (2007). The Neural Basis of Loss Aversion in Decision-Making Under Risk. *Science*, 315(5811), 515–518.
- Trémeau, F., Brady, M., Saccente, E., Moreno, A., Epstein, H., Citrome, L., Javitt, D., ... (2008). Loss aversion in schizophrenia. *Schizophrenia Research*, 103(1–3), 121–128.
- Tripoli, G., Quattrone, D., Ferraro, L., Gayer-Anderson, C., Rodriguez, V., La Cascia, C., & Di Forti, M. (2020). Jumping to conclusions, general intelligence, and psychosis liability: findings from the multi-centre EU-GEI case-control study. *Psychological Medicine*, 1–11.
- Tversky, A., & Kahneman, D. (1992). Advances in prospect theory: Cumulative representation of uncertainty. *Journal of Risk and Uncertainty*, 5(4), 297–323.
- Van den Oord, E. J., Rujescu, D., Robles, J. R., Giegling, I., Birrell, C., Bukszár, J., Muglia, P., ... (2006). Factor structure and external validity of the PANSS revisited. *Schizophrenia Research*, 82(2–3), 213–223.
- Velthorst, E., Mollon, J., Murray, R. M., de Haan, L., Ghermeys, I. M., Glahn, D. C., Reichenberg, A., ... (2021). Cognitive functioning throughout adulthood and illness stages in individuals with psychotic disorders and their unaffected siblings. *Molecular Psychiatry*, 1–15.
- Wallwork, R. S., Fortgang, R., Hashimoto, R., Weinberger, D. R., & Dickinson, D. (2012). Searching for a consensus five-factor model of the positive and negative syndrome scale for schizophrenia. *Schizophrenia Research*, 137(1–3), 246–250.
- Waltz, J. A., Frank, M. J., Robinson, B. M., & Gold, J. M. (2007). Selective reinforcement learning deficits in schizophrenia support predictions from computational models of striatal-cortical dysfunction. *Biological Psychiatry*, 62(7), 756–764.
- Waltz, J. A., Frank, M. J., Wiecki, T. V., & Gold, J. M. (2011). Altered probabilistic learning and response biases in schizophrenia: Behavioral evidence and neurocomputational modeling. *Neuropsychology*, 25(1), 86.
- Weber, E. U. (2010). Risk attitude and preference. *Wiley Interdisciplinary Reviews: Cognitive Science*, 1(1), 79–88.
- Weber, E. U., & Milliman, R. A. (1997). Perceived risk attitudes: Relating risk perception to risky choice. *Management Science*, 43(2), 123–144.
- Xu, S., Wang, H., & Wang, C. (2020). Paying out one versus paying out all trials and the decrease in behavioral and brain activity in the balloon analogue risk task. *Psychophysiology*, 57(3), Article e13510.
- Yakobi, O., & Danckert, J. (2021). Boredom proneness is associated with noisy decision-making, not risk-taking. *Experimental Brain Research*, 1–19.
- Yu, L. Q., Lee, S., Katchmar, N., Satterthwaite, T. D., Kable, J. W., & Wolf, D. H. (2017). Steeper discounting of delayed rewards in schizophrenia but not first-degree relatives. *Psychiatry Research*, 252, 303–309.
- Zhang, L., Tang, J., Dong, Y., Ji, Y., Tao, R., Liang, Z., Wang, K., ... (2015). Similarities and differences in decision-making impairments between autism spectrum disorder and schizophrenia. *Frontiers in Behavioral Neuroscience*, 9, 259.