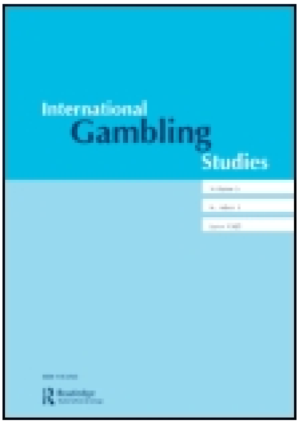

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Psychophysiological arousal signatures of near-misses in slot machine play

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Near-misses in slot machines resemble jackpot wins but fall just short (e.g. two red sevens on the payline and a third just above). These outcomes have been shown to be subjectively arousing outcomes that promote further slot machine play. We assessed the psychophysical responses of 65 participants to wins, losses and near-misses while playing a slot machine simulator. Skin conductance responses were significantly larger for near-misses than either wins or losses. Similarly, heart rate deceleration was significantly larger for near-misses than either wins or losses. These arousal responses were not mediated by players' problem gambling status – near-misses generated large arousal responses even among novice players. We propose that these arousal patterns are due to the frustration of just missing a big win. This research shows the psychophysiological responses triggered by near-misses, and furthers our understanding of how near-misses promote further play.

Keywords: addiction; electronic gaming machines; neuroimaging; neuropsychology; psychology; technology

Introduction

On mechanical reel slot machines near-misses (also referred to as 'near-wins' or 'almost wins' by others) are outcomes that physically resemble large wins, but fall just short (Reid, 1986; Harrigan, 2007a,b). For example, if the jackpot involves three red sevens falling on the payline, a classic near-miss would be two red sevens on the payline and the third just off the payline. Sometimes near-misses of this type will occur by chance alone. In our home jurisdiction of Ontario, Canada, slot machine manufacturers are allowed to design slot machine games so that this type of near-miss occurs up to 12 times more often than by chance alone, as stated in section 20.4.1(a) of Ontario's Electronic Gaming Machine Minimum Technical Standards (AGCO, 2007):

> 20.4.1 (a) Games with reels must meet the following requirements for each of the game reels: For single line games, jackpot symbols may not appear in their entirety more than 12 times, on average, adjacent to the payline, for every time they appear on the payline.

As documented by Harrigan (2007b, 2009), the programming of near-misses of this type are allowed in Nevada.

Near-misses are undesirable outcomes since the player loses their wager on that spin, yet they have been shown to foster the urge to continue gambling (Clark, Lawrence, Astley-Jones & Gray, 2009) and to increase the duration of slot machine play (Cote, Caron, Aubert

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& Ladouceur, 2003; Kassinove & Schare, 2001). Near-misses have been shown to evoke high levels of subjective arousal (Griffiths, 1990, 1991; Parke & Griffiths, 2004), suggesting that they might play a similar role as regular wins (also shown to evoke autonomic arousal; Coventry & Constable, 1999; Coventry & Hudson, 2001; Coventry & Norman, 1998; Sharpe, 2004; Sharpe, Tarrier, Schotte & Spence, 1995; Leary & Dickerson, 1985). Research has suggested that the seeking of this aroused state may be the primary motivation for gambling (Boyd, 1982; Brown, 1986). If that were true, then near-misses could motivate continued gambling because of the sympathetic arousal that they generate.

Near-misses have been construed as a form of cognitive misrepresentation whose effects may generate arousal. Dixon and Schreiber (2004) used subjective similarity ratings to show that participants rated near-misses closer to regular wins than regular losses. Based on this finding they concluded that, 'the near-miss (or in Skinner's words an "almost win") appears to be evaluated by participants as approximating a winning trial more so than a total loss trial type' (p. 344). Griffiths (1991) conjectured that, 'if these excessive gamblers become physiologically aroused when they win *or nearly win*, then in their minds they are not constantly losing but constantly nearly winning' (p. 356). We refer to these types of mentations as cognitive misrepresentations. Our interpretation of this research is that the surface similarity between near-misses and regular wins causes players to mistakenly treat near-misses as somehow akin to a win. The role of surface similarity in triggering reward was highlighted by Peters, Hunt and Harper (2010). They programmed a simulator with slot machine-like features where matching symbols on spinning reels led to food reward for rats. They suggested that near-misses (or 'near-wins') were reinforcing because of Pavlovian generalization. In their view, on winning trials the matching winning symbols on the slot machine become conditioned reinforcers through the pairing of these symbols with food. Near-miss outcomes likewise become conditioned reinforcers because of their visual similarity to the winning outcomes.

The surface-similarity/cognitive misrepresentation account was rejected by Clark et al. (2009) based on players' subjective response ratings of near-misses. When Clark et al. had players rate how pleased they were with different types of slot machine outcomes, wins were evaluated as pleasant, but near-misses were rated as distinctly unpleasant – even more unpleasant than regular losses. If the cognitive misrepresentation account were correct, then participants should have rated near-misses as pleasant (like wins), not unpleasant, and certainly not more unpleasant than losses.

Clark et al. hypothesize that the rewarding property of the near-miss is related to the illusion of control. In their view, players mistakenly interpret the ability to win at slots as a skill, and near-misses reflect this skill. In this sense, players appear to equate near-misses in slots with near-misses in games of skill, like basketball. Just as a three point shot that hits the back of the rim is seen as more skilful than an 'air ball' that completely misses the rim, to some gamblers a near-miss (or 'near-win') in slots is seen as a reflection of their skill that enables them to get very close to the jackpot.

Clark et al. (2009) used brain-imaging techniques to record players' neural activations while playing a two-reel simulator. Regular wins were associated with greater activation in the ventral putamen, anterior insula, midbrain and anterior cingulate cortex than losses. Near-misses were also associated with greater activation of the ventral putamen and right anterior insula. Habib and Dixon (2010) found similar results, with wins activating the left midbrain near the substantia nigra and ventral tegmental area. Furthermore, they found that near-misses activated the same areas that were also activated by regular wins in pathological gamblers, but not non-pathological gamblers, despite both groups rating the near-misses as being similar to the regular wins. Finally, Chase and Clark (2010) found that near-misses activated areas of the ventral striatum similarly to regular wins, and that midbrain activation correlated positively with the severity of symptoms of problem gambling among regular gamblers. The activation of the ventral striatum and dopaminergic midbrain centres is compelling evidence that near-misses activate structures that are widely known to be part of a subcortical system that mediates behavioral reinforcement.

In the Clark et al. (2009) study participants rated near-misses as unpleasant, but the neuroimaging study showed clear evidence that the near-misses activated some brain areas associated with reward. This puzzling result may be resolved by the fact that the mesolimbic reward system contains two distinct functional components. One of these components may be characterized as consummatory (Alcaro, Huber & Panksepp, 2007), and is responsible for the subjective 'liking' of hedonic enjoyment (Robinson & Berridge, 2000). The second component is linked to more appetitive behaviours. It triggers the anticipatory 'wanting' of opportunities that ultimately lead to the satisfaction of needs like food and drink, safety, and status. These two subsystems of the reward circuitry are closely interconnected, but serve distinct motivational and affective functions and have dissociable neurophysiological substrates (Berridge, 2007). The pathophysiology of addiction has been postulated to comprise sensitization of the appetitive system (i.e. 'wanting'), but habituation of the consummatory system (i.e. 'liking') when people are chronically exposed to powerful sources of hedonic reward such as drugs of abuse (Koob & LeMoal, 2008). If near-misses promote appetitive 'wanting' but not consummatory 'liking', then it is possible that near-misses could reinforce persistent gambling behaviour despite the absence of conscious pleasure. Furthermore, when goal pursuit is frustrated (Amsel, 1958), as clearly happens in the case of near-misses, the appetitive approach system of some individuals may respond by activating increased effort and resistance to extinction of the reward-seeking behaviour (Carver & Harmon-Jones, 2009).

Reid (1986) was an early proponent of the frustration hypothesis regarding near-misses. He proposed that near-misses triggered further play in the hope of diminishing this frustrated state. Note that the cognitive misrepresentation theory and the frustration theory both suggest that near-misses are by classical definition *reinforcing* (i.e. near-misses increase the likelihood of further play). However, while the cognitive misrepresentation hypothesis suggests that near-misses are reinforcing because they are hedonically rewarding (i.e. they are miscategorized as wins), the frustration account suggests that misses are reinforcing because they induce a high arousal state of frustration that players wish to get out of by spinning and hopefully winning.

Previous research indicates that frustration can engender large increases in physiological arousal. Hokanson and Burgess (1964) and Burgess and Hokanson (1968) found that inducing frustration in a laboratory increased participants' tonic heart rates by over 20 beats per minute, values far larger than heart rate increases noted for players who won while playing a slot machine (Coventry & Constable, 1999; Coventry & Hudson, 2001; Coventry & Norman, 1998; Leary & Dickerson, 1985).

In all of these studies, researchers measured tonic psychophysiological arousal – changes measured over durations of 60 seconds or more. In real slot machine play, gamblers spin about once every 3–6 seconds and either lose or win on each spin. Researchers have only recently begun to show phasic, event-related psychophysical changes accompanying winning spins and compare these changes to losing spins. Dixon, Harrigan, Sandhu, Collins and Fugelsang (2010) showed that wins led to greater event-related skin conductance responses (SCRs) than losses during multi-line slot machine play. Similar event-related findings have been shown by Wilkes, Gonsalvez and Blaszczynsky (2010). In addition, the magnitude of event-related SCRs have been shown to directly increase with subjective reports of increasing arousal (Lang, Greenwald, Bradley & Hamm, 1993), and are directly related to the sympathetic nervous system activity that leads to arousal (Wallin, 1981).

Importantly, however, SCRs are not only elicited by positive events – frustration can elicit large SCRs. In a study comparing SCRs to different types of feedback (Lobbestael, Arntz & Wiers, 2008), SCRs to frustrating events such as being told they had the wrong answer on a 'Trivial Pursuit' question ($M = 9.14$ μS [microsiemens]) were far larger than the SCRs to being told they had the correct answer ($M = 5.07$ μS). In a study that is particularly relevant to slot machine play, Otis and Ley (1993) measured SCRs to monetarily rewarded lever presses, and compared these responses to the SCRs that occurred when reinforcement stopped. The frustration that occurred with extinction of the reinforcement led to larger SCRs than during the reinforced trials.

In addition to event-related changes in SCRs, event-related changes in heart rate have also been measured for positive outcomes vs negative outcomes. Such outcomes have been shown to lead to a momentary slowing of heart rate. Dixon et al. (2010), for example, showed that slot machine wins led to greater phasic heart rate deceleration (HRD) than losses. They compared the distance between successive heart beats (the so-called 'inter-beat interval' [IBI]) following wins and losses, and showed that IBIs were longer following wins compared with losses. Similarly, studies using picture stimuli have reported that HRD occurs when viewing positive pictures (Bradley, Codispoti, Cuthbert & Lang, 2001; Codispoti, Bradley, & Lang, 2001; Sanchez-Navarro, Martinez-Selva & Roman, 2006) but others have failed to show such effects (Azevedo et al., 2005; Bernat, Patrick, Benning & Tellegren, 2006; Ritz, Alatupa, Thons & Dahme, 2002). Importantly, studies have uniformly shown that HRD occurs in response to viewing *negative* emotional stimuli (Bradley et al., 2001, Codispoti et al, 2001; Lang et al., 1993; Lang, Bradley & Cuthbert, 1997). In addition, Osumi and Ohira (2009) showed that anger/frustration led to a greater HRD than pleasure-inducing triggers. In sum, HRD for frustration appears to be more robust than HRD for positive events – a pattern that mimics the finding that SCRs are larger for frustrating events than for hedonically pleasurable ones.

One goal of this study is to demonstrate empirically, using several psychophysiological measures, that near-misses trigger physiological arousal. A second goal of this study is to attempt to differentiate between frustration theories of near-misses and cognitive misrepresentation theories of near-misses. If near-misses are somehow miscoded as wins, then they should show a pattern of arousal similar to wins. As such, the cognitive misrepresentation theory predicts that near-misses, despite being losses, should show more arousal than regular losses – but not more arousal than wins. If, by contrast, the arousal elicited in response to near-misses reflects their frustrating properties, near-misses should produce even more arousal than wins. In the present study we had players play a three-reel slot machine simulator in which they were randomly exposed to losses, near-misses and wins. During play, we recorded skin conductance responses, heart rate deceleration, and pupil dilation.[1] In the hope of sensitizing players to near-misses, we also had players win a simulated jackpot half way through the experiment. This allowed us to see if the arousing properties of near-misses increased after seeing a jackpot win. For players who seldom played slot machines (novices or low frequency non-problem gamblers), we proposed that a near-miss might cause a negligible arousal response prior to winning the jackpot, but show a more marked response following the jackpot. For experienced players, especially problem gamblers, we reasoned that the responses to near-misses should be significant both before and after the jackpot win.

Finally, because Chase and Clark (2010) showed that the degree to which near-misses activated brain reward centres of the brain depended on gambling severity level, we sought to assess whether larger arousal responses to near-misses might be related to gambling severity.

Method

Participants

We tested 65 people in total (34 females). Gamblers ranged in age from 19 to 63, with a mean age of 44 years old. Five groups of participants were recruited: novice gamblers, low frequency non-problem gamblers (low freq NPGs), high frequency non-problem gamblers (high freq NPGs), at risk gamblers (ARGs), and problem gamblers (PGs). Gambling status was assessed using the PGSI (Problem Severity Gambling Index) of the Canadian Problem Gambling Index (CPGI). NPGs scored two or less on the PGSI, ARGs scored between three and seven, and PGs scored eight or above on the PGSI. Gamblers were recruited from the community using newspaper advertisements, or on-line advertisements on Craigslist and Kijiji. To qualify as a novice, participants must have informally indicated that they did not gamble on slot machines and formally answer zero when asked how many times in the last year they had gambled on slot machines. The demographics of the five groups are shown in Table 1.

Apparatus

All testing was conducted using a slot machine simulator, programmed in Flash, and presented on a 20-inch monitor. A depiction of the slot machine simulator is shown in Figure 1.

The slot machine simulator has three animated reels, a pay-table and counters. The counters indicate the players' bet, the amount won on a given spin, as well as the running total. Skin conductance responses and heart rate changes were acquired using an eight channel, ADinstruments Powerlab (model 8/30). The Powerlab system amplified the ECG signal from three reusable clamp-on electrodes that were attached to the left and right biceps, and the left wrist (ground). Skin conductance levels were recorded using non-gelled electrodes attached to the upper phalanges of the left middle and index fingers. The simulator sent a signal to the Powerlab that served as an event marker indicating the type of outcome (win, near-miss, or loss). The marker was immediately sent as the third reel stopped spinning (i.e. as soon as the outcome was known to the gamblers). These event markers enabled us to time-lock simulator outcomes (commencement of feedback on wins, losses and near-misses) to participants' changes in heart rates and skin conductance levels.

Table 1. Number of participants, mean age (standard deviation in parentheses), gender and frequency of slots playing.

Group	No.	Age (SD)	Males	Females	Slots playing freq. per year	SD
Novices	17	23.71 (9.29)	12	5	0	(0.00)
Low freq NPGs	12	37.58 (17.99)	6	6	7.13	(5.69)
High freq NPGs	13	45.38 (14.03)	5	8	49.38	(48.99)*
ARGs	13	44.31 (14.22)	6	7	32.5	(15.41)
PGs	10	38.10 (11.57)	2	8	55.80	(58.24)

Note: SD = standard deviation; freq = frequency; NPG = non-problem gambler; PG = problem gambler; ARG = at risk gambler
*One high frequency NPG and one PG played 208 times in the 12 month period prior to testing.

Figure 1. A screenshot of a 'near-miss' outcome on the slot machine simulator used. Reproduced with permission.

Participants played the slot machine by clicking on the 'Bet Max' button shown in Figure 1. When players clicked the mouse button, 5 milliseconds (msec) later the three reels began to spin. The first reel stopped after 1140 msec, the second reel stopped 573 msec later and the third reel stopped 616 msec after that. The timing of the reels is shown in Figure 2. As soon as the third reel stopped, an outcome marker was sent to the analysis software allowing the time-locking of psychophysiological responses.

Research design

The simulator presented 240 individual spin outcomes in two pre-randomized orders (made up of 155 losses, 36 near-misses and 49 wins in order 1, and 154 losses, 36 near-misses and 50 wins in order 2). The spins within each order were pseudo randomly intermixed.

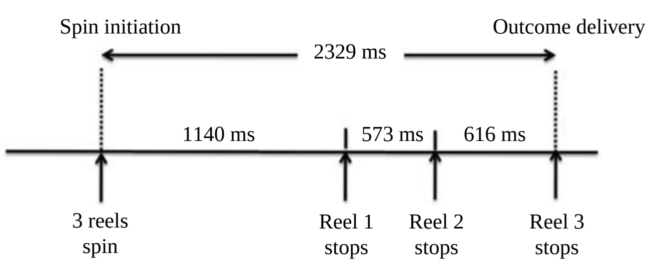

Figure 2. Timing of a typical spin on the simulator. Note that the msec values are approximate (within 1 frame-rate of the 60 Hz monitor).

Wins led to credit gains (5, 15, 25 credits). Although players could see potential wins on the pay table of 50 and 250 credits, such outcomes did not arise. Spins were presented in three separate, 80 spin blocks. Halfway through block 2 (on the 120th spin), a jackpot win worth 2500 credits occurred (three red sevens on the payline). The jackpot win led to a 'hand pay' of $5.00 (Canadian dollars).

Near-misses were of the 'classic' 7–7–X variety in which the first two reels stopped on a red seven, with the third reel showing a red seven just off the payline. We also included six instances of the 7–X–7 near-miss type, and six instances of the X–7–7 type. These latter types of near-misses were included but because of low numbers of instances, were not analysed.

This resulted in 24 classic near-misses being presented in each order. Equivalent numbers of near-misses ($n = 12$) appeared prior to the jackpot win and following the jackpot win. The spin rate was constrained so that there was a minimum of 5 seconds after each outcome delivery (to allow the recording of a sufficient number of inter-beat intervals and to let any SCRs return to baseline).

Procedure

Participants signed a consent form and were administered the Canadian Problem Gambling Index (CPGI). The experimenter then attached the Galvanic Skin Response electrodes and the heart rate electrodes. Participants were told about the pay table and that they would be playing three coins on each spin. Participants were informed that the largest win possible required three sevens which would yield 2500 credits, and that if they hit the jackpot they would win a 'hand pay' of $5. They were told that they would be betting the maximum bet each time, and the various winning combinations were described (three bars, three cherries, etc.). Participants were told where on the pay-table to look to see how much these combinations would yield on a winning spin. They were told that we would be keeping track of their end balance and that we would pay up to $10 at the end of the study depending on the accumulation of these end balances – the more they won on the slot machine, the closer to $10 they would receive.

The experimenter then described specific aspects of the slot machine game, including that the 'winner paid' indicator would indicate how many credits were gained after each win, and that after losses this amount would be 0. The experimenter then pointed out the 'credits' running total indicator and that they would be betting $3 per spin. Participants then put their chins in a chin rest and underwent a brief calibration procedure during which their pupil diameter was continuously measured. They then were shown how to enter $120 of simulated 'money' into the machine using the computer mouse. Blocks were presented using one of the two pseudo randomized orders of the 240 spins, counterbalanced across participants. After participants played all three blocks they were debriefed and compensated.

Results

Two dependent variables were measured: skin conductance responses (SCR magnitudes) and Inter-Beat-Intervals (IBIs).

Skin conductance response magnitudes

To measure skin conductance responses to each spin outcome, we defined a 3-second time-window beginning 1 second after outcome delivery to 4 seconds after outcome delivery (Dawson, Filion, & Schell, 2000). SCRs were defined as the maximum within this window minus the value at the beginning of this window. Average SCRs were calculated for each outcome type (wins, near-misses and losses).

For each participant the skin conductance response magnitude for every single spin outcome was measured. The SCRs of each individual's wins, near-misses and losses were pooled and averaged. Separate averages were calculated for outcomes prior to and after the jackpot. Prior to calculating these averages, the raw SCRs were subjected to an outlier removal procedure advocated by Van Selst and Jolicoeur (1994). When attempting to detect outliers in samples with markedly different numbers of observations there is a bias towards preferentially finding outliers in the larger relative to the smaller samples. The Van Selst and Jolicoeur procedure rectifies this bias by weighting the criterion for removal by the number of observations. This outlier trimming procedure was necessary because regular losses far outnumbered wins and near-misses. Trimming using the Van Selst and Jolicoeur procedure resulted in elimination of 6.2% of the data. Following the outlier procedure, the average SCR amplitudes for each participant were re-calculated for wins, near-misses and losses. After trimming and subsequent averaging, each participant had six average SCR values (pre jackpot losses, pre jackpot near-misses, pre jackpot wins, post jackpot losses, post jackpot near-misses and post jackpot wins).

These SCR values were analysed first using a Time (pre vs post jackpot), by Condition (loss, near-miss, win) by Group (novice, low freq NPGs, high freq NPGs, ARGs and PGs) Analysis of Variance (ANOVA). All effects and interactions employed a Greenhouse–Geisser correction for sphericity. The main effect of group, $F(4, 60) = 1.615$, the main effect of time, $F(1, 60) = 1.15$, the time by group interaction, $F(1, 60) = .668$, the condition by group interaction, $F(8, 120) = 1.607$, the time by condition interaction, $F(2, 120) = 1.130$, and the time by condition by group interaction, $F(8, 120) = 1.044$, were all non-significant. The only significant effect was a strong effect of condition, $F(2, 120) = 17.53$, $p < .001$, $\eta^2 = .226$, observed power = .99. Post-hoc analyses on condition using a Bonferroni correction revealed that near-misses triggered significantly larger SCRs than both wins and losses, but wins and losses did not differ from one another. As can be seen below in Table 2, despite being losses, near-misses generated far more arousal than regular losses, and were over eight times larger than actual wins.

We had predicted that prior to experiencing a simulated jackpot win, novice and low-frequency gamblers would be unlikely to show any arousal responses to near-misses. Once the simulated jackpot win was experienced, however, it would then sensitize these groups to the near-misses in the following spins. By contrast we predicted that high frequency NPGs, at risk and problem gamblers would all show large responses to near-misses right from the inception of the experiment. These predictions were not confirmed by the data – statistically, the time by condition by group interaction was not significant and, as can be seen in Table 3 below, all gambling groups showed unexpectedly large arousal responses to near-misses both before and after experiencing a jackpot.

Importantly, as can be seen in Table 3, nominally the highest arousal responses to near-misses were from the novice and low frequency non-problem gamblers. The problem

Table 2. Mean skin conductance response magnitudes (standard errors in parentheses) for slot machine outcomes.

Condition	Losses	Near misses	Wins
SCR magnitude (μS)	0.078 (0.013)	0.868 (0.186)	0.094 (0.018)

Note: SCR = skin conductance response; μS = microsiemens.

Table 3. Average skin conductance response magnitudes (μS) before and after jackpot wins for novices, low and high frequency non-problem gamblers, at risk gamblers and problem gamblers (standard errors in parentheses).

	Prior to jackpot win			Following jackpot win		
Group	Losses	Near misses	Wins	Losses	Near misses	Wins
Novices	0.08 (0.02)	1.16 (0.33)	0.16 (0.04)	0.09 (0.03)	1.58 (0.41)	0.12 (0.04)
Low freq NPGs	0.11 (0.03)	1.41 (0.39)	0.15 (0.05)	0.10 (0.04)	1.37 (0.49)	0.13 (0.05)
High freq NPGs	0.07 (0.03)	0.39 (0.37)	0.07 (0.05)	0.09 (0.03)	0.44 (0.47)	0.80 (0.04)
ARGs	0.04 (0.03)	0.46 (0.37)	0.04 (0.05)	0.04 (0.03)	0.73 (0.47)	0.03 (0.04)
PGs	0.06 (0.03)	0.39 (0.42)	0.16 (0.04)	0.16 (0.04)	0.28 (0.54)	0.07 (0.05)

Note: freq = frequency; NPG = non-problem gambler; PG = problem gambler; ARG = at risk gambler

gamblers had the lowest SCR magnitudes for near-misses, but they were still far larger than their responses to wins (eight times larger prior to the jackpot and 3.8 times larger than wins following the jackpot). The fact that the grouping variable was not involved in a group by condition interaction underscores the power of the near-miss – it is an outcome that generates high levels of arousal among all levels of gamblers. To ensure that our inability to find main effects or interactions was not due to insufficient numbers in each group, we split the gambling groups into 21 'problematic' gamblers (PGs and ARGs) and 42 'non-problematic' gamblers. Despite having larger numbers of participants in each group, this analysis also failed to reveal any effects or interactions with gambling status, confirming our finding that near-misses generate high levels of arousal among all levels of gamblers.

Inter-beat intervals

Inter-beat intervals are the temporal distance (in msec) between *R*-waves of consecutive heartbeats. The five inter-beat interval (IBIs) for the first six heart beats following spin initiation were recorded for wins, losses and near-misses (IBI 1 = the temporal distance between beat 1 and beat 2, IBI 2, between beats 2 and 3, etc.). Initially, we analysed the IBIs time-locked to outcome delivery (similar to our SCR analysis), but this method revealed significant differences between conditions at the very first IBI. This finding indicated that heart rate changes for certain outcomes (near-misses and wins) were initiated prior to outcome delivery. In light of this finding we time-locked IBI changes to 2 seconds prior to outcome delivery (after the button press but before the stopping of the first reel) in order to capture the gradual unfolding of changes in inter-beat intervals as the consecutive reels stopped to ultimately reveal the outcomes. Heart beat trains were scanned and filtered to minimize artifacts typically due to arm movements. For three participants, the ECG signal was too noisy to analyse (optimal filtering still led to hundreds of artifacts). For the remaining 62 participants, *R*-waves were labelled and the five IBIs between the first six heartbeats were analysed. Prior to calculating averages for each person, the IBIs were submitted to the Van Selst and Jolicoeur (1994) observation-dependent outlier elimination procedure. This ensured that any artifacts not detected by the scanning protocol were caught prior to the main analysis. Trimming using the Van Selst and Jolicoeur procedure resulted in elimination of 1.7% of the data.

This outlier-free data was analysed using a $3 \times 2 \times 5 \times 5$ mixed-model ANOVA with Condition (losses, near-misses, wins), Time (pre-jackpot, post-jackpot) and IBI

(IBI1, IBI2, IBI3, IBI4, IBI5) as the within factors, and with Gambling Status Group (novice, low freq NPG, high freq NPG, ARG, PG) as the between factor. As with SCRs, Group had neither a main effect, nor was it involved in any other interactions (the largest effect being a Group by IBI interaction, $F(4, 232) = 1.020$, $p = 0.423$, n.s.). The data was therefore reanalysed without this variable. The significant main effects and interactions reported below included Greenhouse–Geisser corrections. There was no main effect of time, $F(1, 62) = 0\ .136$, n.s., or IBI, $F(4, 248) = 2.246$, n.s. In addition, neither the Time by Condition interaction, $F(2, 124) = 0.004$, nor the Time by Condition by IBI interaction, $F(8, 496) = 1.691$, were significant.

The ANOVA did reveal a significant Time by IBI interaction, $F(4, 248) = 5.782$, $p = 0.001$, caused by IBIs 4 and 5 being shorter after the jackpot than prior to the jackpot. Since this interaction was not predicted and does not involve heart rate deceleration it will not be discussed further.

There was also a main effect of Condition, $F(2,124) = 14.143$, $p < 0.001$, that must be interpreted in terms of the higher order Condition by IBI interaction $F(8, 496) = 8.379$, $p < 0.001$, $\eta^2 = 0.119$, observed power = 0.998. This interaction is shown in Figure 3. As can be seen in the Figure, there are no differences between the lengths of the interval at IBI 1. For losses, there is no meaningful change in the interval between IBIs 2 and 5. For wins, there is a marked heart-rate deceleration, peaking at IBI 4 with a return to baseline line levels at IBI 5. For near-misses, there appears to be an *even greater deceleration*,

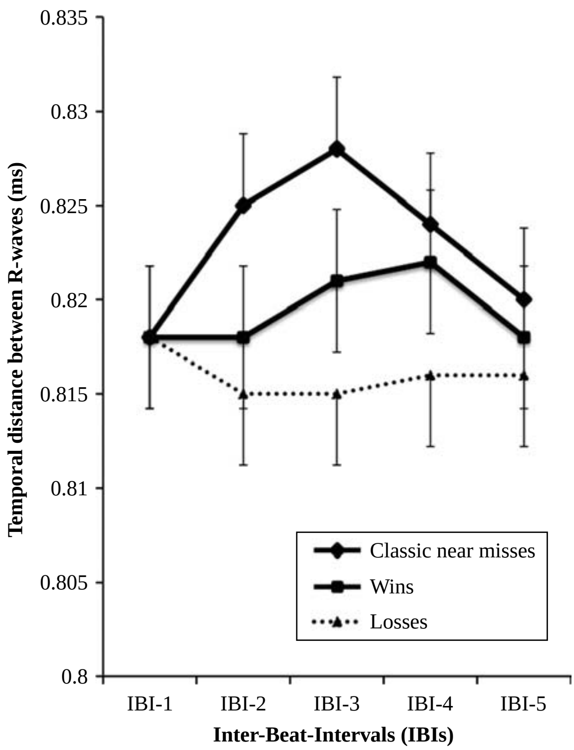

Figure 3. The mean inter-beat-interval durations for near-misses, wins and losses. The five IBIs were calculated using the first six heart beats following the start of the reels spinning. Error bars are Masson and Loftus v 95% confidence intervals for repeated measures designs.

peaking at IBI 3. To statistically verify the impressions conveyed by Figure 3, simple-main effects analyses were conducted on the Condition variable at each separate IBI. Separate two-way (Time × Condition) ANOVAs were conducted to assess the main effect of condition. If the main effect was significant, post hoc comparisons between the means for near-misses, wins, and losses with Bonferonni corrections for multiple comparisons were conducted. These analyses revealed no significant differences between IBI lengths for near-misses, wins, and losses at IBI 1. At IBI 2, however, the main effect of Condition was significant, $F(2, 124) = 17.4$, $p < 0.001$. *Post hoc* analyses revealed that all means were significantly different from one another – wins were associated with significantly longer IBIs than losses ($p < 0.003$), and near-miss IBIs were significantly longer than the IBIs for wins ($p = 0.002$). At IBI 3, the main effect of condition was also significant, $F(2, 124) = 21.779$, $p < 0.001$. Again, *post hoc* analyses revealed that all conditions were significantly different from one another – wins had longer IBIs than losses ($p < 0.001$), and near-misses had longer IBIs than both wins ($p = 0.008$), and losses ($p < 0.001$). Similarly at IBI 4, the main effect of condition was significant, $F(2, 124) = 11.423$, $p < 0.001$. Post-hoc analyses revealed that near-misses were significantly longer than losses ($p = 0.001$) and wins were significantly longer than losses ($p < 0.001$), but near-misses and wins did not differ. At IBI 5 none of the contrasts were significant.

Much like the skin conductance responses induced by near-misses, the heart rate decelerations induced by this type of outcome were similar for all participants in all gambling levels. The group variable neither generated a main effect, nor was involved in any interactions (all F-values involving this interaction were less than 1). To ensure that our inability to find main effects or interactions involving gambling level was not due to insufficient power, we split the gambling groups into 21 'problematic' (PGs and ARGs) and 41 'non-problematic' gambling groups. As with the SCR analyses, the additional power from pooling participants also failed to reveal any reliable effects or interactions with gambling status (the largest effect was a Group by Time by IBI interaction, $F(4, 240) = 1.661$, $p = 0.181$, confirming our finding that near-misses generate high levels of heart rate deceleration among all levels of gamblers.

Discussion

This experiment provided converging evidence of the arousal-inducing power of near-misses. These outcomes generated significantly greater skin conductance responses (SCRs) and significantly larger heart rate decelerations (HRDs) than any other type of outcome. Thus, even though near-miss outcomes resulted in participants losing their wager, they generated more arousal than when participants actually won money.

As a cautionary note, other than the jackpot win, the win sizes were relatively small (5, 15, or 25 credits). Win sizes were intentionally kept small to offset the jackpot win. It is possible that with larger win sizes SCR and HRD effects may have been more similar to those for near-misses. However, the crucial point here is that despite being a loss, near-misses generate far more arousal than other types of losses and far more arousal than wins.

This research provides empirical support for contentions made by Griffiths and colleagues (Griffiths, 1990; Parke & Griffiths, 2004) that near-misses were associated with high levels of arousal. Our findings using SCRs and HRDs all converge to show that this is indeed the case. Whereas Griffiths (1990) and Parke and Griffiths (2004) documented players' feelings of subjective arousal following near-misses, we have shown that such feelings are accompanied by a distinct psychophysiological arousal signature that can be documented with SCRs and HRDs.

Arguably the most important finding is not that near-misses are arousing, but that they are actually more arousing than regular wins. This pattern of data is consistent with other research that shows that frustrating events induce larger SCRs than positive events (Lobbestael et al., 2008; Otis & Ley, 1993), and is also consistent with the findings of Osumi and Ohira (2009) who showed that frustration led to greater HRD than pleasure inducing triggers. Taken together, these findings support the contention of Reid (1986) that near-misses are frustrating events that trigger further gambling as players continue to gamble to get themselves out of this frustrating state.

Importantly, we showed that players of all gambling levels showed the marked elevation of SCRs and increases in HRD in response to near-misses. This finding is in contrast with Chase and Clark (2010) who showed that those with more severe gambling problems showed greater activation in reward coding areas of the brain than those with fewer gambling problems. One possibility for this discrepancy involves the differences in the context by which near-misses were presented to participants. In Clark et al.'s fMRI study, near-misses were presented using a simple two-reel display where on half the trials participants could select the symbol on the leftmost reel. Our three-reel simulator was designed to mimic mechanical reel slot machines where the outcomes on all three reels were all computer selected. Allowing participants to select the symbol to be matched on half the trials likely increases the propensity to engage 'agency' mechanisms, thereby inducing participants to attribute chance outcomes to skill (they *chose* the correct symbol on wins). Thus, near-misses may have been interpreted as skill-related 'just-miss' outcomes in Clark et al.'s design, whereas this agency feature was absent in our design, since our simulator was patterned after traditional mechanical reel slot machines. With reference to our simulator, the stopping positions on all three reels were always computer selected and the outcomes were more complex – different symbols had different payoff amounts.

Our results lead us to contend that near-misses are hedonically unrewarding outcomes that are nonetheless highly arousing. Although they are unpleasant outcomes, they are reinforcing insofar as they encourage further play. We contend that evoking an unpleasant state of frustrated arousal is the mechanism by which near-misses encourage further play. By continuing to play, the gambler attempts to escape that state of frustration. Furthermore, these frustrating outcomes may also heighten the activity of the appetitive "wanting" systems in the brain (Koob & Le Moal, 2008).

In sum, our findings when combined with previous research suggest that near-misses are highly arousing losses that can nevertheless foster the urge to continue gambling (Clark et al., 2009) and lengthen the time players spend at the machine (Cote et al., 2003). Our research suggests that near-misses can be viewed as reinforcing, but not hedonically rewarding. By better understanding players' physiological reactions to the structural features of slot machines such as the near-miss, we hope to provide a factual basis on which regulators can draw upon to inform their decisions when creating or modifying their slot machine regulations. Moreover, we hope this research will guide the development of better intervention strategies that will help players to minimize problem gambling.

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Note

1. Although pupillometry measures were collected, pupil dilation effects were not analysed in because the differently coloured stimuli that represented wins, losses and the predominantly red near-misses could not be equated.

Notes on contributors

Dr Mike J. Dixon is a Professor and former Chair of Psychology at the University of Waterloo. His gambling research includes investigations of 'Losses Disguised As Wins' (LDWs) in multiline slot machines. These are outcomes where the player wins back fewer credits than their total spin wager (e.g. the player bets 1 dollar, and wins 50 cents) yet the slot machine celebrates these net losses with winning sounds and flashing lights. Dixon and colleagues showed that the reinforcing sights and sounds that accompany LDWs trigger arousal responses that are similar to the arousal responses triggered by actual wins. He was awarded the best-oral presentation award from the Alberta Gaming Institute in 2011 for his research on near-misses.

Dr Kevin Harrigan is the Head of the Gambling Research Team at the University of Waterloo. His primary research interest is in gambling addictions with a focus on why so many slot machine gamblers become addicted. Topics of interest include: the structural characteristics of slot machine games, alternative designs for slot machine games, slot machine player education, gaming regulations, PAR Sheets, near misses, losses disguised as wins (LDWs), limitations of random number generators (RNGs), and computer algorithms used in slot machine games. http://gamblin-gresearch.uwaterloo.ca/

Dr Michelle Jarick obtained her PhD at the University of Waterloo. She has conducted research on the electrophysiological brain differences between problem and non-problem gamblers while playing slot machines. Using electroencephalographic recording (ERPs), she has examined the brain activity that is produced by different slot machine outcomes (e.g. wins, losses, near misses, and losses disguised as wins) as soon as they occur. Michelle aims to uncover the neural mechanisms underlying different gambling outcomes to investigate whether or not some outcomes, for example 'near misses', are interpreted (incorrectly) by the brain as 'wins' or (correctly) as 'losses'. As well, she is interested in the differences in brain activation patterns between problem and non-problem gamblers, as it is possible that the brain activity across the different outcomes could be mediated by the amount of gambling experience.

Dr Vance MacLaren was a post-doctoral fellow in the Univenity of Waterloo gambling lab. His research focuses on individual characteristics that may increase vulnerability to addictive behaviour, and the mechanisms by which disinhibition may interact with situational influences to create compulsion.

Dr Jonathan Fugelsang is an Associate Professor at the University of Waterloo. His research focuses on how we integrate multiple sources of information when making complex decisions. He is investigating how various slot machine structural characteristics may influence decisions made by problem and non-problem gamblers.

Emily Sheepy is a Research Assistant with experience in conducting psychophysiological research. She has extensive experience in both acquiring time-locked, event related psychophysical, and in psychophysiological data analytic techniques.

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