Erroneous gambling-related beliefs emerge from broader beliefs during problem-solving: A critical review and classification scheme

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Abstract

Erroneous gambling-related beliefs (EGRBs) can be defined as beliefs that imply a failure to recognise how commercial gambling activities are designed to generate a guaranteed loss to players. In theorising about how EGRBs develop, previous reviews have proposed that EGRBs are extensions of decision-making heuristics and associated biases. We propose an alternative generative mechanism: one in which gambling games make substantial wins seem possible through problem-solving and eventual correct strategic action. EGRBs are then beliefs in the possibility of correct strategic action (illusion of control) that develop as players trial candidate strategies – strategies selected based on various broader beliefs. We further propose that EGRBs can be classified based on what is theorised in cognitive science about categories of general human beliefs about the world. For example, it has been theorised that human beliefs about supernatural forces and randomness have certain similarities across cultures, and so we propose that there exists a category of supernatural EGRBs, as well as a category of EGRBs based on broader beliefs about the nature of randomness. We review evidence for this classification scheme and discuss how it can be applied in researching and treating gambling disorder.

Keywords

illusion of control; gambler’s fallacy; luck; problem-solving; gambling disorder

Commercial gambling activities, such as slot machine gambling, Blackjack, and sports-betting, are designed to generate random or highly uncertain outcomes with a guaranteed long-term loss for the player. The player's loss translates into a profit for the gambling provider – or "the house". Thoughts and verbal statements implying a misunderstanding of the systems in place for creating this profit can be termed erroneous gambling-related beliefs (EGRBs; Ladouceur et al., 2001). This paper presents a novel explanation for how EGRBs develop, describes a classification scheme for EGRBs that follows from the explanation, and discusses applications of the classification scheme in researching and treating gambling disorder. Existing explanations of EGRBs and associated classification schemes are premised on the idea that EGRBs map onto biases that stem from decision-making short-cuts (or "heuristics"), which provide fast, but not always accurate, solutions in gambling environments and beyond (Fortune & Goodie, 2012; Griffiths, 1994; Leonard, Williams, & Vokey, 2015; Toneatto, 1999; Toneatto et al., 1997; Wagenaar, 1988). The heuristics-and-biases conceptualisation of human decision-making has been challenged in the past two decades (Chase, Hertwig, & Gigerenzer, 1998; Gigerenzer, 1991, 1996; Gigerenzer & Gaissmaier, 2011; Oaksford & Chater, 2001; Osman, 2004). We propose instead that EGRBs are products of a problem-solving process – contemplated solutions to the problem of how to beat the house, generated based on background beliefs about the properties of supernatural forces, random sequences and business dynamics. In our view, classifying EGRBs involves identifying the general background-belief domain to which they relate.

We begin, in Section 1, by describing EGRBs in different kinds of gambling activities and across 40 studies. A substantial proportion of contributing studies were concerned with the illusion of control – a phenomenon that, we argue, can be considered an umbrella term for EGRBs. In Section 2, we present an explanation of EGRBs grounded in the notion of problem-solving informed by background beliefs. The section goes on to classify various EGRBs based on what is currently known in cognitive science about categories of background beliefs. Emerging psychometric evidence for the classification scheme is discussed, as are the scheme's implications for measuring EGRBs. Given that treatment programs for gambling disorder are often targeted at correcting EGRBs even though EGRBs are not mentioned in diagnostic criteria for gambling disorder, we dedicate Section 3 to discussing the implications of our classification scheme for researching and treating gambling disorder. Factors identified as contributing to the development of gambling disorder in the Diagnostic and Statistical Manual of Mental Disorders (DSM-5; American Psychiatric Association, 2013) include intermittent wins, trait impulsivity, and mood disorders that motivate persistent gambling as an escape route. We discuss the potential role of a theory-based EGRB classification scheme in research streams on each of these factors. With respect to the treatment of gambling disorder, one of our key arguments is that our scheme's implications for measuring EGRBs are points to consider in improving brief interventions, in which clients' levels of endorsement of various EGRBs are explicitly compared to average levels reported by the general population.

1 EGRBs across gambling activities: definition and examples

EGRBs can be defined as beliefs that imply a failure to recognise the mechanisms in place for guaranteeing a negative long-term return-to-player in commercial gambling activities. In this section, we flesh out this definition by describing how the negative winning expectancy is assured in different commercial gambling activities. We then present a comprehensive tabular summary of EGRBs documented since the 1960s across 40 studies. We also discuss the close parallels between EGRBs and the illusion of control – the phenomenon studied in over a quarter of the reviewed studies.

Mechanisms for guaranteeing negative long-term winning expectancies in gambling: overlooked in EGRBs

Like all gambling activities, commercial gambling involves betting money on the possibility of receiving a payout larger than the bet amount in the event of a highly uncertain outcome. Often, the game outcome is determined by a random outcome generator (ROG): namely, a lottery drawing, a card deck, a die, a roulette wheel, or a computer. The outcomes of ROGs are not predictable based on past outcomes or any other variable (e.g., Nickerson, 2002). An alternative to betting on the outcomes of an ROG is to bet on uncertain future events that depend on a very large number of variables, including the competitors' form, playing conditions, and many possible real-time match events (e.g., Reith, 2002). Gambling, therefore, involves both ROG-based games (i.e., slot machine gambling, roulette, Blackjack, Craps, poker, lotteries, and Bingo), also known as "gaming", and non-ROG-based games (i.e., betting on sports and animal racing), also known as "wagering" (Reith, 2002).

The negative return-to-player in both types of commercial gambling activities translates into a positive return (i.e., profit) for the house. To guarantee profit, the house offers payout amounts that are always less than the amount that would be fair given the probability of the staked-on outcome (Dow Schüll, 2014). In gaming, the outcome probabilities can be calculated based on game rules, and payout amounts for any possible bet can be fixed based on those calculations (although the system works differently in poker [1]). In gambling activities not based on an ROG – that is, in wagering on sports and animal racing – the probability of any particular outcome depends on a large number of variables, so, in most cases, the house determines outcome probabilities and payout rates using complex algorithms that combine data from extensive records of relevant variables. An exception is pari-mutuel betting, in which the house takes a proportion of the total amount bet by the pool of players before the close of betting (e.g., Griffith, 1949). A very small percentage of players can maintain a positive winning expectancy in this context, dedicating themselves fulltime to record-keeping and algorithm development (Walker, 1992, p. 20).

EGRBs can be defined as beliefs implying that it is possible to not be subject to the negative winning expectancy in commercial gambling; that is, to consistently beat the house. Ladouceur and colleagues (2001) define EGRBs as beliefs in winning "even in the face of negative odds" (p. 774).

Notably, it is not erroneous to believe that the negative winning expectancy can *in theory* be overturned in pari-mutuel sports- and race-betting (as well as poker; see Endnote 1). Moreover, it is not erroneous to believe that the negative winning expectancy can be *minimised* in many other gambling activities, including ROG-based games with complex rules – rules that some players become better than others in learning and applying (Bjerg, 2010; Dow Schüll, 2014). Similarly, in non-pari-mutuel sports- and race-betting, some players develop prediction algorithms that are more effective than algorithms developed by other players but inferior to those maintained by the house.

EGRBs documented across a range of studies

Table 1 describes EGRBs documented across 40 studies, using a range of methodologies: interviews, observation of real-world gambling behaviour, analysis of quantitative trends in real-world gambling behaviour, experimental research, and research using surveys of EGRBs (for a review of available EGRB surveys, see Goodie & Fortune, 2013 and Leonard, Williams, & Vokey, 2015). Broadly speaking, the table suggests that people might expect to beat the house through strategies for playing (e.g., Beliefs 1-3, 10-11) or through strategies for being a "good" person or performing the correct rituals so as to be rewarded with big wins by higher (supernatural) powers (e.g., Beliefs 4-9, 12-13). Notably, experiments provide objective evidence of strategy-use but are not always conclusive as to whether the evident strategies are intended to systematically beat the house or simply to minimise the house profit margin. Intentions can be investigated more directly through interviews and surveys.

The table also shows that, with the exception of Keren and Wagenaar's (1985) study of blackjack players (Beliefs 3, 7 and 8), Ohtsuka and Chan's (2010) study of mahjong players (Belief 6), and Lam's (2007) study of baccarat players (Belief 13), EGRBs in games where losses can be minimised through skill have lacked research attention. Surveys of EGRBs have been published as surveys applicable to all kinds of gambling activities, but their lack of recognition of the role of strategies in loss-minimisation in many games has been criticised (Leonard, Williams, & Vokey, 2015).

EGRBs and the illusion of control

The dozen-or-so studies documenting Belief 14 are demonstrations of a phenomenon that has come to be widely known as the “illusion of control”, and Beliefs 20 and 21 are survey statements labelled as tapping into the illusion. Uncovered in one of the studies cited in the footnotes to Table 1 (Langer, 1975), the illusion of control can be defined as the expectation that certain personal actions can be taken to increase the probability of ending a game of pure chance with a net win. Langer (1975) found that participants who had selected their own lottery ticket named a higher re-sale price for their tickets than participants who had been assigned a randomly drawn ticket. Langer concluded from this that some participants (erroneously) believed that there was a positive causal relationship between their strategic actions in choosing a ticket and the probability of winning the lottery.

While the illusion of control has predominantly been studied in the context of lotteries, roulette and slot-machine gambling, references have been made to the illusion of control over health (Langer 1983), investments (De Carolis & Saparito 2006) and gambling activities in which it is possible to reduce the house profit margin (e.g., Keren & Wagenaar 1985). However, all these activities involve a degree of skill – a contingency between actions and outcomes – so attempting to strategise during these activities does not necessarily constitute an illusion or error. At the same time, since commercial gambling activities are losing games, the definition of the illusion of control is often broadened to include the error of assuming that optimal strategising can generate more than mere loss minimisation in commercial gambling. In effect, the illusion of control is often used as an umbrella term for EGRBs. Distinctions have been made between “primary” and “secondary” illusions of control (e.g., Clark, 2010; Ejova, Delfabbro, & Navarro, 2015; Rothbaum, Weisz, & Snyder, 1982), and in the next section, we describe the theoretical basis for our classification of EGRBs, we make a similar broad distinction between “natural” and “supernatural” EGRBs. Our theory about the conceptual origins of primary/natural and secondary/supernatural EGRBs might be among the explanations for the illusion of control (see Ejova, in press), but Langer originally suggested that the illusion is a product of a universal “need for control” that protects psychological wellbeing. In the next section, we propose that such a need might partly account for why people infer that there is a problem to be solved in gambling activities.

Table 1. EGRBs documented across 40 studies.

Interviews	*Observations and quantitative analyses of real-world gambling*	*Experiments*
1. In a focus group study, slot-machine players reporting gambling-related problems expressed the belief that slot-machine operators reprogram slot machines to pay out less on popular days for gambling, such as pension days (Livingstone, Wooley, & Borrell, 2006; see also Hahmann, 2017, p.149 "Hot Machines").	**10.** An analysis of number choices in two United States lotteries indicated that numbers were less likely to be chosen if they had been recently drawn out (Clotfelter & Cook, 1993; Terrell, 1994; see also Fong, So & Law, 2016, for a similar finding with options analogous to roulette's "red" and "black" in the Chinese dice game, Cussec).	**14.** In lotteries*, roulette^, slot machine gambling[~] and bingo[#], the researchers listed in the table notes below demonstrated that participants in versions of the game with more response options (e.g., a stoppage lever or known jackpot combination on a slot machine) were characterised by higher ratings of personal control, ratings of confidence in winning, bet amounts or number of trials played. Since chances of winning were visibly and objectively unaffected by the number of available response options, the results suggest that participants interpreted the options as advantageous based on a belief that it is possible to take action to influence pure-chance outcomes.
2. The slot-machine players from Livingstone et al.'s study above displayed a preference for a minimum-bet, maximum-lines strategy in expectation that one of the lines would be likely to show the winning outcome as the playing session progressed (Livingstone, Wooley, & Borrell, 2006; see also Ohtsuka, 2013).	**11.** In a group of craps players joined by an observing sociologist, it was common for players to throw dice harder when they needed higher numbers (Henslin, 1967).	**15.** Ayton and Fischer (2004) observed a tendency to predict a colour (red or blue) in a simplified roulette game less and less, the longer the colour appeared consecutively in immediately preceding trials (see also Boynton, 2003, Experiment 2, and Studer, Limbrick-Oldfield and Clark, 2014).

3. Blackjack players at a casino reported a preference for playing on two boxes, as they expected poor outcomes on one to be counterbalanced by favourable outcomes on the other (Keren & Wagenaar, 1985; see also Baboushkin et al., 2001).	**12.** A Canadian survey-based research programme identified a relationship between gambling urge and perceived personal deprivation, controlling for relevant confounds (Callan, Ellard, Shead & Hodgins, 2008).	
4. "When I first got started, I went a whole year without winning. Then I changed my attitude. I give 10 percent of my winnings to the church. When I win, I put it in an envelope. If you do that, you'll get ahead" (from an interview with a bingo player; King (1990) p. 53; see also Henslin, 1967)	**13.** In the study of craps players described above, players who happened to accidentally drop the dice rubbed them against something before proceeding (Henslin, 1967; see also Lam, 2007, for a description of rituals used by casino baccarat players in Macau).	**16.** In one of a series of experiments by Wohl and Enzle (2009, Experiment 3), participants were more likely to delegate the drawing out of a lottery ticket to a confederate after she described her continued gambling success following a visit to a museum, during which she was able to touch a widely-known lucky sporting object. This finding suggests that people believe luck to be carried by objects, which can be ritualistically touched to obtain good luck.
5. Vietnamese interviewees in an Australian casino expressed the belief that gambling losses are a consequence of bad acts committed in the past, acts that can be redeemed through future good acts (Ohtsuka & Ohtsuka, 2010).		**17.** In a different set of experiments by Wohl and Enzle (2002) participants in a roulettle-like game (wheel-of-fortune) engaged in higher levels of ritualised behaviour following their own wheel spins (as compared to the experimenter's; Experiment 2). Participants also rated their chances of winning as higher when they could be in physical or visual contact with an object resembling the ball-bearing during spins (Experiment 3). Together, the findings suggest that some people seek to exert magical influence on chance outcomes when there is opportunity to do so.

6. Players of casino Mahjong – a dice-like game – in Macau described a number of widely-performed rituals, including not playing immediately after a haircut and not letting anyone touch their shoulder during the game (Ohtsuka & Chan, 2010).		**18.** Xu, Zwick and Schwarz (2012) found that participants required to wash their hands after recalling (Experiment 1) or experiencing (Experiment 2) an episode of bad luck (in Experiment 2, the episode consisted of two unsuccessful gambling outcomes in a row) were more risk-seeking than participants not required to wash their hands. Meanwhile, after recalls or experiences of episodes of good luck (in Experiment 2, the episode consisted of two consecutive gambling wins), washing hands had the opposite effect. The findings are evidence of a belief in the possibility of desirable cleansing from bad luck and undesirable cleansing from good luck.
7. "[Lucky ink dabbers in bingo] lose their thing you know… the colors just fade away… the colors just lose their appeal to me. I need something new, a different color to bring me luck." (King, 1990, p. 56; see also Keren & Wagenaar, 1985, p. 152 for a discussion of perceived "waves" of luck)		**19.** In further experiments by Wohl and Enzle (2009, Experiments 1 and 2), participants were more likely to delegate a roulette spin to a confederate when, in casual conversation prior to the spin, the confederate described himself as "lucky" on account of having enjoyed consistent gambling success. This finding suggests that people also believe that luck can be carried by people.
8. Blackjack players reported believing that a bad flow of cards could be reversed by betting in an unusual way or simply changing tables. The players clarified that this belief was, in turn, informed by the belief that card flow is determined by luck or "fate", an omniscient force which assumes that players maintain an optimal strategy. Breaking the flow, therefore, requires doing something out of the ordinary (Keren & Wagenaar, 1985, p. 152).		
9. "I don't believe in lucky seats, but some people do… They look around and see… which table has a lot of winners. Then the next week they try and sit with those players. They figure the luck will rub off on them." (King, 1990, p. 56)		

Notes: *Lotteries: Langer (1975, Experiments 2 and 3); Nichols, Stich, Leslie and Klein (1996); Wortman (1975),
^Roulette: Dixon (2000); Friedland, Kienan and Regev, 1992; Tobias-Webb et al., 2016; Wohl and Enzle (2002, Experiment 1);
~Slot machines: Clark et al., 2009; Dixon et al. (2017); Ladouceur and Sevigny (2005); Rockloff et al. (2015, Chapter 4, Experiment 2);
#Bingo: Gilovich and Douglas (1986)

2 The problem-solving theory of EGRBs and ensuing classification

After proposing that, at least for some, gambling involves problem-solving informed by background beliefs – or theories – about the world, we discuss how the EGRBs described in Section 1 can be classified into those generated based on human theories of supernatural forces, those generated based on human concepts of randomness, those generated based on concepts of randomness and theories of supernatural forces simultaneously, and those generated based on human theories of natural phenomena other than randomness. We then briefly discuss how problem-solving – the generative mechanism for EGRBs – acquires some unique properties when influenced by universally fallacious concepts of randomness. After describing emerging psychometric evidence for our classification scheme – that is, evidence from surveys factor-analysed to identify underlying categories of EGRBs --we conclude with a discussion of the implications of our scheme for measuring EGRBs.

Gambling as problem-solving based on background beliefs

Alongside visible opportunities for financial gain, gambling activities feature visible action alternatives, including buttons on slot machines, the grid of possible bets in roulette, and a myriad of betting options in sports- and race-betting. Because the action alternatives and potential monetary prize are among the only visible design features of gambling environments, at least some players are likely to conclude that the two features might be causally connected. Moreover, gambling activities are widely labelled “games”, which, in other domains, such as sports and multi-player card games, involve a causal connection between available actions and the prize on offer.

We propose that, because gambling activities are designed to suggest a potential causal connection between actions and outcomes, and, possibly, because human psychological wellbeing might depend on overestimating the extent to which actions might be effective in obtaining desired outcomes (Cummins & Nistico, 2002; Langer, 1975; Leotti, Iyengar & Ochsner, 2010; Weinstein, 1980), some players proceed to approach gambling as a problem-solving exercise. Problem-solving consists of physically trialling or mentally simulating actions to determine whether they achieve the goal state or bring the goal state closer (e.g., Anderson, 1993). For example, a person might contemplate three actions for bringing about substantial wins through slot-machine gambling: (1) selecting machines that have not produced a win for some time, (2) not playing on popular days for gambling to avoid being tricked by venue owners, and (3) taking a lucky charm to the venue. In a search through physical trial, the person might perform the first action for some number of sessions. Should he find that the amount of money he has available is consistently shrinking rather than growing, he is likely to switch to performing one of the other two contemplated actions, and to mentally simulating other possible actions. Upon running out of action alternatives to trial, the person would cease pursuing the goal of gambling wins; that is, he would give up on the problem. This would mean ending the gambling session or continuing without an action plan, driven by social or emotional reasons. People playing just to stay longer at the venue – in the “gambling zone” – instead of facing problems at home (Dow Schüll, 2014) might be among those playing for purely emotional reasons, for example.

Similarly, regular sports betting can be motivated purely by the desire to join friends at the pub or racetrack (Walker, 1992, p. 18).

In what constituted a preliminary demonstration of reliance on problem-solving during gambling, Ejova, Navarro and Delfabbro (2013) manipulated the trajectory (i.e., “slope”) of wins in a laboratory gambling task. That is, participants experienced wins primarily at the beginning of the session, primarily at the end, or spread evenly throughout. Reports of strategy effectiveness were found to be higher in the late-wins condition compared to the early-wins condition. This suggests that those experiencing late wins engaged in some trial-and-error learning – a component of problem-solving. Boynton (2003, Experiment 2) also observed a win-stay approach among participants predicting the next outcome among two possible outcomes known to be randomly generated. Thus, in a situation where “wins” were correct predictions, participants continued trialling an option that had worked in the past, despite knowing that outcomes were independent of each other.

We can further speculate that near-wins (instances of narrowly missed wins; for example due to one reel being out of line on a slot machine) are likely to speed up the process of iterating through a set of contemplated actions by eliciting regret and subsequent upward counterfactual thinking – mental simulation to imagine how a different detail or action might have led to a better outcome (Coricelli, Dolan & Sirigu, 2007; Epstude & Roese, 2008). Meanwhile, an optimistic personality is likely to be associated with slowed iteration through possible strategies, due, in part, to less efficient learning from outcomes that were worse than expected. Lefebvre and colleagues (2017) observed evidence of learning with an optimism bias in a chance-driven problem-solving task. Participants were instructed to maximise monetary rewards by selecting, from two symbols on the screen, the stimulus associated with a monetary reward. The alternatives were equally likely to generate rewards, but 50 percent of participants distinctly preferred one of the options to an extent resembling a computer simulation engaged in learning with an optimism bias. Functional magnetic resonance imaging conducted during the task suggested that participants who displayed this optimistic learning pattern differed from the remainder of participants specifically in terms of how rewards were encoded in the neural network known to be involved in reward processing (see also Gibson & Sanbonmatsu, 2004).

Our overall proposal that gambling can involve iterating through strategic actions has implications for the classification of EGRBs because, in light of our earlier definition of EGRBs as beliefs that there is potential to beat the house, any strategic action conceived of during the iterative process represents an EGRB. A further highly relevant consideration in classifying EGRBs under our problem-solving framework is that the content and quantity of actions contemplated during problem-solving have been found to be influenced by the individual's background beliefs. Chi, Feltovich, and Glaser (1981) compared trained physicists and novices on how they categorised a set of physics problems. Physicists created a small number of categories based on the Newtonian Laws required for solving the problems, whereas novices created a large number of categories on the basis of the problems' wording. Similarly, in a laboratory gambling task described to participants as a slot-machine-like task, Ejova and colleagues (2013) found that post-game beliefs about the effectiveness of various strategies were more strongly held by people who had, in a pre-game survey, expressed stronger beliefs in the controllability of slot machine outcomes.

A third relevant consideration with respect to classifying EGRBs is that background beliefs have been more precisely defined in cognitive science as internally represented theories of the world that vary in generality (Murphy & Medin, 1985; Tenenbaum, Griffiths & Niyogi, 2007; Thagard, 1992; Wellman & Gelman, 1992). Effectively, under this view, all but the most general theories are "beliefs" that emerge from more general theories, and all but the most situation-specific beliefs are "theories" capable of generating more specific theories or beliefs. Thus, for example, the EGRB that venue managers reprogram slot machines to provide a lower return on popular days for gambling, such as pension days – Belief 1 in Table 1 – is likely to be rooted in one of the most general theories available to humans: the *theory of mind* (e.g., Wellman & Gelman, 1992). According to the theory of mind, all human beings, including oneself, act according to certain beliefs and desires (or goals), which are in turn influenced by relevant states of the world. In business settings, a common goal is to maximize profit, taking into account current states of the world, which include business cycles. This application of the theory of mind to defining business decision-making is, in itself, a theory; a theory capable of generating the even more situation-specific theory that the owners of commercial gambling venues would wish to make changes to the structure of games in response to the business cycle. In the next section, we argue that it is possible to classify EGRBs based on what the cognitive science literature hypothesises about the content of higher-level generative theories relevant to gambling.

Classification of EGRBs based on cognitive-scientific hypotheses about the content of relevant background beliefs

EGRBs generated by concepts of the supernatural. Theories in the cognitive science of religion point to a general belief structure that generates all variants of religious belief (Atran & Norenzayan, 2004; Boyer 2001; Kirkpatrick, 1999), including beliefs about less human-like supernatural agents such as fate and karma (Wilson, Bulbulia & Sibley, 2013). The structure consists of beliefs in the existence of supernatural agents (gods, ghosts, angels, etc.), the power of supernatural agents to avert natural calamities (usually for "deserving" individuals), and rituals as a means of appealing to supernatural agents. The universality of this belief set has been attributed to the fact that it is a by-product of evolved cognitive mechanisms, such as propensity towards detecting agents (e.g., predators) given the faintest of clues (e.g., a wind gust) [2].

Among the beliefs that can be generated by this broader belief structure are beliefs that outcomes in life – and, by implication, in gambling – can be improved through good conduct noticed by supernatural agents, as well as through ritual-based appeals to those agents. In Table 1, Beliefs 4, 5 and 12 postulate that gambling wins can be "deserved" through good conduct or prior suffering and deprivation. Meanwhile, Beliefs 6, 7, 13, 16, 17, 18, 26, 27, 28 and 29 pertain to advantages gained through rituals, and Belief 25 – "Sometimes I get spiritual help when gambling" – is a general statement that captures a belief in the availability of help from supernatural agents without specifying the associated mechanisms. Belief 8 about luck's all-knowing (i.e., supernatural) role in blackjack represents, along with Belief 7 about selecting lucky dabbers in bingo, evidence that luck is among the supernatural agents players to which appeal through rituals. A seemingly conflicting documented EGRB – exemplified by Beliefs 9, 19 and 30 – is that good luck (significant and enduring success amidst close calls in gambling and other contexts; Pritchard & Smith, 2004) is a personal trait, rather than an external higher force. This EGRB that good luck is a character trait is, however, not incompatible with the notion that good luck is conferred by higher forces on those who deserve it, or perhaps on those who share a "lineage" with deserving ancestors (Sommer, 2007, p. 275).

EGRBs generated by a universal concept of randomness, the "gambler's fallacy."

Following numerous studies in which participants were required to produce "random" sequences, it has been suggested that, universally, humans have a tendency to expect that sequences generated by random-number generators are highly unlikely to feature overly long runs of any one possible outcome (e.g., eight Heads in a row during coin tossing). This expectation is known as the "gambler's fallacy" and is formally defined as the expectation of a dynamically changing negative recency in random outcomes; that is, an expectation that the probability of an alternation in random outcomes increases with each repetition (for reviews, see Nickerson, 2002, and Oskarsson, Van Boven, Hastie & McClelland, 2009).

Various explanations for the gambler's fallacy have been advanced (see reviews cited earlier), and a number of recent explanations (Hahn & Warren, 2009; Rabin, 2002; Rapoport & Budescu, 1997) allow for the possibility that the gambler's fallacy stems from a general belief about the nature of randomness – a theory available to problem-solvers encountering outcomes they believe to be random. At first glance, having a theory of randomness appears to make no logical sense, since, by definition, sequences of random outcomes are “incompressible” – infinitely complex, and not describable by rules (Nickerson, 2002, p. 333). However, in board games, gambling and systematic random draws (e.g., for tax audits), humans do encounter sequences that are likely to be explicitly labelled random (what Nickerson, 2002, p. 335, refers to as “products” of randomness). People can form concepts (i.e., theories) of randomness based on those encounters. Limitations in working memory and over-inference from small samples have been discussed as reasons for why human theories of randomness converge on a notion of a dynamically changing negative recency (Hahn & Warren, 2009; Rapoport & Budescu, 1997). For example, making a case for the role of working memory limitations, Hahn and Warren (2009) demonstrated, through simulations, that sequences of up to 50 chance-determined outcomes such as coin-tosses have the property that, if any series of six consecutive outcomes is selected from the sequence, the series is *least* likely to consist of uniform runs (e.g., six tails) and perfect alternations (e.g., the sequence *tails-heads-tails-heads-tails-heads*). The property is even more pronounced in sequences of 20 outcomes but does not hold in longer sequences of 500, or even 100, outcomes. In a typical board game or coin toss sequence, people experience random outcomes in sequences of no more than 50. Over the course of those 50-outcome-long playing sessions, they are likely to notice structure across only five or six outcomes at a time, as that is the capacity of human working memory (Miller, 1956). Thus, in attending to fragments of what are already short random sequences, people learn (i.e., develop the theory) that randomness is a process that is unlikely to generate uniform runs and perfect alternations.

Under our classification framework, in a commercial gambling setting, the gambler's fallacy generates EGRBs such as Beliefs 2, 10, 15, 22, 23, and 24 in Table 1. Apart from beliefs in the increasing future probability for less recent outcomes (Beliefs 10, 15, and 22), the generated beliefs include beliefs in the value of consistently betting small amounts while waiting for a winning combination, imminent amidst repetitions of losing combinations (Belief 2), beliefs in the value of "staying on" a single response option (e.g., a particular roulette number) that is bound to become the winning option in alternation with other options (Belief 23), and beliefs in the ability to change up responses in line with the next *new* (rather than repeated) outcome a random number generator is going to generate (Belief 24).

EGRBs generated by theories of the natural world other than the gambler's fallacy. The strategy of avoiding slot machines on pension days and other days believed to be popular for gambling (Belief 1 in Table 1) is, under our framework, an example of a strategic EGRB generated by a theory of the natural world other than a theory of randomness. As suggested during our description of gambling as problem-solving, this EGRB proceeds from background beliefs about business cycles, which, at the broadest level, proceed from a theory of human interaction as per theory of mind. Apart from theories of "other minds", humans have broad theories of physics and biology (Dennett, 1987; Griffiths & Tenenbaum, 2007; Wellman & Gelman, 1992). As people participate in commercial gambling games or imagine doing so, these general theories of mind, physics and biology can generate layers of sub-theories that give rise to EGRBs. It is possible that Belief 11 in Table 1 – the belief that harder throws of the dice are more likely to produce a higher number – has its origins in a theory of physics.

In gambling games where it is possible to minimise the house profit margin, strategies based on concepts of the supernatural and the gambler's fallacy are the only strategies that are erroneous irrespective of game context and player skill. In games with controllable (albeit always positive) house profit margins, strategies based on natural theories other than an erroneous theory of randomness are so context-dependent that it is difficult to determine whether they are erroneous based on player reports or short-term observation (Bjerg, 2010).

EGRBs generated by concepts of randomness and concepts of the supernatural simultaneously. It is possible for the previously described supernatural belief structure to combine with beliefs about the natural world in generating EGRBs. Indeed, most beliefs in the supernatural are predicated on theories of biology, matter and mind, deviating from those beliefs in minor and systematic ways (Atran & Norenzayan, 2004; Barrett, 2000). For example, the common ritual of washing one's hands of bad luck (Belief 18; see also Ohtsuka & Chan, 2010) represents only a small deviation from washing one's hands of some physical pollutant. We speculate that the EGRB that luck follows a cyclical pattern, appearing periodically and then vanishing, as reflected in Belief 7, might likewise follow simultaneously from natural and supernatural background beliefs. The "periodicity" aspect of the belief might derive from the generalisation of the gambler's fallacy – a theory about randomness or "chance" – to the closely-related concept of "luck". Luck and chance are closely-related in that emotionally significant good chance outcomes are lucky by definition. This is because chance outcomes have many close counterfactual alternatives, and lucky outcomes are, by definition, emotionally significant successes amidst many counterfactual scenarios involving failure (Pritchard & Smith, 2004; see also Ejova, in press, for a discussion of how the use of random-number-generators in fortune-telling might have lead to the formation of notions about cyclical luck). The second component of the EGRB in cyclical luck – the belief that luck is an agent capable of deciding when to "appear" – is consistent with the finding that luck is often conceived of as a supernatural being, responsive to rituals and states of the world.

EGRBs not yet classified under our framework – Beliefs 14, 20 and 21 in Table 1 – were uncovered in research on the illusion of control and refer generally to "strategies for playing". In light of their generality, these beliefs could belong to any of the belief categories in our classification scheme: beliefs generated based on theories of supernatural forces, concepts of randomness, concepts of randomness and theories of supernatural forces simultaneously, and theories of natural phenomena other than randomness.

Unique characteristics of problem-solving informed by the gambler's fallacy

In proposing that many of the EGRBs documented in the literature develop through problem-solving, which involves an iterative search for an action capable of supplying a sizeable win, we imply that participants in games of chance should eventually learn that there is no action available for increasing win probability above the chance-determined level. However, we additionally propose that participants in games of chance bring to the search for effective actions a concept of randomness or cyclical luck according to which a losing streak on a particular line on a slot machine, on a particular number in roulette, or while holding on to a particular lucky charm can signal that a win is imminent. In holding this fallacious concept of randomness, participants in games of chance are likely to tolerate longer losing streaks during the problem-solving process than they would in any other problem-solving situation.

Research into how the gambler's fallacy affects the problem solver's trial-and-error process has begun to be conducted, with early findings suggesting that the fallacy is drawn upon (presumably, as a theory) only after errors (Boynton, 2003; Mossbridge, Roney & Suziki, 2017). So far, however, studied tasks have featured only two response options and explicit instructions that outcomes are randomly generated. In such tasks, it is possible to track the gambler's fallacy, but commitment to a single particular response (consistent "trial" of an option) is unlikely to emerge as an alternative strategy.

Psychometric evidence of two broad types of EGRBs: natural and supernatural

Consistently with our proposal that EGRBs are broadly classifiable as "natural" and "supernatural", numerous studies using exploratory factor analysis have found that similarities in responding to groups of items were best described by two underlying ("latent") constructs: a construct relating to items mentioning luck and rituals, and a construct relating to items referring to the gambler's fallacy and other non-supernatural phenomena (Ejova, Delfabbro & Navarro, 2015; Steenbergh et al., 2002; Wood & Clapham, 2005; see also Leonard, Williams & Vokey, 2015 for a review). Ejova and colleagues uncovered the same two-factor structure in participants' self-reports of strategies used in a laboratory slot-machine task (Ejova, Delfabbro & Navarro, 2010).

It has further been demonstrated that a concept of randomness underpins both natural EGRBs relating to the gambler's fallacy and supernatural EGRBs reflecting a notion of cyclical luck. The associated study (a confirmatory factor analysis by Ejova, Delfabbro and Navarro, 2015) sought to find the optimal model to account for relationships between six scale scores, reflecting endorsement of (1) gambling strategies generally, (2) gambling strategies based on the gambler's fallacy, (3) the value of persistent play, (4) the cyclical nature of luck, (5) supernatural agents such as luck and god, and (6) gambling rituals. Good model fit was obtained for a factor structure in which Scales 1 to 3 loaded on a latent variable reflecting "natural strategies and concepts of randomness," while Scales 5 and 6 loaded on a latent variable reflecting "supernatural strategies." Critically also, Scale 4 – belief in the cyclical nature of luck – loaded on both latent variables, suggesting that concepts of randomness might inform supernatural beliefs in the cyclical nature of luck.

Implications for measuring EGRBs

Our conceptualisation of EGRBs points to two main sources of ambiguity in EGRB surveys that should be taken into account when selecting an EGRB survey, designing a survey, or developing objective (i.e., behavioural) measures of EGRBs. Firstly, we attribute EGRBs to problem-solving based, at the most general level, on beliefs about natural or supernatural phenomena, and it follows that survey statements referring to gambling "strategies" or "systems" without further clarification are ambiguous as to whether they refer to natural or supernatural strategies. A person endorsing a statement such as "Show me a gambler with a well-planned system and I'll show you a winner" (Belief 21 in Table 1) could theoretically believe in only natural or only supernatural systems for winning. Notably, exploratory factor analyses of EGRB surveys suggest that, in practice, people tend to conceive of strategies as manipulations of physical rather than supernatural phenomena. Statements mentioning strategies have been consistently found to load on a factor separate from statements referring to supernatural forces (Ejova, Delfabbro & Navarro, 2015; Steenbergh et al., 2002; Wood & Clapham, 2005).

As hinted in the discussion of EGRBs generated by concepts of randomness and concepts of the supernatural simultaneously, a second source of ambiguity in EGRB surveys is that “luck” and “chance” are closely-related concepts that are considered synonymous by some people (Ohtsuka & Ohtsuka, 2010). In a survey enquiring about agreement with statements reflecting various EGRBs, people who equate luck and chance would endorse strategies reflecting the gambler’s fallacy to the same degree that they would endorse strategies proceeding from the notion that luck is cyclical. In such cases, it would be impossible to detect which of the two EGRBs is actually endorsed without including a survey item such as “Luck is nothing more than random chance” (Darke & Freedman, 1997). Notably, progress has been made in developing objective measures of individual differences in endorsement of the gambler’s fallacy (Delfabbro & Winefield, 1999; Gökaydin & Ejova, 2017; Gökaydin, Navarro, Ma-Wyatt & Perfors, 2016; Leonard, Williams, & Vokey, 2015; Ryterska et al., 2014). Objective measures should, nevertheless, be administered alongside survey items relating to beliefs in cyclical luck and the equivalence of luck and chance to account for any confounding effects of supernatural belief in cyclical luck.

A measurement implication of the definition of EGRBs – independently of the proposed classification scheme – is that survey and interview reports of wining expectations due to the application of some natural strategy are not necessarily erroneous for most gambling types, unless winning is clarified as referring to the elimination of the house edge. Survey and interview questions need to be specific about the gambling activity in question and the definition of winning (e.g., as per Ejova, Delfabbro, & Navarro, 2015, Leonard, Williams, & Vokey, 2015).

3 Implications for researching and treating gambling disorder

Gambling disorder, characterised by craving, withdrawal, and financial difficulties in relation to gambling (American Psychiatric Association, 2013), affects 1 to 2 percent of those who gamble (Shaffer, Hall & Vander Bilt., 1999; Wardle et al,, 2011) and is often treated using cognitive-behavioural therapy, a central aim of which is to challenge EGRBs (Rash & Petry, 2014). At the same time, EGRBs have not featured prominently in explanations of how gambling disorder develops, most likely because EGRBs are generally theorised to arise out of universal decision-making processes while gambling disorder develops in only a small minority of people (Clark, 2010). The development of gambling disorder is, instead, typically attributed to one or more of the following processes (American Psychiatric Association, 2013; Blaszczynski & Nower, 2002): (1) difficulties with "unlearning" after learning from intermittent rewards during gambling sessions, (2) excessive risk-taking spurred by trait impulsivity, which is likely to be particularly pronounced in people with personality disorders or ADHD, and (3) persistent (or, as Dow Schüll (2014) described it, "zoned-out") gambling to escape extreme mood states resulting from anxiety or depression. In this section, we discuss how EGRBs, as classified under the problem-solving framework, might combine with reinforcement learning effects, impulsivity, and psychiatric conditions in supporting the development of gambling disorder. In a final sub-section, we consider the implications of our classification framework for cognitive behavioural therapy for gambling disorder.

EGRBs, intermittent reinforcement and gambling disorder

An early explanation for persistent gambling amid losses drew on the classic observation that animals who learned behaviours based on unpredictable rewards – that is, based on "intermittent" or "partial" reinforcement – were slower to abandon those behaviours once all reinforcement ceased (i.e., during "extinction"). It was suggested that gambling behaviours are similarly learned with only partial reinforcement (Skinner, 1953). More recently, Redish and colleagues (2009) developed an explanation of why persistent gambling reaches pathological levels in only a small percentage of those who engage in learning with partial reinforcement during gambling. The explanation was based on a study in which simulated learners could select, from 10 possible actions, a single action that was partially reinforced but, as in gambling, costly to perform, to the extent that the long-term winning expectancy was negative. After 250 choices, the learner experienced 100 trials during which the reinforced but unprofitable action suddenly attracted reinforcement at a higher rate and became profitable. In a subsequent 250 trials with the original (unprofitable) reinforcement conditions, Redish found that the probability of choosing the unprofitable action was particularly high among learners who had won more in total during the winning streak. Our explanation of EGRBs suggests that learners in gambling settings often possess the gambler's fallacy, so one direction we see for extending Redish et al.'s research programme involves incorporating the gambler's fallacy as an additional information processing constraint for the simulated learner. Effectively, the learner could be programmed to associate a run of non-reinforcements on an action with higher probability of reinforcement for that action. It should then be possible to examine the extent to which large wins remain a chief risk factor for persistent gambling and larger losses in these more realistic learners.

EGRBs, impulsive decision-making and gambling disorder

Impulsivity can be defined as a trait that results in "decreased sensitivity to negative consequences of behaviour, rapid unplanned reactions to stimuli before complete processing of information, and lack of regard for long-term consequences" (Moeller et al., 2001, p. 1784). While many self-report-based and behavioural measures of impulsivity have been developed, there is substantial lack of agreement as to how the measures cluster together in expressing what are likely to be multiple components of impulsivity (Meda et al., 2009). There is, however, accumulating evidence that impulsive traits become visible early in human development and have distinctive neural correlates, with higher impulsivity being associated with decreased activity in prefrontal cortical networks (Whelan et al., 2012). Since impulsivity and its neural correlates have been found to be more pronounced among people with various addictive disorders, including gambling disorder, a popular view is that gambling disorder is among the disorders to which highly impulsive individuals are predisposed from childhood (for reviews, see Clark, 2010; Grant, Odlaug & Chamberlain, 2016).

Our theory of EGRBs contributes to this literature a hypothesis regarding the mechanisms by which impulsivity might influence gambling behaviour. There exists neuropsychological evidence that, among people without a gambling disorder, higher impulsivity is associated with reduced signalling in the ventral striatum and amygdala following near-misses (Shao, Read, Beherens & Rogers, 2013). Since such signalling is potentially indicative of reduced regret – a process that leads to counterfactual thinking and, with that, under our theory, faster iteration through gambling strategies – it is possible that highly impulsive individuals exhibit a distinct problem-solving pattern characterised by slower discarding of ineffective strategies. Future research could compare people high and low on impulsive traits with respect to rate of decline over time in the degree of reported strategy effectiveness in games of chance. The neuropsychological correlates of the rate of decline could also be examined.

EGRBs, psychiatric conditions and gambling disorder

Cross-sectional and longitudinal research suggests that gambling disorder and psychiatric conditions, including personality disorders, anxiety, depression and substance use co-occur, and possibly reciprocally cause each other (Abdollahnejad, Delfabbro, & Denson, 2014a, 2014b; Afifi et al., 2010; Dussault et al., 2011; Hartmann & Blaszczynski, 2016). Whether EGRBs play a mediating or moderating role in any potential causal processes is just beginning to be investigated, with Abdollahnejad, Delfabbro and Denson (2015) finding that, cross-sectionally, among people fulfilling and nearly fulfilling diagnostic criteria for gambling disorder, symptoms of borderline personality disorder related to gambling involvement levels both directly and through a positive relationship with general delusion-proneness (i.e., preoccupation with beliefs in telepathy, one’s likelihood of becoming someone important, etc.). Delusion-proness was, in turn, positively related to EGRB endorsement. While requiring longitudinal replication, this finding is consistent with the possibility that people with psychiatric disorders might turn to extensive gambling because certain EGRBs are highly consistent with other delusions accompanying their psychiatric conditions.

Further investigations of the relationship between psychiatric conditions, delusions, EGRBs and gambling behaviour would benefit from more precise and theoretically-grounded measurement of EGRBs – in line with our measurement recommendations in Section 2. Improved measurement would allow for conclusions to be drawn as to which particular EGRBs are prone to inflation through delusions and other symptoms of psychiatric disorders. For example, research employing detailed (self-report-based and objective) measures of the gambler's fallacy as the outcome variable could investigate whether being "in the zone" among people with anxiety or depression can, in fact, involve waiting for a big win based on the gambler's fallacy.

Cognitive behavioural therapy (CBT)

Most validated treatment programmes for gambling disorder are based on the CBT model, under which programmes assist clients with finding and implementing strategies for challenging existing patterns of thought and connected behaviour (Rash & Petry, 2014). The end goal is to reduce gambling frequency or abstain from gambling completely (e.g., Hodgins, Currie, Currie & Fick, 2009), and almost all programmes present active EGRB-correction (through reading and discussions) as a strategic step towards this goal (Goodie, Fortune, & Shotwell, 2019). Other strategies typically supported by CBT programmes include (1) becoming aware of the negative financial, emotional and social consequences of gambling, so as to remind oneself of them when the urge to gamble arises, (2) identifying triggers of the urge to gamble and avoiding them through increased involvement in family life, social activities and hobbies, (3) learning to harness more positive coping strategies, such as problem-solving, assertiveness, and support-seeking, across a variety of domains not limited to gambling, and (4) improving financial management skills (Petry, 2005). Our theory of EGRBs has implications for the EGRB-correction component of treatment programmes, sessions on the consequences of continued gambling, and two recently validated programme innovations aimed at reducing client drop-out rates: online delivery and brief interventions.

With respect to EGRB-correction and the recognition of the adverse consequences of continued play, our problem-solving theory of EGRBs provides not only a belief typology and theoretical framework that can be explicitly discussed with clients, but also an explanation of why gambling environments are dangerous, given unavoidable (potentially memory-capacity-related) errors in human concepts of randomness. Our explanatory framework for EGRBs suggests that the gambler's fallacy is likely to continue generating EGRBs even when strategies based on other background beliefs are exhausted.

With respect to online versions of therapies for gambling, which are gaining popularity due to improved client retention rates (Rash & Petry, 2014), our problem-solving-related conceptualisation of EGRBs suggests that natural EGRBs not deriving from concepts of randomness can be highly game-specific. An implication of this is that, beyond accessibility, online therapies have the advantage of being customisable to each client's dominant gambling activity.

Apart from online delivery, approaches to improving client retention rates include brief treatments involving personalised normative feedback (e.g., Cunningham, Hodgins, Toneatto & Murphy, 2012; Larimer et al., 2012). Treatments of this type are typically administered in a single session, and involve, first, the measurement of gambling frequency, gambling spending and erroneous beliefs; second, a demonstration of the extent to which the client's responses exceed mean levels in the general population; and, third, a brief outline of steps to follow in reducing gambling behaviour (e.g., by spending more time on other activities). Given the emphasis placed on EGRB measurement within this treatment approach, our theory's implications for measurement – discussed in Section 2 – are clinically relevant.

Conclusion

This paper introduces a theoretically and empirically supported classification scheme for various documented EGRBs based on a number of research directions in cognitive science. The relevant research directions concern problem-solving, generative knowledge structures (internal theories), the cognitive science of religion, and concepts of randomness. While demonstrating a real-world application for these research directions, our classification scheme is, most critically, a necessary step in improving research designs and measurement instruments for investigating the role of EGRBs in the development of gambling disorder. Measurement instruments developed based on the theory should, in turn, improve the effectiveness of brief gambling disorder treatments centred around EGRB measurement. Indeed, our classification scheme has a host of implications for gambling disorder treatment programmes.

Notes.

1. Poker is an ROG-based game in which players compete against each other rather than the house. The house makes a profit by charging a proportion of each stake (Bjerg, 2010). Poker is, therefore, a commercial gambling activity in which a negative return-to-player is not guaranteed, although 80 to 95 percent of online players report a negative rate of return (Siler, 2010).
2. In the cognitive science of religion, the proposal that religion is a by-product of evolved cognitive mechanisms is countered by the view that certain features of religion were evolutionarily selected for because of their benefits for group fitness (e.g., Sosis, 2009). It has, for example, been proposed that costly rituals enhance group solidarity (e.g., Bulbulia & Mahoney, 2008). While we believe that the "by-product" and "adaptationist" accounts of religion are complementary, we focus on the by-product account because it readily explains the existence of beliefs in gambling-relevant supernatural agents in secularised societies.

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Declaration of interest

The authors have no conflicts of interest to report.

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