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Use Of Computer-based Mathematical Simulations To Understand Gambling Games And Potential Risks For Problem Gambling

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Abstract. Background: There is a long tradition of the use of simulation by the gambling industry to understand the statistical properties of gambling games such as the house edge, hit frequency, and volatility. In this paper, we examined the use of simulation studies to understand the structural characteristics of gambling games. Method: A literature review was conducted to determine the number of simulation studies that have been conducted to measure the properties of gambling games. Results. A search for papers on simulations and gambling generated a large number of papers, but very few that examined the properties of the games themselves. However, we identified 27 papers that have used pure simulations to help us understand how gambling games work. These papers covered a variety of topics including 9 papers on volatility, 8 on house edge, 5 on near-misses, 5 on betting strategies on non-skill games, 4 on betting strategies on skill games, 3 on losses disguised as wins, and 1 on nudging. Studies revealed that volatility and losses disguised as wins were related to the number of lines covered by the player. Discussion: In this paper we discuss the insights gained from game simulation research and how these findings have contributed to understanding the addictive potential of gambling games. In addition, we discuss how these insights have encouraged experimental, and intervention directed research about gambling games and call for more simulation research to advance the field of gambling studies.

Keywords: Sports Wagering, Fantasy Sports, Casino Gambling, Lottery Gambling, Online Gambling.

Introduction

Simulations are used in many fields to test theoretical models when many complex variables are involved such as climate change, evolution, the life cycle of stars, planetary movement, and so forth (see Palmer, 2022). Simulations are often necessary to study the nature of these systems because the theoretical models are quite complex. There is a long tradition of using simulation to understand the statistical properties of gambling games; however, most of these analyses have been utilized to assist the gambling industry in determining concepts such as the house advantage, hit frequency, and volatility of games, as well as to ensure that games do not have any weaknesses that can be exploited by players (Ernkvist, 2009; Kilby et al. 2004; Turner, 2011). In addition, professional gamblers have used simulations to test out strategies for long-term wins for games such as blackjack, poker, horse racing and sports betting. A notable publication was Thorpe's (1966) book *Beat the Dealer* which used simulations to determine the optimal play for each hand as well as the potential efficacy of card counting. Simulations have also been used by poker players to work out optimal strategies (e.g., Warren, 1996). Software is available that uses simulations to help people learn poker and other games (see Turner et al., 2003). For a list of some software simulations see endnote 1.[i] More importantly, players have used simulations to compute expected variance, expected losing streaks, win rates, and how much "bad luck" they can expect over hundreds of thousands of hands played. There are online calculators that can help players compute the variance of play (e.g., Klöhn, 2024) and these calculators are well-known on online poker forums. However, an exploration of the research literature for the use of simulations in the field of gambling studies is relatively rare. Nonetheless there have been a few papers that explored the structural characteristics of gambling games using simulations. Turner (1998) for example, studied incremental betting strategies to illustrate how disastrous the strategy can be. Harrigan (2007, 2008) used simulations to determine how the design of the game increases near misses and distorts the apparent probability of winning the game. Haw (2008) used simulated data to illustrate the difference between variable ratio reinforcement and random ratio reinforcement. These papers show that the simulation methodology has the potential to improve our understanding of these gambling games. Our interest in this topic for the current paper is how simulations can help uncover the nature of gambling outcomes that may help us understand the addictive potential of these games.

In preparing our review paper, we were aware of several papers in the problem gambling field that used simulations to understand gambling games (e.g., Harrigan & Dixon, 2009; Lucus and Singh, 2013; Turner, 1998;

Turner & Fritz, 2001). Our goal was to document this field of research and to stimulate additional publications using this methodology. Our focus is on computer based mathematical simulations or pure simulation: papers that simulate some aspect of gambling games to examine the parameters and properties of the game. This excludes simulations that are presented to participants in experiments to study the participants. Rather in this paper we are only interested in simulations that attempt to uncover the nature of the games themselves.

The purpose of this study is to (1) document how simulations have been used in gambling research, (2) categorize this research into broad themes, (3) illustrate the potential for this methodology in the field of gambling studies, and (4) encourage further use of the simulation methodology in the field of gambling studies. In this paper, we present a narrative review on how simulations have been used to help us understand gambling games. Our focus is on pure simulations. These are simulations of gambling games that involve generating randomly distributed data with some pre-defined parameters that reflect (but may simplify) real-world gambling games. These studies have measured the properties of various games and provide insights into how the player experiences the game.

Methods

Definitions

This paper is a narrative review of studies that have used computer-based mathematical simulations to study the nature of gambling games. In particular the focus is on simulations of the games, designed to measure the properties of the structural characteristics of the game. To simplify the report, we will call these pure simulations and define a pure simulation as a simulation study designed to examine the structural properties of the games themselves, rather than studying gamblers, per se.

Search Strategy and Inclusion Criteria

Figure 1 provides a graphic depiction of the overall search process. We used two search strategies that were run in parallel. We were already aware of several papers published on pure simulations. In addition, we searched for citations of those papers that also used a pure simulation method and searched through their references for additional papers that were also pure simulations. This search strategy yielded a total of 17 papers that used a pure simulation method.

The second search strategy was to conduct a literature review of three databases using the OVID search platform: Embase Classic + Embase,

APA PsychInfo, and Medline. The papers had to be a pure simulation designed to study the nature of gambling games to understand the parameters and properties of the game. In addition, the paper had to be published in the past 30 years. The literature search utilized keywords "simulat*" and "gambl*". The search yielded a large number of papers (n=1257), many of which were not relevant to the goal of the paper.

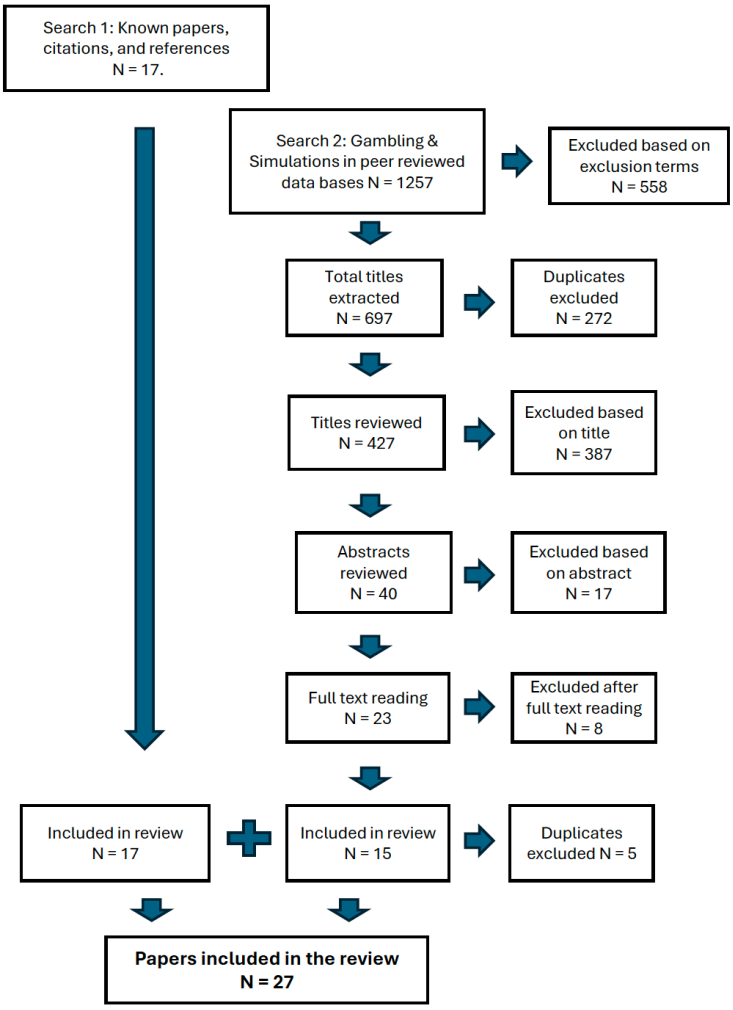

Figure 1. Literature review process for papers that include pure simulations of gambling games.

Study Selection, Inclusion, and Exclusion Criteria

Many of the 1257 papers identified in the initial search, used the search term Simulat* to mean something other than pure simulations so to narrow down the search we excluded papers using the words gambling and simulation in a different way. To find exclusion terms we examined some of these titles and identified titles that came up that were not relevant to our study and thus could be excluded. First several studies were found that use the word simulation to mean gambling like games where no actual money is spent; these games are also called "social casino" games and are "free to play". These papers were excluded from the study using the excluded terms: "social casino", "free to play". Secondly, some experimental studies have used the term "simulated" gambling to describe games that are not actual commercial games but simulated to study some structural parameter (e.g., near misses). We therefore excluded papers that used experimental methods with human participants using the excluded term experiment*. Third we excluded papers that used simulations of gambling games to educate people about some aspects of gambling in intervention studies for prevention or treatment of problem gambling using the exclusion terms: prevention, treatment. Experimental, prevention, and treatment studies are indirectly relevant to our study and will be considered as knowledge exchange in the discussion. We also excluded papers using the terms "structural equation model", molec*, drive* and receptor which also often came up in the output of the literature search. The results of the search are indicted in Figure 1

The abstracts, titles, keywords, and citation were extracted into an excel file. The authors screened the abstract and identified potential papers to include in the review. The senior author read through the list of papers selected and conducted a full text review to select the ones that were relevant to the goals of the study. The literature search initially identified 1257 papers through database searches. Of these 558 were excluded based on exclusion terms and a further 272 papers were excluded as duplicates.

Removing duplicates resulted in a total of n=427 papers. After title and abstract screening, the papers were reduced to n=40 papers. This number was further reduced to 23 papers based on their abstracts. The first author made a detailed examination of full-text of these papers and reduced the list to n=15 relevant unique publications. We added these 15 to the 17 we had identified as known papers from search strategy 1. Removing duplicates resulted in 27 unique papers.

Data Extraction

This information from the final articles selected was extracted into a table that included the authors, the date, a summary of the paper, and a check

list of the key topics studied in the simulation (see Table 1). The papers were read in detail, and key topics were extracted and sorted into broad categories. The results of this extraction process were then synthesized and interpreted in consultation with the authors of the paper. Some of these papers examined more than one topic and will be included in each of those topic sections. We then used a narrative synthesis approach to report on the results. Given the heterogeneous nature of the simulation studies, we did not assess quality of the paper.

Results

The results of this review have been divided into a number of overlapping topics of volatility, Near-misses, losses disguised as wins, betting strategies on non-skilled games, betting strategies on games of skill, nudging, and house edge. Each will be discussed below.

Table1. A summary of the parameters examined by each study.

Authors	Year	Game Strategie	Partial skill	Near-misses	Volatility	Return to Player	LDWs	Nudging	Key points
Turner	1998	Yes							Studied the outcome of a strategy of doubling after a loss on roulette and showed that it leads to small wins in the short term, but huge losses in the long term.
Turner & Fritz	2001		Yes						Studied effect of skilled players on less skilled players in games with partial skill
Turner & Horbay	2003	Yes							Examines various betting strategies on roulette and on slot machines
Turner & Horbay	2004			Yes					A tutorial on how slot machines work included an example of how the RNG works (designed to ensure profit for operators while maintaining player engagement)
Thorngate & Tavakoli	2005					Yes			Examined the long-term consequences of gambling using simulations with positive and negative expected returns
Turner et al.,	2006	Yes				Yes			Simulated the game of Faro to determine the house edge, finding that depending on the play strategy, simple bets had a house edge ranging from ,19%-2%
Harrigan	2007			Yes					Examined near-miss effects and distorted probabilities indicated above and below payline due to virtual reels.
Harrigan	2008			Yes					Examined near-miss effects and distorted probabilities due to virtual reels.
Barr & Durbach	2008	Yes			Yes				Used Monte Carlo simulation to examine the effect of line dependence (having fixed virtual reels): dependent lines reduced hit probability and increased volatility

Haw	2008				Yes				Examined the difference between variable ratio reinforcement and random ratio reinforcement
Harrigan	2009			Yes					Examined PAR sheets from gaming machines to determine probabilities and near misses on slot machine play
Harrigan & Dixon	2009			Yes					Studies show near misses are enhanced by virtual reels in older EGMs and fewer win symbols on key reels in modern multiline machines
Harrigan & Dixon	2010					Yes			Examined 2 slot machine versions with different return to players, and found that while the typical player's experience was similar, the higher RTP version led to significantly more large wins.
Harrigan et al.	2011	Yes					Yes		Found out that different EGM betting strategies didn't affect he house edge, and betting minimum amounts across maximum lines increased both the win rate and the number of LDWs
Turner	2011				Yes	Yes			Showed how commercial games are set up with sufficient volatility to make it difficult to determine the house advantage
Singh et al.	2013				Yes	Yes			Examined how volatility and the resulting skewness of outcome distributions affect mean player returns, comparing a low-volatility game like Baccarat with a high-volatility game like EGMs
Lucas & Singh	2013				Yes	Yes			Illustrated that most simulated players would be unable to reject the hypothesis that the house edge was the same between 2 games. Highlighting how volatility can obscure differences in long-term expected returns

Harrigan et al.	2014				Yes		Yes		Compared to placing a large bet on a single line, spreading the same total bet across more lines on a multiline EGM fosters a false sense of skill and control, despite simulations showing no impact on overall payout percentage
Browne et al.	2015		Yes		Yes				Bets on simulations of off-track horse races showed the high outcome volatility; examination of 3 actual players illustrated that players would not be able to determine if they had any actual skill.
Harrigan et al.	2015						Yes		Covering more lines on a slot machine reduces outcome variance, increases LDWs, fewer players winning and fewer players experiencing large loses
Turner & Shi	2015				Yes				Show that covering more lines, reduces volatility; multiline games offer options for both high and low volatility catering to players who prefer large prizes or frequent smaller ones
Potter van Loon, et al.	2015		Yes						Uses online player data to demonstrate that people skill level in poker is reliable; in a second part, they use simulations to show that in the long-term skill dominates over random chance.
Rodermund et al.	2020							Yes	Digital nudging can guide decision-making, improve outcomes and serve as a cost-effective method for preplanning experiments to address gambling-related issues
Hsu & Chie	2021		Yes						Showed that advantage players can legally profit from casinos using skill and premium offers, posing a financial risk to casinos.

Houghton & Moss	2022					Yes			Found that bets advertised on social media had worse outcomes with the chance of making a profit decreasing as players continued to engage with them
Palomäki et al.	2023				Yes				Found that higher volatility in video poker led to more players experiencing wins, but with shorter winning streaks compared to low volatility games
Palomäki et al.	2024					Yes			Demonstrates gambler's fallacy, showing how the return to player (RTP) can be misleading, as players may misinterpret it and believe the outcome will self-correct, leading them to chase their losses
Number of papers		5	4	5	9	8	3	1	

Volatility

Gambling games are often equated to variable ratio (VR) reinforcement schedules, but Haw (2008) points out a key difference between VR schedules and the random reinforcement (RR) that one finds in gambling games is the distribution wins across the trials. For example, with a VR schedule of 2.5 the maximum number of unrewarded trials in a row would be 4. In contrast, the maximum number of unrewarded trials with an RR schedule is indefinite. Haw (2008) used graphs based on simulated data to illustrate how an RR schedule will more often result in an immediate win compared to a VR schedule, but also more likely result in a long sequence of losses. The RR schedule is therefore less predictable and more volatile than a V R schedule.

According to Turner, volatility is a measure of the variation in potential outcome from bet to bet. The industry computes this measure using the 90% confidence interval ($z = 1.65$) of the theoretical standard deviation of the outcome of the game after 10,000 bets or spins (see also Harrigan and Dixon 2009; Kilby et al. 2004). Turner (2011) reports that in commercial games there is a pragmatic relationship between volatility and house edge with table games (e.g., Blackjack) having a small house edge and a low level of volatility whereas EGMs have a larger house edge and more volatility. The house edge is the long-term average percentage of money that the casino keeps per bet. For table games, the house edge is typically between 1% and 5% whereas for low stakes electronic gambling machines (e.g., slot machines), the house edge may be anywhere from 5% to 15%. Turner (2011) illustrated how the mix of house edge and volatility combine to make it difficult for the players to appreciate the long-term results of these games (losing). They report that the combinations of volatility and house edge of both standard table game and commercial gambling machines produced a high numbers of short-term winners (less than 1 h), but very few long-term winners (50 h).

Turner and Shi (2015) followed up this study by analysing how game volatility, house edge, and prize structure influence gambling game design. They demonstrated that in multiline games, the player has the opportunity for high volatility games (one line covered) and low volatility games (all lines covered) which may suit different people. That is, some people prefer the thrill of the large prizes from high volatility games, while other people prefer the frequent smaller prizes from low volatility games. Several studies have shown that covering more betting lines results in lower levels of volatility, which increases short term wins, decreases long-term wins and leads to a steadier decline in money towards the long term

expected house edge (Harrigan, et al., 2011, 2014, 2015; Turner & Shi, 2015;). The more lines covered the lower the volatility.

More recently, Palomäki et al. (2023) created simulations to study the impact of increased volatility in video poker. The results showed that for higher volatility games, while more players experienced wins, winning streaks were generally shorter than in low volatility games. Similarly, Harrigan et al. (2015) report that covering more lines on a slot machine reduces the outcome variance and reduces both the number of players who are winners and the number of players with large losses.

Barr & Durbach (2008) uncovered another variable that affects volatility in gaming machines. In typical slot machine games with multiple betting lines, the outcome of one line is linked to the outcome of all the other lines. This is simply due to each reel having a fixed order to symbols. They illustrated that line dependence had the effect of reducing hit probability and increasing the volatility of the game while suggesting that slot machines should be constructed so that their winning lines are minimally dependent on each other. A paper by Singh et al. (2013), while not explicitly a study of volatility, used simulation data to examine how volatility and the resulting skewness of the outcome distribution in determining the mean return to the player with gambling games comparing a low volatility game, Baccarat, with a high volatility game, Slot machines (a type of EGM). Their results are consistent with Turner (2011). Lucas and Singh (2013) also demonstrated that for high volatility games, most simulated players would not be able to reject the hypothesis that the house edge was the same between two games. Similarly, Browne et al. (2015) found that after 10,000 racetrack bets, the track outcomes were so volatile that it was not possible to differentiate actual "skilled" racetrack gamblers from a random distribution.

Near-Misses, Virtual Reels and Distorted Probabilities

Turner and Horbay (2004) provided an in-depth analysis of the mechanics of slot machines and other electronic gambling machines (EGMs). They explained the mathematical principles behind these games and how they are designed to ensure profitability for operators while maintaining player engagement. Their study included an examination of how slot machines created an increased number of apparent near-misses using virtual reel mapping. Additional research on virtual reels has been conducted by Dr. Harrigan and colleagues who have published several papers that explore the structural characteristics of gambling games using PAR sheets, simulations, or mathematical calculations based on PAR sheet data. The PAR sheets are design documents published by the gambling

industry and are used in marketing the game (Harrigan & Dixon, 2009). PAR sheets include information on the hit rates, the house edge, the volatility, options that the casino can implement, and the distribution of the symbols on the virtual reels, as well as bonus features. Harrigan (2008, 2009) obtained PAR sheet for specific games used in Ontario, Canada using the Freedom of Information and Protection of Privacy Act (Harrigan, 2009). These studies examined near-miss effects and distorted probabilities due to virtual reels or other features of gambling machines (Harrigan, 2007, 2008, 2009; Harrigan & Dixon, 2009). Studies have shown that near misses are enhanced by virtual reels on older EGMs, and by lower rates of win symbols in one reel (e.g., the first reel) on more modern multiline EGMs (Harrigan & Dixon, 2009).

Losses Disguised as Wins

Another topic of simulation research is losses disguised as wins (LDWs) occurring in multiline slot machine games when the player experiences a win that is less than the total amount of their bet. For example, the person may bet a total of five dollars but only wins three dollars. Harrigan et al. (2015) examined the structural characteristics of the role of electronic games focusing on one particular commercial game. They computed the outcome assuming that the player had covered 1, 10 and 20 lines holding the total bet per spin constant and analyzed the simulated outcomes in terms of wins, losses, bonuses, and LDWs. The return to player for each configuration was the same, but covering more lines increased the number of LDWs experienced, increased the time spent in bonus rounds, decreased the volatility of the game, and decreased the number of long-term winners; but also decreased the number of simulated players with large losses. When only one line was covered there are no LDWs while with 20 lines covered, most of "wins" were LDWs. Thus, these games encouraged continuous gambling, potentially increasing the risk of gambling-related problems (Harrigan et al. 2015).

In addition, studies by Harrigan, et al., (2011) and Harrigan et al., (2014) confirm that covering more lines increases the number of losses disguised as wins arguing that the high reinforcement rate of the frequent LDWs contributes to their potential addictiveness.

Game Strategies

There have also been simulations examining gambling strategies. As noted above, in some games, simulations can reveal strategies for long-term wins (Thorpe, 1966), but in most games, strategies are either irrelevant or harmful. Turner (1998) created simulations comparing the martingale

system (doubling bets after a loss) to constant betting strategies. If a player starts with a small bet ($5) and doubles until they win: 5, 10, 20, 40 etc. Most of the time the player wins back their money, but only ends up winning the initial $5 bet. If a person wins the $40 bet, they will have risked a total of $75 across the 4 bets, to get back $80 on the 4th bet, for a profit of $5. A person, running this strategy, will experience wild swings in their fortune, but the player will eventually be unable to win back their losses when they either run out of money or reached the maximum bet The authors note that the outcome of the strategy is quite different from constant or random bet sizes, and thus argue that the martingale system creates a strong illusion of control. Turner and Horbay (2003) revisited the effects of incremental betting strategies by examining other systems with smaller increases (e.g., increasing the bets by 1 unit after each loss) or increasing a bet after a win. Their study highlighted the mathematical flaws in all of these system, and they speculate about the psychological impact of systems that often seem to work in the short-term but inevitably leads to substantial losses in the long term.

Harrigan, et al., (2011) also explored different betting strategies on EGMs such as placing the minimum bet on the maximum lines compared to other combination such as placing a maximum bet on a single line. The *mini-max* strategy resulted in an increased their win rate, more losses disguised as wins, lower volatility, shorter winning streaks. According to the authors these properties may increase its potential addictiveness (Harrigan et al., 2011, 2014). Harrigan et al., (2014) examined five different wagering strategies and none had any real effect on the return to the player, but the fact that simulated player was able to control the volatility of the game may enhance the player's illusion of control.

Barr & Durbach's (2008) study that examined independent and dependant lines in slot machine type EGMs, also has some relevance to betting strategy. They suggested that with dependent lines the player would be better off covering an intermediate number of lines.

Playing Games of skill

Relatively few studies of gambling skill have been conducted. Turner and Fritz (2001) explored how the presence of skilled gamblers affects the success of less skilled gamblers. In both study 1 (poker) and study 2 (sports gambling) they examined the effect the number of skilled players on the outcome of the game for less skilled players. In both simulations, as the percentage of skilled players was increased, the games outcome became more random. When the majority of players were skilled, all of the players had a negative expected return though the more skilled players still lost less

than the less skilled players. If 100% of the players were equally skilled, then the outcome of the game was essentially random. Their study revealed that skilled gamblers tend to dominate the game, often reducing the chances of success for less skilled players, which has implications for understanding competitive dynamics in gambling settings.

Browne et al. (2015) studied the distribution of outcomes in a game of skill, off-track horse race. They conducted simulation of outcomes, assuming a naïve player, Mr. Random. Unlike most of the other papers in this review, Browne et al. (2015) also examined the betting habits of 3 actual gamblers to verify their conclusions. The random results of the simulation were compared to the 3 actual players. Browne et al. (2015) report that the outcome of horse bettering was so volatile that even after 10,000 spins, they could not demonstrate an effect of skilled gamblers, however their sample of skilled gamblers (n = 3) was too small to properly determine if skilled gamblers can outperform less skilled gamblers.

In contrast, a study on poker players by Potter van Loon, et al., (2015) examined the data from thousands of online poker players and demonstrated a persistence of skill level across time periods and that in the long term, the outcome of poker games was more related to skill level than to random chance.

Similarly, in Blackjack it is possible to play with a positive expected return using strategies such as card counting (Patterson, 1990; Thorpe 1966). Hsu and Chie, (2021) used computational and stochastic measures to demonstrate the negative impacts on the casino of advantage players who are skilled in blackjack and can legally rely on their knowledge to earn a profit at licensed casinos. The findings illustrate how advantage players are capable of exploiting premium offers and profiting from the casinos. The goal of Hsu and Chie (2021) paper was to discuss how the casino can protect itself from the advantage players, but it does add to our understanding that some games do have a skill element. Interestingly they do not discuss the possible value of advantage players in attracting less skilled players to the casino (Raskin, 2014).

Nudging

Rodermund et al. (2020) present a very different use of simulation methods. Their study was a proof of concept, intended to help researchers preplan of experiments to analyze the effects of nudging *in digital environments.* According to the authors, people often make irrational decisions, but with digital nudging, they can be guided to make better decisions by adapting design elements of the user-interface and the user's choice environment. This study introduced a model that replicates human

behavior in gaming scenarios, focusing on loss aversion. The model was extended to include nudging methods to influence decision-making, demonstrating how these interventions can guide behavior and improve outcomes. According to the authors "The term *nudging* summarizes methods that change a given decision architecture to generate behavior that is beneficial for the decision-making or general public. *Digital nudging* mainly focuses on altering elements of the user interface in order to guide the user's decisions" (P. 2). Nudging is in fact a method used by the gambling industry to increase gambling (Newall, 2019), but can also be used as a method of preventing gambling problems (Auer & Griffiths, 2024; Fortier, et al., 2024). The simulations by Rodermund et al. (2020) showed plausible results and demonstrates how nudging ,might be an effective method of altering behavior to reduce the harm of gambling. The authors propose that simulation-based preplanning can be used to design future experiments that are more cost-efficient and have more ethical experimental designs.

House Edge / Return to Player

Sometimes the expected loss from a game is expressed as return to player (RTP) instead of house edge (see Palomäki, Kunnari, and Laakasuo, 2024). The relationship between house edge and RTP is as follow: 100% - house edge% equals RTP%. Casinos will often advertise their RTP to attract players. In a letter to the editor of Addiction Palomäki et al., (2024) used simulations of the long-term outcome of a coin-flipping game to clarify how RTP may encourage a belief in the gambler's fallacy. RTP can easily be mis-interpreted by players to mean that they can expect to win back what they have lost, as if their wins or losses were "self-correcting" towards the RTP. However, in reality, RTP is merely a mathematical concept that applies over very large samples and many players, and it has significantly less relevance for a single player's realized wins or losses. They authors use graphs of random walks to illustrate that the actual long-term outcomes in gambling do not correct themselves, and it is always possible to, for example, to keep losing more than RTP rates would suggest.

A number of studies have suggested that volatility obscures the house edge. For example, the papers by Singh et al. (2013) and Lucas and Singh (2013) demonstrated that the volatility of many slot machines was so large that most simulated players would be unable to determine the house edge of the game they are playing, and thus actual human players would most definitely not be able to determine the house advantage (see also Browne et al., 2015). As described above, Turner (2011) argues that there is a pragmatic relationship between the volatility and the house edge in

commercial gambling games: games with a lower house edge tend to have lower levels of volatility and vice versa. Related to this issue, both Turner & Shi (2015) and Harrigan et al., (2015) have shown that covering more lines on an EGM resulted in less volatility and a steadier a decline in money based on the long term expected house edge.

Harrigan & Dixon (2010) examined the PAR sheets of two versions of what appear to be identical looking slot machine games which differed in terms of RTP having either an 85% or 98% return to player. They ran simulations to Gambler's Ruin (the point at which the player runs out of money) for 2,000 simulated players, assuming a bankroll of $100, who would play until the bankroll was gone. They found that the typical (median) player's experience did not differ significantly between versions, but that the upper tails of the distributions differed with those in the 98% version having dramatically more total spins, winning spins, entries into the "bonus mode", and large wins ($125 on a given spin). Most importantly, the number of simulated players who had reached a peak balance of more than $1,000 increased from 5 in the 85% version to 54 in the 98% version. These results would suggest that the higher return to player could pose a greater risk of gambling problems.

Houghton and Moss (2022) studied house edge in a very different context. They examined the outcome of bets that were heavily advertised on social media, and found that such bets have a much worse expected outcome than other bets. These findings raise concerns about how social media advertising is being used to direct gamblers to bets with large expected losses. Their results illustrated that the chance of a player making a profit decreases the more they played these advertised bets and suggested that future research is needed as to whether or not players actually respond to such marketing.

Thorngate & Tavakoli (2005) examined the long-term outcomes for *hypothetical gamblers* under various levels of prizes and probability. Their purpose was understanding economic theory and included simulations with positive and negative expected returns and examined some of the consequences of volatility. They report that when the expected value was zero or positive, gamblers playing low risk games with a high hit rate had longer runs of success than gamblers playing high cost, high risk games. However, when the expected value was negative, high-risk games produced longer runs of winning than low-risk games. The result with games with a negative expected return is consistent with the data reported by Turner (2011) and Palomäki et al. (2023).

Turner, Howard, Spence, (2006) conducted simulations of the game of Faro to determine the house edge and to determine how play strategies

impact the outcome of the game. Faro is a card-based gambling game that was popular in the 19th century, but has since largely disappeared, except for some tourist casino that reenact the old west. The dealer turns over two cards at a time. The player places bets on which of the two cards will be higher or one of several more complicated bets. According to Asbury (1938) it was impossible to compute the house advantage of Faro. Turner et al., (2006) show that unlike many games Faro does not have a fixed house edge, but varies depending on a number of parameters and changes as the game progresses. They report that simple bets such as which card is higher, have a house edge from 0.19% to 2.00%.

Overview of the results

Out of the 27 papers reviewed in this paper, the most common topic studied was volatility (9 papers). As shown in Table 1, other papers examined return to player (8 papers), near-misses (5 papers), betting strategies on non-skill games (5 papers), betting strategies on games of partial skill papers (4), losses disguised as wins (3 papers), and nudging, (1 papers). The most active authors using this methodology have been Harrigan with 8 papers, Turner with 8 papers, Dixon with 6 papers, Singh with 2 papers, Palomäki with 2 papers, and Horbay with 2 papers; the remaining authors have only published one paper each.

Discussion

In this study, we identified a total of 27 papers that used pure simulations to study various structural parameters of gambling games. The topics studied included volatility, near-misses, and betting strategies. Some papers covered multiple topics because these parameters of games are not independent of each other. For example, covering multiple lines on a slot decreases volatility and increases the number of losses disguised as wins. Furthermore, volatility and house edge are linked in the design of the games. Games with higher levels of volatility typically have a larger house edge. In addition, there are incentives on multiline EGMs such as near-misses and wins (or LDWs) on the lines not covered, that might encourage people towards covering more lines as they regret missing those winning symbols on the lines not covered (Harrigan et al, 2015; Turner and Shi (2015).

These papers highlight some important aspects of commercial gambling games that may increase the addictive potential of the games. Near misses and losses disguised as wins for example both increase the reinforcing effect of games (Harrigan et al., 2014, 2015). Betting strategies such as doubling after a loss (Turner, 1998; Turner & Horbay, 2003) or covering the maximum number of lines (Harrigan, et al., 2014) may also

change the volatility of the game and may increase the addictive potential of the games. However, the results of Barr & Durbach (2008) suggest that having multiple dependent paylines may reduce the reinforcing effect of more lines covered, suggesting an optimal reinforcing effect of some intermediate number of lines.

The role of volatility in the addictiveness of gambling games may be somewhat complex. Turner argues that in commercial games, volatility is directly related to the house edge such that in all commercial games, the level of volatility is sufficient to obscure the house edge (see Turner, 2011). Low volatility games have a smaller house edge; whereas games with a higher volatility have a larger house edge; and the most volatile games, lotteries, have the largest house edge. In all cases, it would take several thousand bets before the player could accurately assess the long-term house edge. The industry uses 10,000 plays as their benchmark for measuring the volatility of a game for EGMs (Turner, 2011; Ernkvist, 2009). However, even if house edge rates are held equal across gambling games with different levels of volatility, there are notable differences in the number of winning players and the average lengths of winning and losing streaks (Palomäki et al., 2023). For higher volatility games, few lucky players win "the big prize", but all the other players in fact lose significantly more than what the game's house edge would suggest. A fact also reported in Turner (2011) regarding major lotteries: in any short-term evaluation, the lottery's house edge is most likely to be much higher than its long-term expected value, because most of the prize money comes from very rare and very large jackpot prizes.

In addition, it is likely that different combinations of house edge and volatility appeal to different players. For example, tables games which have a lower level of volatility appeal more to males than females (LaPlante, et al., 2019), though both males and females play on moderate volatility EGMs. Browne et al. (2015) also illustrate how the moderately high volatility of horse races bets enhances the illusion of control in that even after 10,000 bets, some players could still be winning even if the choice of bet was purely random.

Finally studies by Browne et al., (2015), Turner (2011), Singh et al. (2013) and Lucas & Singh (2013) indicates that high volatility prevents players from accurately assessing whether a game is fair. Turner (2011) argues the link between house edge and volatility is an intentional aspect of game design to ensure that the player has an enjoyable short-term experience, and that the casino would have a nearly guaranteed win (97%) within 10,000 plays (see Turner, 2011).

A major purpose of this paper is to summarize the research in order to encourage greater use of the simulation method in gambling research. Use of simulations has the potential for improving our understanding of how games work, and can also be used to teach people about long term outcome of the games. This information could improve experimental research studies of gambling and inform prevention initiatives. In addition, such simulations can be used to improve the transparency of the games so that the general public, as well as treatment counsellors and prevention workers, can understand how these games work (see Turner & Horbay, 2003).

Experimental And Prevention Studies Using Simulations

In this paper, we have focused our study on pure simulations that were conducted to understand the structural parameters of gambling games. During our initial literature search we also came across several studies that used the word "simulation" in (1) experimental studies of gambling games parameters including near misses, LDWs, and volatility and (2) interventions studies that use simulated gambling games to teach people about random chance. We will briefly summarize this literature because they are applications of some of the research we have examined in this paper.

Several studies have reported that near-misses can increase motivation to continue playing, increase bet size, and increase arousal (Barton et al., 2017; Clark et al., 2013; Finserås et al., 2021; Palmer, et al., 2024, Pisklak et al., 2020; Wu, et al. 2017). Computer based mathematical simulation studies play an important role in this research by clarifying the nature, type, and frequency of near misses that are programmed into actual gambling machines (see Harrigan, et al., 2007, 2014; Turner & Horbay, 2004).

Similarly, the work on LDWs by Harrigan and colleagues (2007, 2011; 2014; 2015), has stimulated the experimental study of LDWs (Lole, 2013; Myles et al., 2024; Salaghe et al., 2023) and these studies have confirmed that it is an important topic in understanding the potential addictive nature of gambling games. Experimental studies have shown that LDWs increase arousal and motivation to continue playing (Barton et al., 2017). LDWs can be thought of as a way of masking the "negative punishment" of losing (Poling et al., 2002), by giving the player a small "positive reinforcement" of part of their money as well as the pleasurable sounds, and the visual stimuli of winning.

In addition, the nature of game volatility revealed by stimulation studies, (e.g., Barr & Durbach, 2008; Turner, 2011) has become a topic of experimental research (Gallagher et al., 2016; Newall, et al., 2022; Percy et

al., 2021). Research conducted by Percy et al. (2021) has shown that the relationship between game volatility and player behavior is complex and often non-linear (Freeman &Gelber, 2010), Gallagher et al., 2016; Newall et al. 2022; Percy et al. (2021).

Pure simulation studies can play an important role in understanding gambling games and when combined with experimental studies, have led to important gains in our understanding of topics such as near misses, volatility, and LDWs.

In addition to experimental studies, several authors have explored using gambling simulations as prevention or treatment methods aimed at decreasing cognitive biases. Broussard & Wulfert, (2019) call this approach Debiasing Strategies; it may involve physical (e.g., dice) or computer simulations of gambling games. Methods have included school based educational interventions (e.g., Abel, Cole, & Zia, 2015; Turner et al., 2008 a, b, c), interactive tutorials (Horton, et al., 2001; Turner et al., 2008c. 2018; Vitali et al., 2014), virtual reality (Bouchard et al., 2017), and interventions on mobile devices (Andrà et al. 2015; Canale et al. 2016). The focus is typically on understanding the nature of random chance, and may include lessons on volatility, near misses, LDWs, and the long-term house edge (Abel, Cole, & Zia, 2015; Andrà et al., 2015; Broussard & Wulfert, 2017, 2019; Canale et al. 2016; Graydon et al., 2017, 2019, Horton, et al., 2001; Newall, et al., 2022; Percy, et al., 2021; Turner et al. 2018; Wohl et al., 2013). These studies demonstrate that simulations of gambling games can be used to educate people about the nature of gambling and may be effective at reducing the harms of gambling.

A Primer on Simulations

The first aspect of conducting computer-based mathematical simulation studies of gambling games is to carefully research the parameters of the games. The syntax for the simulation should include the rules of the game that are being simulated, as well as the number of items being simulated for each game (e.g., number of reels, dice, or cards). For some games each pay is independently random (e.g., dice, slot machines), however, some games use random without replacement either within a game (e.g., major lotteries, bingo, poker) or between games (e.g., blackjack, and baccarat) and these factors also need to be programmed into the simulation. For some table games (e.g., roulette, craps) the simulation is fairly straight forward and can be accomplished with a relatively simple program. Games that depend on player choice however become more complicated as one needs to factor in choices by the player. For blackjack Thorpe's (1966) computed the outcome for various player choices until he came up with the

optimal choice per game. It is also important to note which set of rules one is including in the simulation as variation in the rules from one casino to another, results in differences in the outcome of the game.

The simulations can be conducted using any commercially available programming language (Visual Basic, C++, Python) or conducted using syntax with a data processing program such as SPSS or Excel (which uses Visual Basic). SPSS has a wide range of different pseudo random distributions to choose from. Commands for random events in all of these program are not actually random, but pseudo random based on a very erratic sequences of numbers produce by an algorithm (see Turner & Horbay, 2003). In using computer generated pseudorandom numbers be sure to set a different number for the seed values in order to get pseudo random results. Otherwise, the results will be exactly the same each time you run the program. Typically, the seed value is set using the time function. However, in testing out the algorithm it might be helpful to use the same seed value each time until you are sure the syntax is correct.

Having set up the program to mimic the rules, one then has to implement the key variables of interest such as differences in house edge (Houghton and Moss, 2022; Palomäki et al., 2023), volatility (Harrigan and Dixon 2009; Turner 2011), differences in lines covered (Harrigan, et al., 2011 ; Turner & Jing, 2015), betting strategies (Harrigan, et al., 2011; Turner, 1998), number of near misses (Harrigan, 2008), advantage play (Hsu and Chie, 2021), losses disguised as wins (Harrigan et al. (2015), dependence between lines (Barr & Durbach, 2008), or other parameters.

Electronic gambling machine outcomes can also be simulated with fairly simple programs when measuring volatility, some betting strategies, or return to player, however if measuring the number of near misses (See Harrigan, 2008; Harrigan & Dixon, 2009) or the number of losses disguised as wins (Harrigan et al., 2014, 2015) one needs to obtain an accurate description of the distribution of symbols on each of the virtual reels from the PAR sheets for the specific game (See Harrigan, 2008; Harrigan & Dixon, 2009; Harrigan et al., 2015).

In some cases, the effects of interest can be directly computed from the PAR sheets (see Harrigan, 2009), but in other cases the game play needs to be simulated. In addition, it should be noted that no two electronic gambling games have exactly the same parameters, but in general parameters such as enhanced near misses and LDWs can be generalized from one specific game to other games with a similar structure.

One caution is to place realistic limits on the amount of money that the simulated player can win or lose. Turner (1998) initially found that the system of doubling after a loss was in fact working and resulted in a

substantial win for the simulated players. This problem was resolved by placing a limit on either the bet size (maximum bet allowed) or bank roll of the simulated player; Either was sufficient to result in the simulated players losing money (Turner, 1998).

Limitations

In this paper we have focused our study on pure simulations that were conducted in order to understand the structural parameters of gambling games. The basic search strategy of "gambling" and "simulations" mostly uncovered papers that were not relevant to the particular search and missed several (12) papers that we knew about already. We did not identify any search terms that were uniquely associated with studies that employed pure simulations and excluded other papers such as social casino games or experimental studies. Consistent keywords to identify studies that use computer-based mathematical simulations of gambling games would facilitate greater awareness and use of this method. In addition, this paper only focused on the published literature, and it is not known if there are relevant studies in non-published reports.

Conclusions

In this paper we examined literature on the use of simulations to understand gambling games. In total we identified and reviewed 27 papers that describe pure simulations that were conducted to understand the nature of the games. The focus has been on papers that involve pure simulation of gambling games with no human participants that were conducted primarily to understand the games themselves. As noted above, the gambling industry utilizes simulations extensively to determine the profitability of the game before the game is released onto the gaming floor (Ernkvist, 2009; Harrigan, 2007; Kilby et al., 2004; Turner, 2011). The industry uses this simulation data published as PAR sheets, to prove that the game fits within the legal parameters for the jurisdiction in which they are being distributed. These PAR sheets are also used in the marketing of the game (Harrigan & Dixon, 2009). However, in terms of problem gambling research there have been surprisingly few studies that have used pure simulations of gambling games to understand the parameters of the games. Those that were uncovered focused on volatility, near-misses, losses disguised as wins, betting strategies, nudging, and return to player. These papers have alerted gambling researchers to important aspects of gambling games including near misses from virtual reels, losses disguised as wins, game volatility, the long-term outcome from betting strategies, and return to players; and have encouraged some researchers to experimentally study these game

parameters, and other researchers to incorporate some of these parameters into prevention interventions. An important goal of this paper is to summarize pure simulation research to encourage additional researchers to utilize simulation methodology to enrich our understanding of both the games and the psychology of the players. The simulations we reviewed were somewhat similar to the simulations run by the gambling industry, but rather than measuring the potential profitability of the games, these simulations were used to (1) understand the nature of the games themselves, (2) to inform prevention and treatment methods about the nature of the games, and (3) to facilitate greater "transparency" of the games making it easier for therapist, researchers, educators, players and the general public to understand the expected long-term outcome of gambling including losses over time and the very small chances of ending up with a net winning. The use of simulation to understand game design has the potential to spur further developments in prevention and treatment methods that utilize our understanding of these games.

Statement of Competing Interest
None declared

Ethics approval
Not required.

Contributions
NET came up with the idea for the review. JP contributed to the planning of the project. JX, AG, and GK conducted some preliminary exploration of the literature on simulations. YAM conducted a formal literature search. NET reviewed the papers and summarized the literature. NET, JM, YAM, and JP wrote and finalized the paper.

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[i] The following is a link that provides some commercially available simulations to help people learn poker https://cardplayerlifestyle.com/poker-software/