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Effects of sequential winning vs. losing on subsequent gambling behavior: analysis of empirical data from casino baccarat players

Nobuhito Abe [a], Ryusuke Nakai [a], Kuniaki Yanagisawa [a], Toshiya Murai [b] and Sakiko Yoshikawa [c]

[a]Kokoro Research Center, Kyoto University, Kyoto, Japan; [b]Department of Psychiatry, Kyoto University Graduate School of Medicine, Kyoto, Japan; [c]Kyoto University of the Arts, Kyoto, Japan

ABSTRACT

Problem gambling is characterized by intense urges to repeatedly engage in gambling and is highly deleterious to individuals' financial and social well-being. A fundamental issue in problem gambling is how repeated and risky betting behavior varies as a function of outcome history. We used empirical data on gamblers playing baccarat, one of the most popular casino games, to examine the effects of sequential winning versus losing on subsequent gambling behavior. Specifically, we analyzed data from 7,935,566 games played by 3,986 players at a land-based casino to examine changes in the betting amount and in the rate of betting on hands with different dividend rates according to prior consecutive wins or losses. The results revealed that the bet amount in baccarat gradually increased according to streak length, and this effect was more pronounced after sequential winning than after sequential losing. The proportions of multiple bets, including 'longshots' – hands with low winning percentages and high dividend rates – decreased after sequential losing but increased after sequential winning. The present study, as the first attempt to analyze a large dataset on baccarat betting, indicates that gamblers shift their gambling behavior to be more reckless after experiencing consecutive wins more than consecutive losses.

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Introduction

Casino gambling is a very large and prevalent industry in many countries, although its expansion inevitably increases concerns about gambling disorder. The fourth edition of the Diagnostic and Statistical Manual (DSM-IV) classified gambling disorder as an impulse control disorder, but recently, the DSM-V reclassified it as a substance-related and addictive disorder (American Psychiatric Association, 2013; Nicholson et al., 2019). This reclassification has entailed the imposition of new requirements on social and medical service providers to address problem gambling in the same way that they address substance-related addictions. Researchers therefore need to address the urgent task of

CONTACT Nobuhito Abe abe.nobuhito.7s@kyoto-u.ac.jp Kokoro Research Center, Kokoro Research Center, Kyoto University, 46 Shimoadachi-cho, Yoshida Sakyo-ku, Kyoto 606-8501, Japan
Supplemental data for this article can be accessed here.

identifying potential risk factors for problem gambling; they must also evaluate and guide effective policy and responsible gambling operations.

Past studies have proposed several biopsychosocial models, such as the pathways model (Blaszczynski & Nower, 2002) or cognitive-behavioral model (Sharpe & Tarrier, 1993), to account for the progression of problem gambling from initial participation to impaired control and persistence. One key element shared across these models is the assumption that the persistence of gambling behavior is closely linked to the experiences of wins. People receive reinforcement through monetary rewards contingent on wins that are experienced intermittently, thus increasing the likelihood of a return to gambling. The models note that the experiences of losses also contribute to the continuation of gambling behavior, especially problem gambling. Losing streaks or the accumulation of losses inevitably occur in gambling, which leads to 'chasing' behavior characterized by the continuation of gambling to recoup money that has been lost (American Psychiatric Association, 2013). Thus, both winning and losing results in continued gambling, and how repeated and risky gambling behavior varies as a function of outcome history is one of the fundamental issues in problem gambling.

To date, many studies have investigated the underlying psychological processes of how the outcomes of prior decisions influence subsequent decisions in different domains, including lotteries, stock prices, and others (for a review, see Oskarsson et al., 2009). More specifically, previous studies on gambling have focused mainly on whether winning or losing is more likely to lead to risky betting, and the results are mixed (e.g. Cummins et al., 2009; Kostek & Ashrafioun, 2014; Leopard, 1978; Mentzoni et al., 2012; Monaghan et al., 2009; Smith et al., 2009; Thaler & Johnson, 1990). For example, Leopard (1978) reported that individuals became more risk-taking following a gambling loss. Before starting each of four gambling tasks, the subjects were provided with 10USD. The amount of money participants had at the end of each gambling task was summed to determine an overall payoff. The results revealed that 67% of the participants became more risk-taking when they were losing rather than when they were winning. Smith et al. (2009) also reported that experienced poker players tend to play less cautiously after a large loss, evidently hoping for lucky hands that will erase their loss. In contrast, Thaler and Johnson (1990) reported that risk-taking behavior increases after a gambling win. They presented participants with a list of hypothetical statements such as 'you have won/lost X, now choose between gamble A and sure-outcome B'. Here, gamble A was a risky option with a greater potential payoff, while sure-outcome B was a riskless option with a smaller payoff. They found that the participants were more likely to choose the risky option of gamble A after a win than after a loss. Another strand of evidence comes from an experiment reported by Cummins et al. (2009). They tested whether college students bet more recklessly following an experimentally induced winning or losing streak in a computerized game of cards. They showed that participants who initially won bet significantly more recklessly than did participants who initially lost.

It seems that the findings from the aforementioned studies support different conclusions, but they are not necessarily mutually exclusive. Instead, it is possible that both consecutive wins and consecutive losses lead to risky betting. For example, Ma et al. (2014) used data from a gambling website and found that long-term cumulative gains and losses both positively predicted an individual's increased online gambling. Lister et al. (2016) used an immersive virtual reality casino and reported that gamblers with a higher motivation to win money were more likely to show chasing behavior in response to both wins and losses. These results suggest a reconciliation between the two competing hypotheses on the effects of winning versus losing on subsequent gambling behavior.

While these past studies have provided insights into changes in betting behavior, a major limitation is that many studies have used highly controlled experimental paradigms, which lack ecological validity. Specifically, some studies have exposed participants to predetermined outcomes (e.g. Cummins et al., 2009; Kostek & Ashrafioun, 2014; Mentzoni et al., 2012), and others have used hypothetical scenarios rather than an actual gambling task (e.g. Thaler & Johnson, 1990). These approaches provide a well-controlled setting to test the specific hypotheses, but the data are largely based on 'moderately' motivated participants, making it difficult to detect the exact effects associated with real monetary decisions. This limitation can be overcome by using field data from casinos. Casino players, unlike typical university students in experimental studies, are motivated to make real decisions using their own money, thus providing the strongest test of how the outcomes of prior decisions influence subsequent gambling behavior.

Another limitation of past studies is that even in the case of field studies, the data on gambling behavior were aggregated or only partially available (e.g. Croson & Sundali, 2005; Keren & Wagenaar, 1985; Narayanan & Manchanda, 2012; Oldman, 1974; Sundali & Croson, 2006). For example, Narayanan and Manchanda (2012) reported that approximately 8% of consumers in their sample could be classified as addicted based on data mainly derived from gamblers playing slot machines. However, the lowest level of data in their study was a 'play', which starts when a customer begins gambling at a station and ends when she exits the station. Thus, the data for the exact sequence of activities within a play, such as each time a consumer puts a coin into the slot machine, were not retained. This limitation prevents researchers from sufficiently analyzing the changes in betting behavior depending on sequential winning versus sequential losing.

In this study, we use a large empirical dataset on gamblers playing baccarat in a casino to examine the effects of sequential winning vs. losing on subsequent betting. Baccarat is the most popular game among high-roller casino players, especially in East Asia, accounting for the majority of casino revenue in gambling enclaves such as the Macao Special Administrative Region (SAR) (Loi & Kim, 2010; Philander et al., 2016). The current dataset on baccarat players has two important features that are suitable for the present investigation. First, the system used in the present study tracks all bets made by all baccarat players throughout the day. Specifically, the data are derived from 'player account-based gambling' (Gainsbury, 2011), which is based on a centralized account that is linked to an individual. That is, the system has unique player identifiers, thus enabling us to analyze player demographics, including age (by 5-year increments), gender, and ethnicity. Second, the duration of the game of baccarat is at most approximately a few minutes, and hence, players often engage in repeated rounds (e.g. even hundreds of times within a day). Thus, the current dataset has rich information on the gambling behavior of each player, enabling us to thoroughly analyze how risky betting behavior varies as a function of outcome history.

The main purpose of the present study was to determine – using empirical data from casino players – whether winning or losing is more likely to lead to risky betting. For this end, we have taken advantage of the rules of baccarat: when the players bet, they can determine the amount of the bet and choose different dividend rates for each hand (i.e. 1

to 1, 8 to 1, or 11 to 1). We can therefore analyze how the outcomes of prior decisions influence subsequent decisions in terms of both the amount of the bet and the dividend rate. To the best of our knowledge, based on empirical data from gamblers playing baccarat, the present study is the first to demonstrate that gamblers tend to shift to riskier betting behaviors after sequential winning than after sequential losing.

Method

Basic setup of baccarat

Baccarat is one of the most popular card games played at casinos (Supplementary Figure 1). A participant may make a bet by guessing whether the 'player' hand or 'banker' hand will win. The participant can also make a 'tie' wager when expecting a draw. All wagers must be within the table limit. The maximum and minimum limits of wagers are assigned at each table, and a participant may choose the limit he/she desires. The dealer draws cards for the player's and the banker's hands according to the drawing rules, and the hand closest to 9 wins. When the total becomes a two-digit number, the first digit is discarded, and only the second digit retains its value. The player's and the banker's hand each receive two or three cards, and the winner will be determined by the sum of those cards. All winning bets on the player's hand will be paid 1 to 1. However, under the commission rule (see below), all winning bets on the banker's hand will have to pay a 5% commission to the house. A winning tie bet will be paid 8 to 1. The original bet (player/banker) is not collected.

The game procedure is as follows: after the dealer finishes the shuffle, the player will be given an indicator card to cut the cards. After the cut, the dealer loads the cards into the shoe to begin the opening game. The game starts while the dealer leads the betting. The dealer proceeds with the game according to the drawing rules. No bets are admitted after the 'no more bets' call. All wagers should be within the limit. When the indicator card comes out, that game will be the last game of the shoe. The dealer's mistakes during the game are managed according to the casino's guidelines for specific cases.

Several game options are relevant to the present study: commission/no commission and pair bets. Under the commission rule, five percent of the winning banker's bet will be deducted as a commission from the payout. Under the no-commission rule, no commission will be deducted from the winning banker's bet. However, 50% of the winning banker's bet will be deducted as a commission when the banker wins with a total of 6. In the current dataset, most games are based on the no-commission rule (approximately one-fifth of the baccarat tables are based on the commission rule).

If the initial two cards in the player's or the banker's hand make up a pair (two cards with the same value), the winner will be paid at a rate of one to eleven. In the case of no pair, the wager will be taken away. Pair betting is available for both the player's and the banker's hand. 10 – J, 10 – Q, 10 – K, J – Q, J – K, and Q – K are counted as the same value of 0 in baccarat, but none of these combinations is a pair. A tie bet or a pair bet is accepted without an original (player/banker) wager. Card drawing must be open.

In baccarat, multiple bets are allowed (e.g. betting on the banker, a tie, and a pair at the same time). The statistical win frequencies are as follows for eight-deck baccarat: 44.62% for players, 45.86% for bankers, 9.52% for ties, and 7.47% for pairs. The house advantage of each hand is 1.24% for players, 1.06% for bankers (for the no-commission rule, 1.45%), 14.36% for ties, and 10.36% for pairs. We therefore regard betting on ties and pairs as 'reckless' betting in the present study. The game rules and further details are summarized in the Supplementary Materials.

Data acquisition

The data were gathered from baccarat tables at a land-based casino located in the capital region in Korea from 20 April 2017, to 31 January 2018. The casino is an affiliated company of SEGA SAMMY HOLDINGS Inc., a funding body of the present study. The casino is open for operation twenty-four hours a day, seven days a week. All customers are foreign nationals, and they need to create a customer account with ID cards. The casino's covenant explicitly states that the deidentified playing data on customers can be analyzed for the purpose of academic research. The data are electronically derived from card and chip recognition systems, which track all bets made by all baccarat players throughout the day. Specifically, the system records who is playing baccarat (based on the ID card), which table and seat the player is in, how many chips the player is betting, and the outcomes of each game through the electronically regulated baccarat tables that can recognize the amount of chips. The ID card system has unique player identifiers, thus enabling us to analyze player demographics, including age, gender, and ethnicity, although it does not contain any markers of problem gambling, such as self-exclusion. We received the deidentified data from the casino through SEGA SAMMY HOLDINGS Inc. After all the data were anonymized, while keeping the data on sex, ethnicity, and age in 5-year increments, it was not possible for individuals to be identified by the researchers. As this study was retrospective in nature, no written informed consent was obtained from the customers. Due to the contract with the funding body, the current dataset is not publicly shared in a repository. This study was approved by the Ethical Committee of Kyoto University Unit for Advanced Study of Mind (29-P-26).

The data set included 27,641 players playing 18,673,193 games. Of these, the games played by individuals who 1) were aged 21 to 80, 2) visited the baccarat table for at least 3 days (range: 3–220 days), and 3) placed more than 70 bets across single or multiple sessions within one of the visiting days were extracted. The number 70 was determined based on the fact that the baccarat game is dealt from a shoe containing 8 decks of cards shuffled together, and after approximately 70 games, the shoe is renewed with a new set of 8 decks. Thus, the number 70 is an indication of repeated gambling behavior at baccarat tables. We excluded from the analyses all the data with a bet amount of 0, which indicated that players remained at the table but did not place a bet. We also excluded the data in which players used only complimentary chips, but we analyzed the data in which players used their own chips combined with complimentary chips (see Supplementary Materials). Then, we confined our analyses to the games that reflect the effects of sequential winning or losing (once, twice, and thrice) on the change in the betting amount for each game and the proportions of a bet (i.e. whether to bet) on different dividend rates. As a result, 7,935,566 games played by 3,986 players were analyzed.

Statistical analysis

To clarify the effects of sequential winning vs. sequential losing on subsequent gambling behavior, we analyzed the changes in the amount bet on each game and the changes in the proportions of a bet on different levels of the dividend rate (i.e. player/banker, tie, and pair). We regarded an outcome of each game as a win if the payout amount was over the betting amount, as a loss if the betting amount was over the payout amount, or a draw if the two amounts were equal. We also regarded a series of gambling outcomes as sequential wins or sequential losses if a prior win/loss was followed by a subsequent win/loss within 10 minutes (Supplementary Figure 2). Thus, we did not model what occurred between two games if the two games were separated by more than 10-minute intervals. Furthermore, to secure a sufficient number of instances analyzed, we did not model outcomes preceded by more than four consecutive wins or losses.

Here, we note that the cards used in baccarat are not serially uncorrelated; thus, previous realizations influence future likelihoods. In this sense, our data suffer from a violation of independent and identical distribution assumptions (i.i.d), although the effect is minimal, given that it is virtually impossible to control win frequency based on the information on the remaining cards in decks.

We applied generalized linear mixed-effects modeling (GLMM) using the 'glmmTMB' package (Brooks et al., 2017) implemented in R (R Core Team, 2019), where models containing fixed and random effects are fitted using maximum likelihood estimation. The visualization of the regression model's terms of interest was performed using the 'sjPlot' (Lüdecke, 2019) and 'ggplot2' (Wickham, 2016) packages. We entered the prior outcome of each game (1 = win, −1 = loss) and the repetition of outcomes (once, twice, and thrice) as well as their interactions as the fixed effects. The sequential numbers of wins or losses were standardized prior to the analysis. In addition to the fixed effects, all possible random effects (i.e. a random intercept and slopes) for participants were included in the analysis (Barr et al., 2013). We apply log transformation to the amount bet on each game to reduce skewness as well as to facilitate the interpretation of results. Models were fit using a Gaussian family in the amount bet on each game or a binomial family in the proportions of bets on different levels of the dividend rate. Effect sizes were calculated using the 'MuMIn' R package (Barton, 2019), which calculates the marginal and conditional coefficients of determination for mixed-effect models. The marginal R^2 of the model ($R^2{}_m$) calculates the variance explained by the fixed effects, whereas the conditional R^2 of the model ($R^2{}_c$) calculates the variance explained by both fixed and random effects.

Results

Demographics of the players

Supplementary Table 1 shows the age, gender, and ethnicity of the players analyzed. The available data on age were based on 5-year increments. The estimated mean age was 46.4 years. Most players were males, and the proportions of Japanese and Chinese players were approximately 40% each. Thus, the typical player in our sample is a middle-aged Asian male.

Bet amount for each game

Table 1 summarizes the results of the bet amount for each game. We found a significant main effect of the prior outcome of each game (win vs. loss), suggesting that the

Table 1. Results of bet amount for each game.

Groups	Estimate	Lower 95% CI	Upper 95% CI	SE	z value	Pr (>|z|)
Fixed effects						
(Intercept)	12.211	12.168	12.255	0.022	551.259	<.001
(slope)						
The prior outcome of each game (win vs. loss)	−0.006	−0.009	−0.002	0.002	−3.332	<.001
Streak length (once, twice, thrice)	0.026	0.025	0.027	0.001	49.362	<.001
Interaction term	0.008	0.007	0.010	0.001	9.961	<.001
	SD	Lower 95% CI	Upper 95% CI			
Random effects						
Participant						
(Intercept)	1.398	1.368	1.429			
(slope)						
The prior outcome of each game (win vs. loss)	0.104	0.101	0.106			
Streak length (once, twice, thrice)	0.022	0.021	0.023			
Interaction term	0.044	0.043	0.046			

participants tended to bet more money after losing than after winning (B = −0.006, 95% CI [−0.009, −0.002], z = −3.332, p <.001). We also found a significant main effect of streak length (once, twice, and thrice), suggesting that the participants tended to bet more money after sequential winning or sequential losing (B = 0.026, 95% CI [0.025, 0.027], z = 49.362, p < .001). Furthermore, we found a significant two-way interaction (B = 0.008, 95% CI [0.007, 0.010], z = 9.961, p < .001). The R^2_m was .0003, and the R^2_c was .723. The result of the interaction effect is illustrated in Figure 1. We found that the participants tended to bet more money after sequential winning (B = 0.034, 95% CI [0.032, 0.036], z = 38.568, p < .001) than after sequential losing (B = 0.018, 95% CI [0.016, 0.020], z = 16.853, p < .001). In addition, the participants tended to bet more money after losing than after winning when the streak length was 1 (B = −0.012, 95% CI [−0.014, −0.009],

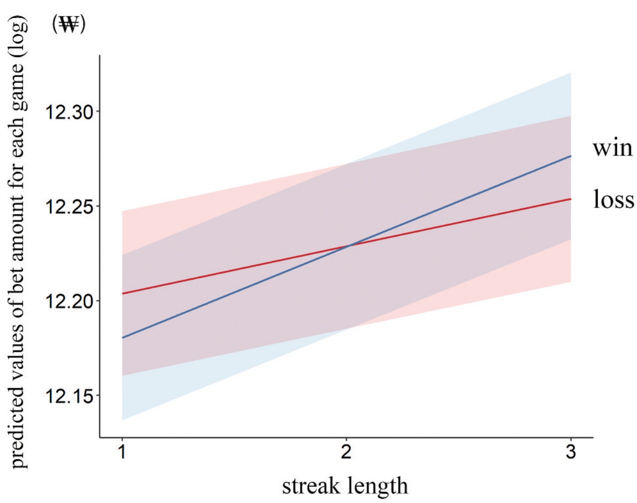

Figure 1. Results of regression analyses predicting the bet amounts for each game (log-transformed) according to the prior outcome of each game (win vs. loss) and the streak length (once, twice, and thrice). The error bands represent the 95% confidence intervals.

$z = -8.670$, $p < .001$), whereas this tendency was not found when the streak length was 2 (B = −0.0002, 95% CI [−0.004, 0.004], $z = -0.078$, $p = .938$), and it reversed when the streak length was 3 (B = 0.011, 95% CI [0.005, 0.017], $z = 3.584$, $p < .001$).

Proportions of bets on each hand

The proportions of bets on each hand were analyzed with logistic mixed-effects regressions. We emphasize that in baccarat, participants bet on the banker or player in most games (> 90%), and they can also simultaneously bet on a tie, pair, or both, in addition to betting on the banker or player. Table 2 summarizes the GLMM results of the proportions of betting on the banker or player (dividend rate: 1 to 1). We found a significant main effect of the prior outcome of each game (win vs. loss), suggesting that the proportions of bets on bankers or players were higher after winning than after losing (B = 0.099, 95% CI [0.089, 0.109], $z = 19.543$, $p < .001$). We also found a significant main effect of streak length, suggesting that the proportions of bets on bankers or players changed with sequential winning or sequential losing (B = 0.008, 95% CI [0.003, 0.014], $z = 2.910$, $p < .01$). Furthermore, we found a significant two-way interaction (B = 0.038, 95% CI [0.031, 0.044], $z = 11.312$, $p < .001$). The R^2_m was .0019 (theoretical) or .0006 (delta), and the R^2_c was .440 (theoretical) or .146 (delta). The result of the interaction effect is illustrated in Figure 2(a). Proportions of bets on bankers or players increased with sequential winning (B = 0.046, 95% CI [0.037, 0.055], $z = 9.859$, $p < .001$), whereas this proportion decreased with sequential losing (B = −0.029, 95% CI [−0.037, −0.021], $z = -7.073$, $p < .001$). In addition, the effect of the prior outcome of each game (win vs. loss) was remarkable when the streak length was 3 (B = 0.178, 95% CI [0.158, 0.197], $z = 17.903$, $p < .001$) or 2 (B = 0.125, 95% CI [0.113, 0.137], $z = 20.018$, $p < .001$), whereas this tendency was weaker when the streak length was 1 (B = 0.072, 95% CI [0.062, 0.081], $z = 14.872$, $p < .001$).

Table 3 summarizes the GLMM results of the proportions of betting on a tie (dividend rate: 8 to 1). We found a significant main effect of the prior outcome of each game (win vs. loss), suggesting that the proportions of bets on ties were higher after winning than after losing (B = 0.141, 95% CI [0.134, 0.148], $z = 40.913$, $p < .001$). We also found

Table 2. Results of the proportions of bets on the banker or player.

Groups	Estimate	Lower 95% CI	Upper 95% CI	SE	z value	Pr (>|z|)
Fixed effects						
(Intercept)	3.416	3.366	3.467	0.026	132.719	<.001
(slope)						
The prior outcome of each game (win vs. loss)	0.099	0.089	0.109	0.005	19.543	<.001
Streak length (once, twice, thrice)	0.008	0.003	0.014	0.003	2.910	<.01
Interaction term	0.038	0.031	0.044	0.003	11.312	<.001
	SD	Lower 95% CI	Upper 95% CI			
Random effects						
Participant						
(Intercept)	1.587	1.548	1.626			
(slope)						
The prior outcome of each game (win vs. loss)	0.210	0.203	0.217			
Streak length (once, twice, thrice)	0.040	0.036	0.046			
Interaction term	0.088	0.083	0.093			

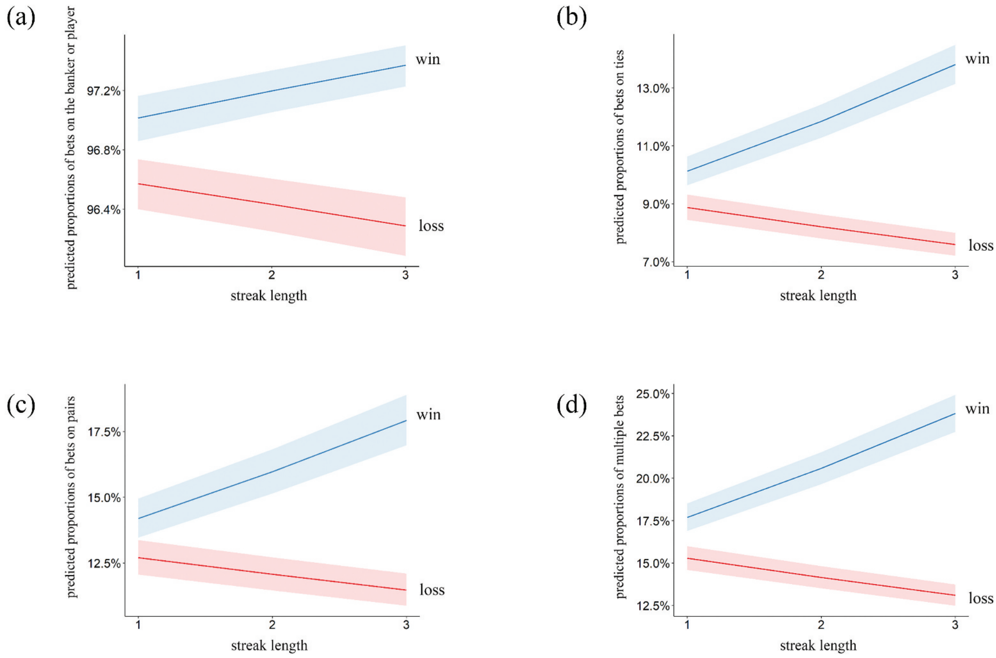

Figure 2. Results of regression analyses predicting the proportions of bets on (a) the banker or player (dividend rate: 1 to 1), (b) ties (dividend rate: 8 to 1), (c) pairs (dividend rate: 11 to 1), and (d) multiple bets, according to the prior outcome of each game (win vs. loss) and the streak length (once, twice, and thrice). The error bands represent the 95% confidence intervals.

Table 3. Results of the proportions of bets on ties.

Groups	Estimate	Lower 95% CI	Upper 95% CI	SE	z value	Pr (>|z|)
Fixed effects						
(Intercept)	−2.233	−2.287	−2.179	0.028	−81.023	<.001
(slope)						
The prior outcome of each game (win vs. loss)	0.141	0.134	0.148	0.003	40.913	<.001
Streak length (once, twice, thrice)	0.032	0.029	0.036	0.002	17.584	<.001
Interaction term	0.092	0.087	0.096	0.002	40.101	<.001
	SD	Lower 95% CI	Upper 95% CI			
Random effects						
Participant						
(Intercept)	1.724	1.684	1.765			
(slope)						
The prior outcome of each game (win vs. loss)	0.158	0.153	0.163			
Streak length (once, twice, thrice)	0.030	0.027	0.034			
Interaction term	0.080	0.076	0.083			

a significant main effect of streak length, suggesting that the proportions of bets on ties changed with sequential winning or losing (B = 0.032, 95% CI [0.029, 0.036], z = 17.584, $p < .001$). Furthermore, we found a significant two-way interaction (B = 0.092, 95% CI [0.087, 0.096], z = 40.101, $p < .001$). The R^2_m was .0046 (theoretical) or .0027 (delta) and the R^2_c was .480 (theoretical) or .279 (delta). The result of the interaction effect is illustrated in Figure 2(b). Proportions of bets on ties increased with sequential winning (B = 0.124, 95% CI [0.119, 0.129], z = 44.992, $p < .001$), whereas this proportion decreased with sequential losing (B = −0.060, 95% CI [−0.066, −0.054], z = −19.328, $p < .001$). In addition, the effect of the prior outcome of each game (win vs. loss) was remarkable when the streak length was 3 (B = 0.334, 95% CI [0.320, 0.348], z = 46.392, $p < .001$) or 2 (B = 0.203, 95% CI [0.195, 0.212], z = 45.797, $p < .001$), whereas this tendency was weaker when the streak length was 1 (B = 0.073, 95% CI [0.067, 0.079], z = 24.621, $p < .001$).

Table 4 summarizes the GLMM results of the proportions of betting on pairs (dividend rate: 11 to 1). We found a significant main effect of the prior outcome of each game (win vs. loss), suggesting that the proportions of bets on pairs were higher after winning than after losing (B = 0.115, 95% CI [0.108, 0.122], z = 31.715, $p < .001$). We also found a significant main effect of streak length, suggesting that the proportions of bets on pairs changed with sequential winning or sequential losing (B = 0.029, 95% CI [0.025, 0.032], z = 17.081, $p < .001$). Furthermore, we found a significant two-way interaction (B = 0.069, 95% CI [0.065, 0.074], z = 30.220, $p < .001$). The R^2_m was .0027 (theoretical) or .0019 (delta), and the R^2_c was .531 (theoretical) or .375 (delta). The result of the interaction effect is illustrated in Figure 2(c). Proportions of bets on pairs increased with sequential winning (B = 0.098, 95% CI [0.092, 0.103], z = 34.837, $p < .001$), whereas this proportion decreased with sequential losing (B = −0.041, 95% CI [−0.046, −0.035], z = −14.199, $p < .001$). In addition, the effect of the prior outcome of each game (win vs. loss) was remarkable when the streak length was 3 (B = 0.261, 95% CI [0.246, 0.275], z = 34.658, $p < .001$) or 2 (B = 0.162, 95% CI [0.153, 0.172], z = 34.471, $p < .001$), whereas this tendency was weaker when the streak length was 1 (B = 0.064, 95% CI [0.058, 0.070], z = 21.439, $p < .001$).

Proportions of multiple bets

Table 5 summarizes the GLMM results of the proportions of multiple bets, and Supplementary Table 2 summarizes the results of proportions of single and multiple

Table 4. Results of the proportions of bets on pairs.

Groups	Estimate	Lower 95% CI	Upper 95% CI	SE	z value	Pr (>|z|)
Fixed effects						
(Intercept)	−1.842	−1.902	−1.782	0.031	−60.208	<.001
(slope)						
The prior outcome of each game (win vs. loss)	0.115	0.108	0.122	0.004	31.715	<.001
Streak length (once, twice, thrice)	0.029	0.025	0.032	0.002	17.081	<.001
Interaction term	0.069	0.065	0.074	0.002	30.220	<.001
	SD	Lower 95% CI	Upper 95% CI			
Random effects						
Participant						
(Intercept)	1.917	1.874	1.962			
(slope)						
The prior outcome of each game (win vs. loss)	0.180	0.174	0.185			
Streak length (once, twice, thrice)	0.032	0.029	0.036			
Interaction term	0.090	0.087	0.094			

Table 5. Results of the proportions of multiple bets.

Groups	Estimate	Lower 95% CI	Upper 95% CI	SE	z value	Pr (>|z|)
Fixed effects						
(Intercept)	−1.600	−1.655	−1.545	0.028	−56.996	<.001
(slope)						
The prior outcome of each game (win vs. loss)	0.160	0.153	0.166	0.003	48.097	<.001
Streak length (once, twice, thrice)	0.034	0.031	0.037	0.002	22.682	<.001
Interaction term	0.098	0.094	0.102	0.002	47.179	<.001
	SD	Lower 95% CI	Upper 95% CI			
Random effects						
Participant						
(Intercept)	1.762	1.722	1.803			
(slope)						
The prior outcome of each game (win vs. loss)	0.168	0.163	0.174			
Streak length (once, twice, thrice)	0.031	0.028	0.035			
Interaction term	0.084	0.081	0.088			

bets. We found a significant main effect of the prior outcome of each game (win vs. loss), suggesting that the proportions of multiple bets were higher after winning than after losing (B = 0.160, 95% CI [0.153, 0.166], z = 48.097, $p < .001$). We also found a significant main effect of streak length, suggesting that the proportions of multiple bets changed with sequential winning or sequential losing (B = 0.034, 95% CI [0.031, 0.037], z = 22.682, $p < .001$). Furthermore, we found a significant two-way interaction (B = 0.098, 95% CI [0.094, 0.102], z = 47.179, $p < .001$). The R^2_m was .0055 (theoretical) or .0038 (delta), and the R^2_c was .491 (theoretical) or .335 (delta). The results for the interaction effect are illustrated in Figure 2(d). Proportions of multiple bets increased with sequential winning (B = 0.132, 95% CI [0.127, 0.137], z = 52.859, $p < .001$), whereas this proportion decreased with sequential losing (B = −0.063, 95% CI [−0.069, −0.058], z = −24.081, $p < .001$). In addition, the effect of the prior outcome of each game (win vs. loss) was remarkable when the streak length was 3 (B = 0.365, 95% CI [0.352, 0.378], z = 53.453, $p < .001$) or 2 (B = 0.226, 95% CI [0.218, 0.235], z = 52.721, $p < .001$), whereas this tendency was weaker when the streak length was 1 (B = 0.088, 95% CI [0.082, 0.093], z = 31.966, $p < .001$).

Discussion

We used casino data on interrelated gambler decisions to analyze the bet amount and the proportions of bets on each hand in baccarat to clarify the effects of prior winning or prior losing on subsequent betting. We found that the amount of bets in baccarat gradually increased according to streak length, and this effect was more pronounced after sequential winning than after sequential losing. The proportions of multiple bets, including longshot bets on ties or pairs, decreased after sequential losing but increased after sequential winning. These results jointly indicate that prior wins on gambling cause baccarat players to bet more recklessly in terms of both the amount bet and the dividend rate.

The increase in the betting amount after consecutive wins is likely to eventually cause heavy cumulative losses and is therefore regarded as a sign of shifting toward risky gambling behavior. The experience of wins supposedly creates expectations that similar consequences will follow in the future. This expectation, along with the intermittent nature of reinforcement in a gambling situation (see Knapp, 1997, on Skinnerian view), encourages the individual to continue to gamble. The behavioral tendency observed in a streak of wins can also be interpreted as a phenomenon reflecting the 'hot-hand fallacy', originally proposed in the context of basketball shooting (Gilovich et al., 1985) – that is, the unreasonable and erroneous belief that the occurrence of a random event is less or more likely to occur. For example, people playing roulette often bet more after winning (Croson & Sundali, 2005), indicating that the players have mistakenly inferred from prior outcomes that they are on a 'hot streak' and that they are more likely to win in subsequent rounds. Likewise, Chau and Phillips (1995) reported that subjects in a simulated blackjack game bet more after a series of wins than they did after a series of losses.

Our interpretation of the effects derived from sequential winning is also substantiated by the analyses of the proportions of bets on different levels of dividend rates. The analyses yielded two main findings. First, the proportions of multiple bets increased after sequential winning. Second, while the change (increase) in proportions of bets on the banker/player was minimal (< 1%), those on ties and pairs were more remarkable. These findings suggest that casino players tend to bet on 'longshot' hands, in addition to regular banker/player hands, after sequential winning. These longshot hands are, by definition, disadvantageous for baccarat players, given that the house advantages of ties and pairs (more than 10%) are much higher than those of the banker/player (approximately 1%). We speculate that baccarat players willingly bet on such disadvantageous hands after sequential winning due to enhanced risk-taking. The present findings are highly consistent with a laboratory experiment reported by Cummins et al. (2009), in which participants who won initially bet significantly more chips on hands that were likely to lose than participants who initially lost.

While the effects associated with sequential winning are relatively clear, patterns of betting behavior after sequential losing are also noteworthy. First, the participants tended to bet more money after losing than after winning when the streak length was lower. Second, although to a lesser extent than after sequential winning, the betting amount increased after sequential losing, despite the decreased proportions of multiple bets. These effects can be interpreted as chasing behavior – risking larger stakes to try to recoup losses. Chasing typically refers to the act of returning to gamble on another day to recoup previous losses (Lesieur, 1977), that is, between-session chasing, but it also refers to the tendency to gamble too long within a particular session, that is, within-session chasing (Breen & Zuckerman, 1999). The effects observed here can therefore be interpreted as within-session chasing, but we do not know whether the present findings generalize to changes in betting behavior across sessions. We leave this question as a topic for future research.

Despite the increase in the betting amount, the proportions of bets, especially those for ties and pairs, decreased after a sequential loss. This finding is consistent with a previous study on online gambling, which found that a recent loss reduced individuals' online gambling, whereas a recent gain increased it (Ma et al., 2014). We propose that while baccarat players might be relatively insensitive to the increase in betting amount over time, they can still shift their behavior to be more risk averse in terms of dividend rates after consecutive losses. It appears that while chasing after losing is an important component of problem gambling, the experience of a win, especially consecutive wins, is more influential on forming risky betting behavior, at least in baccarat games.

The present study has several limitations. First, we have no data on the rates of problem gambling in baccarat players or individual variables that are related to problem gambling, such as self-exclusion. The interaction between the individual variables and in-game markers might explain additional variance in the data. Second, the effect sizes observed in the present study are quite small, pointing to a need for confirmation in future studies. Third, we note once again that the present findings do not provide significant insights into typical chasing behavior, that is, between-session chasing. The analyses focusing on changes in betting behavior across sessions might further shed light on how repeated and risky betting behavior are influenced by the session-by-session outcome history.

While the present findings do not underwrite any specific policy recommendations on gambling operations, it is possible that a better understanding of changes in gamblers' betting behavior will fruitfully illuminate the limitations of capacities upon which we rely in gambling. Given that increased casino visitation is a significant predictor of problem gambling (e.g. Zaranek & Lichtenberg, 2008), our field study provides unique and promising insights into how risky and reckless betting behaviors are escalated even in nonclinical populations. For future studies on problem gambling, it is important to identify betting patterns that can serve as signs to predict the development of gambling-related problems. Further study is needed to classify problem gambling or predict reckless betting behavior on a single-player, game-by-game basis based on behavioral markers (e.g. Braverman & Shaffer, 2012; Dragicevic et al., 2011).

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Ethical approval

HREC institution: Kyoto University Unit for Advanced Study of Mind
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Constraints on publishing

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Competing interests

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Notes on contributors

Dr. Nobuhito Abe, PhD, is Associate Professor at Kokoro Research Center, Kyoto University.

Dr. Ryusuke Nakai, PhD, is Program-Specific Lecturer at Kokoro Research Center, Kyoto University.

Dr. Kuniaki Yanagisawa, PhD, is Program-Specific Lecturer at Kokoro Research Center, Kyoto University.

Dr. Toshiya Murai, MD, PhD, is Professor at Department of Psychiatry, Kyoto University Graduate School of Medicine.

Dr. Sakiko Yoshikawa, PhD, is Vice President at Kyoto University of the Arts.

ORCID

Nobuhito Abe http://orcid.org/0000-0002-9897-4414
Ryusuke Nakai http://orcid.org/0000-0002-3531-2608
Kuniaki Yanagisawa http://orcid.org/0000-0003-0644-5847

References

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (Vol. 5th ed). American Psychiatric Press.

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language*, *68*(3), 255–278. https://doi.org/10.1016/j.jml.2012.11.001

Barton, K. (2019). *MuMIn. Multi-model inference*. R Package Version 1.43.15. https://CRAN.R-project.org/package=MuMIn.

Blaszczynski, A., & Nower, L. (2002). A pathways model of problem and pathological gambling. *Addiction*, *97*(5), 487–499. https://doi.org/10.1046/j.1360-0443.2002.00015.x

Braverman, J., & Shaffer, H. J. (2012). How do gamblers start gambling: Identifying behavioural markers for high-risk internet gambling. *European Journal of Public Health*, *22*(2), 273–278. https://doi.org/10.1093/eurpub/ckp232

Breen, R. B., & Zuckerman, M. (1999). 'Chasing' in gambling behavior: Personality and cognitive determinants. *Personality and Individual Differences*, *27*(6), 1097–1111. https://doi.org/10.1016/S0191-8869(99)00052-5

Brooks, M. E., Kristensen, K., van Benthem, K. J., Magnusson, A., Berg, C. W., Nielsen, A., Skaug, H. J., Mächler, M., & Bolker, B. M. (2017). glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. *R Journal*, *9*(2), 378–400. https://doi.org/10.32614/RJ-2017-066

Chau, A. W., & Phillips, J. G. (1995). Effects of perceived control upon wagering and attributions in computer blackjack. *The Journal of General Psychology*, *122*(3), 253–269. https://doi.org/10.1080/00221309.1995.9921237

Croson, R., & Sundali, J. (2005). The gambler's fallcy and the hot hand: Empirical data from casinos. *Journal of Risk and Uncertainty*, *30*(3), 195–209. https://doi.org/10.1007/s11166-005-1153-2

Cummins, L. F., Nadorff, M. R., & Kelly, A. E. (2009). Winning and positive affect can lead to reckless gambling. *Psychology of Addictive Behaviors*, *23*(2), 287–294. https://doi.org/10.1037/a0014783

Dragicevic, S., Tsogas, G., & Kudic, A. (2011). Analysis of casino online gambling data in relation to behavioural risk markers for high-risk gambling and player protection. *International Gambling Studies*, *11*(3), 377–391. https://doi.org/10.1080/14459795.2011.629204

Gainsbury, S. (2011). Player account-based gambling: Potentials for behaviour-based research methodologies. *International Gambling Studies*, *11*(2), 153–171. https://doi.org/10.1080/14459795.2011.571217

Gilovich, T., Vallone, R., & Tversky, A. (1985). The hot hand in basketball: On the misperception of random sequences. *Cognitive Psychology*, *17*(3), 295–314. https://doi.org/10.1016/0010-0285(85)90010-6

Keren, G., & Wagenaar, W. A. (1985). On the psychology of playing blackjack: Normative and descriptive considerations with implications for decision theory. *Journal of Experimental Psychology. General*, *114*(2), 133–158. https://doi.org/10.1037/0096-3445.114.2.133

Knapp, T. J. (1997). Behaviorism and public policy: B. F. Skinner's views on gambling. *Behavior and Social Issues*, *7*(2), 129–139. https://doi.org/10.5210/bsi.v7i2.311

Kostek, J., & Ashrafioun, L. (2014). Tired winners: The effects of cognitive resources and prior winning on risky decision making. *Journal of Gambling Studies*, *30*(2), 423–434. https://doi.org/10.1007/s10899-013-9365-x

Leopard, A. (1978). Risk preference in consecutive gambling. *Journal of Experimental Psychology. Human Perception and Performance*, *4*(3), 521–528. https://doi.org/10.1037/0096-1523.4.3.521

Lesieur, H. R. (1977). *The chase: Career of the compulsive gambler*. Anchor Press/Doubleday.

Lister, J. J., Nower, L., & Wohl, M. J. (2016). Gambling goals predict chasing behavior during slot machine play. *Addictive Behaviors*, *62*, 129–134. https://doi.org/10.1016/j.addbeh.2016.06.018

Loi, K. L., & Kim, W. G. (2010). Macao's casino industry: Reinventing Las Vegas in Asia. *Cornell Hospitality Quarterly*, *51*(2), 268–283. https://doi.org/10.1177/1938965509339148

Lüdecke, D. (2019). *sjPlot: Data visualization for statistics in social science*. R package version 2.7.0. https://CRAN.R-project.org/package=sjPlot

Ma, X., Kim, S. H., & Kim, S. S. (2014). Online gambling behavior: The impacts of cumulative outcomes, recent outcomes, and prior use. *Information Systems Research*, *25*(3), 511–527. https://doi.org/10.1287/isre.2014.0517

Mentzoni, R., Laberg, J., Brunborg, G., Molde, H., & Griffiths, M. (2012). Effects of sequential win occurrence on subsequent gambling behaviour and urges. *Gambling Research*, *24*(1), 31–38. https://search.informit.com.au/documentSummary;dn=859174546454951;res=IELHSS

Monaghan, S., Blaszczynski, A., & Nower, L. (2009). Consequences of winning: The role of gambling outcomes in the development of irrational beliefs. *Behavioural and Cognitive Psychotherapy*, *37*(1), 49–59. https://doi.org/10.1017/S135246580800502X

Narayanan, S., & Manchanda, P. (2012). An empirical analysis of individual level casino gambling behavior. *Quantitative Marketing and Economics*, *10*(1), 27–62. https://doi.org/10.1007/s11129-011-9110-7

Nicholson, R., Mackenzie, C., Afifi, T. O., & Sareen, J. (2019). Effects of gambling diagnostic criteria changes from DSM-IV to DSM-5 on mental disorder comorbidity across younger, middle-aged, and older adults in a nationally representative sample. *Journal of Gambling Studies*, *35*(1), 307–320. https://doi.org/10.1007/s10899-018-9801-z

Oldman, D. (1974). Chance and skill: A study of roulette. *Sociology*, *8*(3), 407–426. https://doi.org/10.1177/003803857400800304

Oskarsson, A. T., Van Boven, L., McClelland, G. H., & Hastie, R. (2009). What's next? Judging sequences of binary events. *Psychological Bulletin*, *135*(2), 262–285. https://doi.org/10.1037/a0014821

Philander, K. S., Raab, C., & Berezan, O. (2016). Understanding discount program risk in hospitality: A Monte Carlo approach. *Journal of Hospitality Marketing and Management*, *25*(2), 218–237. https://doi.org/10.1080/19368623.2014.1002145

R Core Team. (2019). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing.

Sharpe, L., & Tarrier, N. (1993). Towards a cognitive-behavioural theory of problem gambling. *British Journal of Psychiatry*, *162*(3), 407–412. https://doi.org/10.1192/bjp.162.3.407

Smith, G., Levere, M., & Kurtzman, R. (2009). Poker player behavior after big wins and big losses. *Management Science*, *55*(9), 1547–1555. https://doi.org/10.1287/mnsc.1090.1044

Sundali, J., & Croson, R. (2006). Biases in casino betting: The hot hand and the gambler's fallacy. *Judgment and Decision Making*, *1*(1), 1–12. http://journal.sjdm.org/jdm06001.pdf

Thaler, R. H., & Johnson, E. J. (1990). Gambling with the house money and trying to break even: The effects of prior outcomes on risky choice. *Management Science*, *36*(6), 643–660. https://doi.org/10.1287/mnsc.36.6.643

Wickham, H. (2016). *ggplot2: Elegant graphics for data analysis*. Springer.

Zaranek, R. R., & Lichtenberg, P. A. (2008). Urban elders and casino gambling: Are they at risk of a gambling problem? *Journal of Aging Studies*, *22*(1), 13–23. https://doi.org/10.1016/j.jaging.2007.11.001

Supplementary Materials for

Effects of sequential winning vs. losing on subsequent gambling behavior: Analysis of empirical data from casino baccarat players

Supplementary Methods

<u>Baccarat rules</u>

The rules described below are adopted in the casino at which the current dataset was collected.

In Baccarat, the 10, Jack, Queen, and King are all counted as 0. Other cards are counted at their face value. After all participants place their wagers, the initial 4 cards are dealt by two alternately in the order of player-banker-player-banker. Depending on the outcome of the initial 4 cards, the game may end with 5 or 6 cards. The potential outcomes are as follows: a natural game, a stand game, a more card draw game, and a both sides draw game.

In a natural game, when the initial 2 cards total 8 or 9 on either side, it is natural and the game will be over without drawing any more cards. If the initial 2 cards total 8 or 9 on both sides, the higher value wins. If they are equal, the game ends in a tie.

In a stand game, when the initial two cards of the player total 6 or 7, or the initial two cards of the banker total 7, it is called a “stand”, and the side receives no more draws. If the other side’s card value is less than a stand, one more card is drawn, and the game finishes. The higher value wins; if the two sides have the same value, the game ends in a tie. If both sides are a stand, the game finishes without additional draws.

The higher value wins; if both sides have the same value, the game ends in a tie.

In a more card draw game, if the player's two-card value is less than 5 and the banker's two-card value is 6 or less, the player draws a 3rd card. Depending on the player's 3rd card, the game could end or the banker could draw a 3rd card to end the game. The banker's two-card value (6, 5, 4, 3) and the player's 3rd card decide whether the banker receives an additional draw or not. When the player's two-card value is 5 or less and the banker's two-card value is 6, the game ends if the player's 3rd card is 8, 9, 0, 1, 2, 3, 4, or 5, and the banker gets an additional draw and the game ends if the player's 3rd card is 6 or 7. When the player's two-card value is 5 or less and the banker's two-card value is 5, the game ends if the player's 3rd card is one of 8, 9, 0, 1, 2, and 3, and the banker receives an additional draw and the game ends if the player's 3rd card is 4, 5, 6, or 7. When the player's two-card value is 5 or less and the banker's two-card value is 4, the game ends if the player's 3rd card is 8, 9, 0, or 1, and the banker receives an additional draw and the game ends if the player's 3rd card is 2, 3, 4, 5, 6, or 7. When the player's two-card value is 5 or less and the banker's two-card value is 3, the game ends if the player's 3rd card is 8, and the banker receives an additional draw and the game ends if the player's 3rd card is 9, 0, 1, 2, 3, 4, 5, 6, or 7. The higher the value of the two- or three-card total wins; if both sides have the same value, the game ends in a tie.

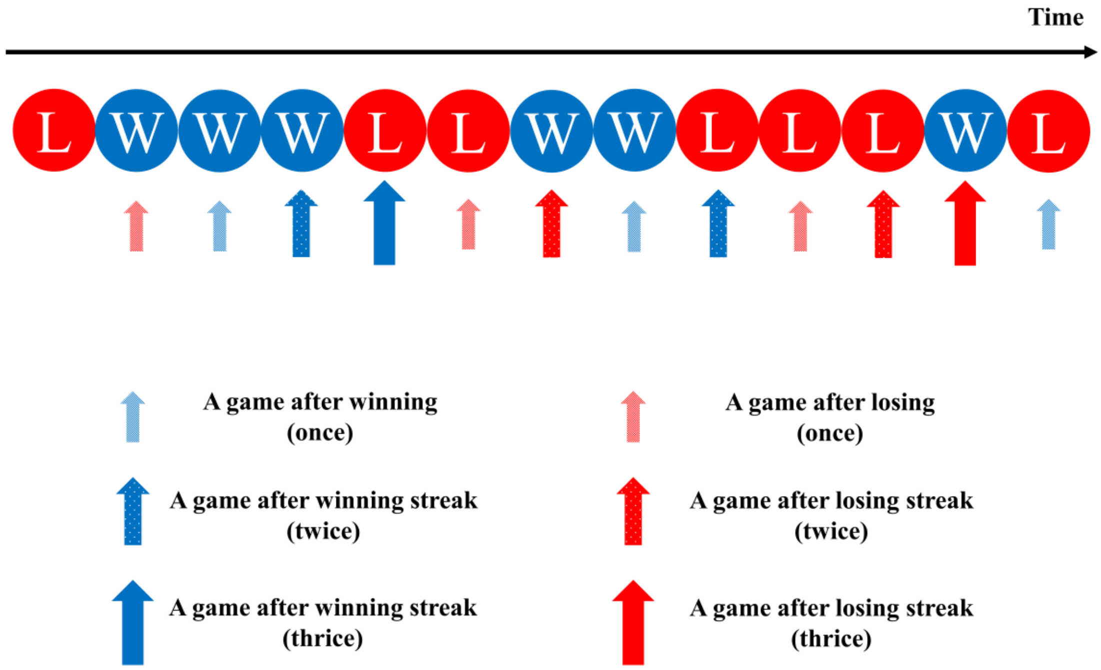
In a both sides draw game, when the player's two-card value is 5 or less and the banker's two-card value is 0, 1, or 2, both sides draw one more card, which is the final draw. The higher value wins. If both sides have the same value, the game ends in a tie.

Complimentary chips

In the casino at which the current dataset was collected, customers can use complimentary chips. However, these complimentary chips are not recorded exactly in the system because some of the complimentary chips are paper-based and cannot be recognized by baccarat tables. In this study, we excluded the data on games in which players used only complimentary chips. However, the data in which players used their own chips combined with complimentary chips remained in the current dataset. We exactly identified that out of 7,935,566 games, 16,334 “win” records (0.21%) fell under this category (based on the “atypical” relationship between the amount of money won and the betting amount), and we estimated that a similar proportion (i.e., approximately 0.21%) of “loss” records were included (which we cannot exactly track within the system due to the amount of monetary outcome being “0”). Given that the proportion of these games is less than 0.5%, the effects of these complimentary chips on our conclusions are thought to be minimal.

Supplementary Fig. 1. Baccarat table. The participant makes a bet on whether the "player" hand or "banker" hand will win (dividend rate: 1 to 1). A bet on a "pair" (two cards with the same value) is available for both the player's and the banker's hands (11 to 1). A "tie" wager can be placed when the participant expects a draw (8 to 1).

Supplementary Fig. 2. Scheme of sequential winning and losing. We regarded a series of gambling outcomes as sequential winning or sequential losing if a prior win/loss is followed by a subsequent win/loss within 10 minutes.



Supplementary Table 1. Descriptive statistics on baccarat players (N = 3986)

Variable	Number	Percentage
Age		
21-25	58	1.5
26-30	247	6.2
31-35	442	11.1
36-40	529	13.3
41-45	629	15.8
46-50	680	17.1
51-55	576	14.5
56-60	368	9.2
61-65	242	6.1
66-70	122	3.1
71-75	63	1.6
76-80	30	0.8
Gender		
Men	3474	87.2
Women	512	12.8
Nationality		
China	1719	43.1
Japan	1650	41.4
Korea	172	4.3
Mongolia	107	2.7
U.S.A.	64	1.6
Vietnam	52	1.3
Taiwan	45	1.1
Others (26 countries)	177	4.4

Supplementary Table 2. Proportions of single and multiple bets

hand	Number	Percentage
Single bet		
player/banker	5354615	67.5
tie	152264	1.9
pair	215602	2.7
Multiple bets		
player/banker and tie	358923	4.5
player/banker and pair	782041	9.9
tie and pair	290996	3.7
player/banker, tie, and pair	781125	9.8