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When the game gets personal: the dark side of affective states in a virtual gambling scenario – an exploratory ERP study

Alessandro Quaglieri[1] · Pierandrea Mirino[2,3] · Sara Mercuri[2] · Clarissa Cricenti[2] · Giulia Lausi[2] · Emanuela Mari[2] · Jessica Burrai[2] · Anna Maria Giannini[2] · Pierpaolo Zivi[2]

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Abstract

Mood and cognition are crucial determinants of risk-taking behavior, yet their interaction remains incompletely understood. This study examined how incidental affective states influence risky decision-making by combining a novel multisensory Mood Induction Procedure (MIP) with an immersive virtual reality (VR) slot machine task. Participants ($N=58$) were randomly assigned to positive, negative, or neutral mood conditions before engaging in a gambling task that elicited wins, full-losses, near-misses, and tie outcomes. Behavioral outcomes (i.e., betting choices, decision time) and neurophysiological responses (RewP and P300 components) were recorded to assess feedback processing. Consistent with prior findings, participants exhibited increased risk-taking following near-misses and full losses compared to wins, and showed prolonged decision times after wins, suggesting a post-reinforcement pause. At the neural level, fronto-central RewP and central P300 patterns were observed. While ERP amplitudes were modulated by outcome valence, near-misses elicited intermediate responses between wins and full-losses. However, mood conditions did not result in statistically significant behavioral and electrophysiological changes. These findings suggest that feedback-related ERP components are more strongly driven by outcome characteristics than incidental affective states, at least under the current experimental conditions. The study highlights the value of combining VR and EEG to investigate affective decision-making with high ecological validity. The results may inform theoretical models of outcome evaluation and point to future directions involving stronger mood inductions and larger samples.

Keywords Emotion · Near-misses · Mood induction procedure · Decision-making · Virtual reality

Alessandro Quaglieri, Pierandrea Mirino and Pierpaolo Zivi contributed equally to this work.

✉ Alessandro Quaglieri
alessandro.quaglieri@unimercatorum.it;
alessandro.quaglieri@uniroma1.it

Pierandrea Mirino
pierandrea.mirino@uniroma1.it

Sara Mercuri
mercuri.1902489@studenti.uniroma1.it

Clarissa Cricenti
clarissa.cricenti@uniroma1.it

Giulia Lausi
giulia.lausi@uniroma1.it

Emanuela Mari
e.mari@uniroma1.it

Jessica Burrai
jessica.burrai@uniroma1.it

Anna Maria Giannini
annamaria.giannini@uniroma1.it

Pierpaolo Zivi
pierpaolo.zivi@uniroma1.it

1 Department of Human and Social Science, University Mercatorum, Piazza Mattei 10, 00186 Rome, Italy

2 Department of Psychology, Sapienza University of Rome, Via Dei Marsi 78, 00185 Rome, Italy

3 AI2life S.R.L., Innovative Start-Up, ISTC-CNR Spin-Off, Via Sebino, Rome, Italy

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Introduction

Affective states significantly influence decision-making, affecting various stages from evaluating options to appraising outcomes (Blanchette & Richards, 2010; Lerner et al., 2015). Research shows that emotional states impact goals, attitudes, and risk perception, focusing on how affective valence, positive or negative, modulates these processes (Paulus & Yu, 2012). Often, the emotions involved are not generated by the decision context and integral, but are unrelated and incidental. Mood, a widespread, diffuse, and enduring affective state, differs from emotions, which are typically intense and short-lived (Beedie et al., 2005; Ekman & Davidson, 1994). Despite being often incidental, mood can still be misattributed as choice-relevant and guide decision-making (Västfjäll et al., 2016; Schwarz & Clore, 1983).

This influence becomes particularly relevant in risky decisions. Risk-taking involves choosing options that could lead to substantial gains or losses. High risk-takers often favor high-reward, high-risk alternatives over safer ones with smaller returns (De-Juan-Ripoll et al., 2021). Although many studies have explored how mood affects risk-taking (e.g., Isen & Patrick, 1983; Isen et al., 1988; Slovic & Peters, 2006; Juergensen et al., 2018), the specific mechanisms and direction of this influence remain unclear. To address this, we examined how experimentally induced incidental mood affects risk-taking behavior and its underlying neural correlates.

Several theoretical models offer competing predictions. The Affect Infusion Model (Forgas, 1995, 1998) suggests that positive mood promotes heuristic, global processing, increasing risk-taking, whereas negative mood fosters systematic, analytical processing, leading to caution. In contrast, the Mood Maintenance Hypothesis (Isen & Patrick, 1983) posits that individuals in a positive mood may avoid risk to preserve their current affective state. Conversely, the Affect Regulation Hypothesis (Hill, 2015) proposes that individuals in negative moods may seek risk as a strategy to regulate or improve their emotions. These models differ not only in predicted outcomes but also in their emphasis on cognitive vs. motivational mechanisms. Our study aims to empirically test these competing accounts by combining behavioral data with neural measures.

A particularly compelling phenomenon for examining affect and risk is the near-miss effect in gambling. Near-misses, outcomes that appear close to a win but result in a loss, elicit higher arousal and motivation than full-losses, despite being monetarily identical (Clark, 2010; Clark et al., 2012). These outcomes, common in slot machines, often increase the urge to continue playing through reward signals, likely due to their emotional salience (Dixon et al., 2013). Yet, whether a person's incidental mood alters psychological and physiological responses to near-misses has not been systematically studied. We addressed this by focusing on near-misses as an index of risk-taking and recorded event-related potentials (ERPs) to explore their neural processing. To enhance ecological validity, we employed a Virtual Reality (VR) slot machine task used in prior research (Quaglieri et al., 2024).

Electrophysiological components related to risk-taking

Although no prior studies have specifically examined how mood influences neural responses to near-miss outcomes, some ERP studies have investigated near-misses in gambling and the broader effects of emotion on risky behavior (Clark et al., 2012; Dixon et al., 2013; Juergensen et al., 2018). Thus, the current gaps in the literature highlight the need to clarify how affective states influence the cognitive processing of near-misses.

ERP components linked to outcome evaluation include the Feedback-Related Negativity (FRN), the Reward Positivity (RewP), and the P300 (for a review, see Dores et al., 2025). For example, the P300 has been observed in gambling tasks and reflects processing of the valence, magnitude, and frequency of monetary outcomes (e.g., Wu & Zhou, 2009). It shows larger amplitudes after wins and near-misses than full-losses, particularly when the near-miss occurs before the pay line (Dores et al., 2020). The RewP is associated with early reward-related processing (Glazer & Nusslock, 2022), while the FRN seems to reflect the suppression of the RewP following non-reward outcomes (Proudfit, 2015). These components are often analyzed using difference-waves between wins, near-misses, and losses.

For instance, Dores et al. (2020) found that FRN amplitude following near-misses before the pay line resembled that of wins and was greater than that observed after full-losses. Furthermore, Fryer et al. (2021) reported larger RewP amplitudes after wins than near-misses. Yin et al. (2024) showed that reward expectancy modulated FRN amplitudes in near-misses compared to full-losses. These findings suggest that neural processing of near-miss outcomes occurs early, though the precise timing remains under debate (for a review, see Barton et al., 2017).

Virtual reality as a tool for gambling research

Virtual reality is increasingly used in behavioral research as a tool to investigate risk-taking and its neural underpinnings in immersive, ecologically valid environments (Dickinson et al., 2020). Compared to traditional lab settings, VR elicits heightened engagement, arousal, and task involvement.

This makes VR particularly suitable for studying outcome-related responses such as near-misses. For example, Detez et al. (2019) found that both full-losses and near-misses triggered heart-rate acceleration and quicker bets in subsequent trials. Quaglieri et al. (2024) reported that adolescents with problematic gambling patterns showed more risk-taking after near-misses than full-losses. VR thus appears effective in highlighting risky patterns and identifying cognitive distortions, with potential applications for preventive purposes (Bouchard et al., 2017). Overall, these findings underscore how physiological and behavioral responses to near-misses contribute to maladaptive gambling and support the use of immersive VR environments for early detection and intervention.

Study aims

This study had two primary aims. First, we sought to investigate behavioral and neural responses to the near-miss effect in a VR-based risk-taking task. Second, we examined how incidental mood, induced before task onset using a multisensory procedure (positive, negative, or neutral), modulates outcome processing and decision-making, independent of task-evoked emotions.

Our first goal was to assess VR's potential in the investigation of dissociable ERP markers of outcome evaluation.

Based on the presented literature, we expected:

- Behaviorally, greater risk-taking after negative outcomes (near-misses and full-losses) than after wins, and more risk-taking after near-misses than full-losses.
- Physiologically, larger RewP and P300 amplitudes after wins than near-misses, and larger amplitudes after near-misses than full-losses (Qi et al., 2011).

Our main aim was to explore how mood modulates risk-taking. In line with the literature, we expected:

- Behaviorally, participants in a positive mood take fewer risks than those in a negative mood based on motivational models (e.g., Mood Maintenance). Conversely, if mood has a stronger influence on cognitive evaluation and strategies, the opposite pattern might emerge.
- Physiologically, mood-related effects would emerge at distinct time windows, earlier for motivational (RewP) and later for cognitive (P300) processes associated with outcome evaluation.

Method

Participants

The participants were recruited through advertisements on the official website of "Sapienza" University of Rome (Italy), or through face-to-face requests or social network groups. Exclusion criteria for the research included the presence of psychiatric disorders, progressive neurodegenerative disorders, and neurological disorders. Participation in this study was voluntary, and all those who had partially completed the research protocol were excluded. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board of the Department of Psychology, "Sapienza" University of Rome (protocol number: 273—17/02/2022). Using a mixed ANOVA design with Group as a between subject factor (3 levels: Positive, Negative, Neutral) and Outcome as a within subject factor (4 levels: Win, Full-losses, Near-miss, Tie), a power analyses using MorePower (Campbell & Thompson, 2012) showed that with a power of 0.8, an alpha level of.05, we were able to detect a medium effect size, Cohen's f=.25, with 63 participants for the main effect of Outcome and 78 participants for the interaction.

High scores in alexithymia (i.e., Toronto Alexithymia Scale, TAS-20) and gambling severity (i.e., South Oaks Gambling Severity, SOGS) were considered as exclusion criteria. Thus, according to these criteria, 7 of the 67 recruited participants scored above the cut-off TAS-20 score (i.e.,$>=61$) and 2 additional participants scored above the cut-off SOGS score (i.e.,>5) and were excluded. The final sample consisted of 58 participants (26 males) aged between 18 and 39 years (M = 23.33, SD = 4.48).

Each participant was pseudo-randomly assigned to one of three mood conditions (positive, negative, or neutral) upon their arrival at the laboratory. This pseudo-randomization was implemented to ensure an approximately balanced number of participants across groups, while maintaining unpredictability in the allocation sequence.

Participants were blind to the group assignment and to the aims of the study. Specifically, they were unaware of the study hypotheses and the condition to which they had been assigned. All participants were debriefed at the end of the experimental session regarding the purpose of the study. The final sample included 16 individuals in the positive condition, 20 in the negative condition, and 22 in the neutral condition. The participants did not show significant age differences across groups, $F(2, 55)=.006$; $p=.994$.

Questionnaires

The **South Oaks Gambling Screen** (SOGS, Italian version Guerreschi & Gander, 2002) is a self-reported 20-item questionnaire based on DSM-III criteria for pathological gamblers. Individuals with a score of 5 or higher are potential pathological gamblers. In this study, the Italian version of the SOGS was used and reported to have a Cronbach's alpha of.94.

The **Toronto Alexithymia Scale** (TAS-20, Italian version, Bressi et al., 1996) is one of the most common measures of alexithymia, a multifaceted personality construct characterizing difficulties in the cognitive processing of emotions (e.g., emotion identification and recognition). It consists of twenty items to be rated on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree), structured in three subscales (i.e., Difficulty Identifying Feelings, Difficulty Describing Feelings, and Externally Oriented Thinking). In this sample, it showed good internal consistency with a Cronbach's alpha of.83. Higher total scores on the TAS-20 indicate greater difficulties in the cognitive processing of emotion.

The **Positive and Negative Affective Schedule** (PANAS, Italian version, Terracciano et al., 2003) is a 20-item (i.e., 10 positive and 10 negative adjectives) that measures positive and negative dimensions of affective experience. In this study, we adopted the state time version by instructing participants to report the extent to which they feel "at this moment" as described by each of the 20 adjectives. It showed a good internal consistency reliability for both the positive (PA),.79, and negative (NA),.82, subscales.

MIP procedure (MIP)

The MIP procedure (MIP) consisted of viewing a 360° video using an OCULUS RIFT S headset. The MIP started with a short one-minute video taken from different cartoons, followed by sequential viewing of 12 s each of 10 Velten's statements and 10 IAPS pictures (described below), and ended with an additional short video clip lasting approximately one minute. The pictures and statements sequences were combined with headphone listening to music congruent with the mood. The total duration of the MIP procedure is approximately six minutes (Fig. 1).

Audio-clips

In this study, we adopted a professional studio recording of two pieces of classical music for both positive and negative conditions. Concerning the positive and negative MIP conditions, a Serenade No. 13 kV 525 G-Major, Allegro by Wolfgang Amadeus Mozart, and the Adagio for Strings, Op. 11 by Samuel Barber were used, respectively. These two music clips have already been used by different studies as positive and negative inductions in the MIP literature (for a review, see Västfjäll, 2001).

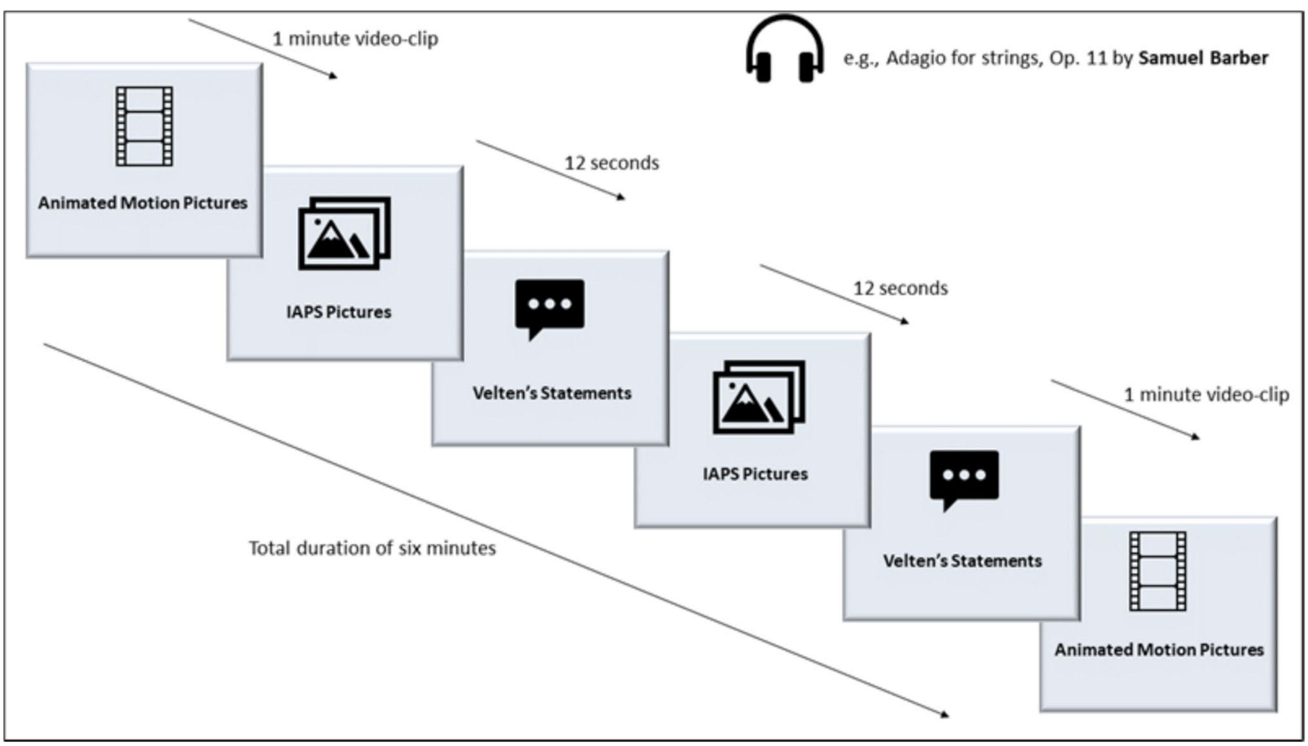

Fig. 1 Example of the timeline for the MIP procedure

Despite the literature proposing different neutral pieces of music, we preferred a different approach, considering the perceived neutrality of music to be extremely subject-dependent (Krumhansl, 1997); therefore, concerning the neutral condition, we decided to present a studio recording of brown noise as a neutral auditory stimulus, instead of a piece of classical music.

Video clips from animated motion capture movies

Positive and negative MIP video conditions started and ended with a short 1-min video clip taken from different famous cartoons (e.g., Aladdin, The Lion King, Dumbo, Jungle Book). From movies, we extracted mood-congruent scenes according to the condition; for example, in the negative condition, we selected scenes such as Mufasa's death (i.e., when Simba is tricked into believing he was responsible for his father's death). For the positive condition, we selected scenes such as the Hakuna Matata dance (i.e., after Mufasa's death, Timon and Pumbaa talking to Simba about moving forward from their troubled pasts and forgetting worries). For the neutral condition, according to the same reason as the neutral audio condition (i.e., the neutrality of video, especially in cartoons, is extremely subject-dependent), we used an open-source fractal editor software "Apophysis" for Microsoft Windows, to develop a short 1-min video clip of fractal art with a kaleidoscopic geometric motive.

Velten's statements

We selected 10 positive, 10 negative, and 10 neutral sentences taken from Velten's statements (Velten, 1967; Jennings et al., 2000). Concerning the positive MIP condition, we selected 10 statements (i.e., item 4; 7; 32; 49; 50; 57; 59; 64; 65; 70, Jennings et al., 2000) with the following criteria: the mean score for "Valence" was 5.8 (ranging from 4.9 to 6.9); while for the "Arousal" the mean was 5.1 (ranging from 4.4 to 5.8). For the negative MIP condition, 10 statements (i.e., 6; 9; 35; 38; 52; 55; 67; 68; 73; 78, Jennings et al., 2000) were selected. The mean value for "Valence" was 4.3 (ranging from 3.7 to 4.9), and for "Arousal" was 4.0 (ranging from 2.9 to 4.8). Lastly, for the neutral MIP condition, 10 statements (i.e., 1; 12; 14; 17; 18; 58; 62; 66; 75; 77) with a mean "Valence" of 4.6 (ranging from 4.0 to 6.1), and a mean "Arousal" of 3.7 (ranging from 3.4 to 4.4) were selected.

Affective pictures

Thirty pictures from the International Affective Picture System were selected (IAPS; Lang et al., 2005); of these, 10 were positive (i.e., 1710; 1463; 2339; 2340; 4599; 5829; 7325; 8461; 8496; 8510), 10 were neutral (i.e., 7003; 7012; 7059; 7130; 7150; 7175; 7559; 7560; 7700; 9468), and 10 were negative (i.e., 2345.1; 2456; 2458; 6838; 9163; 9220; 9530; 9800; 9903; 9940). Concerning the positive MIP condition, the mean of "Valence" was 7.4 (ranging from 6.7 to 8.3, and with a "Arousal" mean of 4.8 (ranging from 3.5 to 5.7). In the negative MIP condition, the "Valence" mean was 2.5 (ranging from 1.6 to 4.6), and the "Arousal" mean was 5.5 (ranging from 4.0 to 6.0). For the neutral condition, the mean of "Valence" was 4.6 (ranging from 4.2 to 4.9), and the mean of "Arousal" was 3.3 (ranging from 1.7 to 5.2). According to normative ratings, positive pictures were more pleasant than negative and neutral ones, and less emotionally arousing than negative; positive and negative pictures were more arousing than neutral pictures.

VR Gambling scenario

The VR gambling scenario was developed on Windows 10 64-bit (Microsoft, Washington, United States) by using Unity 3D engine (Unity Technologies, San Francisco, United States), Oculus Utilities (v1.3.2), and 3DS-Max 2014 (Autodesk, California, United States) for 3D object modelling. The VR scenario used was developed by Quaglieri et al. (2024), in which the authors tested its validity for studying problem gambling behavior in adolescents (i.e., near-miss effect). The scenario entails a participant entering a bar-like setting and then progressing to a slot-machine room using a joystick and footprints on the floor. Once there, the participant selects one of three visually distinct slot machines with the same underlying trial structure. Each round involves selecting a bet amount, starting the round, and potentially winning or losing virtual points based on the reel combinations (see the supplementary materials; Figs. 4 and 5). Participants had to pull the handle to start the spinning reel, which decelerated to a standstill in 6.0 s. To avoid including any ERP components generated by outcome-related audio-feedback, we postponed the occurrence of the sound by 1 s from the visual feedback.

Wins occur when all four reels show the same icon, while full-losses happen with all four different icons. Draws (ties) and near-misses are also possible outcomes. Four types of wins with varying icons and payout rates are presented, with a legend available for reference above the slot machine. Full-losses and near-misses result in the same monetary loss, while ties yield no loss or gain. The predetermined trial sequence consists of 14 wins, 44 full-losses, 28 near-misses, and 14 ties out of 100 trials, aligning with literature recommendations on near-miss ratios (Clark et al., 2012), plus a first trial conveying a tie. For detailed information about the scenario, see Quaglieri et al., 2024.

EEG recording and pre-processing

The EEG was measured (BrainProduct GmbH actiChamp-64 Plus, Germany) using Ag/AgCl active electrodes located in a headset cap in sixty-four channel positions. A total of 64 EEG electrodes were used, arranged according to the international 10–20 system. A ground electrode was located on the forehead, and the FCz electrode was used as a reference channel. Electrode impedances were kept below 25 kΩ (as recommended by the manufacturer), and all signals were sampled at a frequency of 1000 Hz. The 65th and 66th channels of ActiChamp-64 Plus (i.e., auxiliary sensors) were used for acquiring the electrocardiography (ECG) and galvanic skin response (GSR), respectively, but their data will not be discussed in the present paper. Electrophysiological activity was recorded using the BrainVision Recorder software and analyzed using Analyzer software (Brain Products GmbH, Germany) synchronized to the participants' responses and the virtual reality environment. Data preprocessing was performed using the Brain Vision Analyzer software. Firstly, we removed the mastoid channels (TP9, TP10) due to a noisy signal and downsampled to 250 Hz. We used linear derivation between an electrode placed over the right outer canthus (using FT10) and Af7 to compute horizontal ocular activity, and between an electrode placed below the left eye (using FT9) and Fp1 to compute vertical ocular activity. Raw data were band-pass filtered using zero-phase shift Butterworth filters with cutoffs of 0.1 and 20 Hz (order 4) and a 50 Hz notch filter. We performed an automatic raw data inspection, with a maximal allowed voltage step of 50 µV/ms, 0.5 µV of lowest allowed voltage in 100 ms, a maximal allowed difference of 400 µV in 200 ms, and a minimal/maximal allowed amplitude of −200 µV and 200 µV. Then, all electrodes were referenced to the average of all the scalp channels. Lastly, ocular correction was performed as implemented in BrainVision Analyzer by using the Gratton and Coles algorithm.

ERP measurement

We segmented the pre-processed EEG time-locked to the final reel's stop, separately for each outcome (i.e., win, full-losses, near-misses, and tie outcome). For each segment, an automatic rejection of segments presenting a max–min difference higher than 100 µV (within the 1200 ms interval length) was conducted. In the resulting segments, we inspected ERPs related to feedback evaluation processes, specifically the Reward Positivity (RewP) at the FCz electrode and the P300 at Cz as suggested by both the literature (Krigolson, 2018; Olofsson et al., 2008) and visual inspection. The mean number of segments retained for the analyses were 13.74 (SD 1.13) for wins, 27.55 (SD 1.70) for near-misses, 43.10 (SD 3.09) for full-losses, and 14.45 (SD 1.16) for ties in FCz, and were 13.78 (SD 0.90) for wins, 27.62 (SD 1.17) for near-misses, 43.21 (SD 2.18) for full-losses, and 14.45 (SD 0.96) for ties in Cz channel. According to visual inspection of the grand-average potentials and the literature, the RewP was measured as the average amplitude between 250 and 350 ms, while the P300 was measured between 400 and 500 ms. These temporal windows were coherent with those used in the literature, as also highlighted in a recent systematic review on the neurophysiological correlates of near-misses in gambling (Dores et al., 2025). Baseline correction was computed according to a 200-ms window before the stop of the last reel.

Procedure

Before entering the lab, participants were briefed about experiment procedures with a brief description of the head-mounted display functionality (i.e., Oculus Rift S) and the potential symptoms of cybersickness. All participants provided written informed consent. The protocol developed includes three MIP conditions: a positive, a negative, and a neutral condition. All conditions combined elements from three of the most widely and already used successful procedures (e.g., IAPS, "Velten" statements, video and audio clips; for a meta-analysis see Westermann et al., 1996). The participants completed questionnaires on the variables of interest (e.g., gambling severity, alexithymia) before the experimental session through the Qualtrics platform.

Participants were first asked to self-assess their affective state by completing the PANAS questionnaire. After completing this questionnaire, devices for recording physiological measures were set up, and participants were placed in a comfortable chair for an additional 5 min for a baseline recording. Subsequently, the MIP procedure was administered to them (through the headset Oculus Rift). After the MIP, participants were asked to reassess their affective state (i.e., through the PANAS) and finally were invited to play the VR scenario. To prevent participants from complying with the experimental demands, the true purpose of the MIP procedure was concealed until the end of the experimental session. At the end of the experimental session, the participants were debriefed and received a compensation of 25€ (i.e., a shopping voucher) for participating and completing the study.

Statistical analysis

Statistical analyses were performed by using SPSS software (version 26). First, the internal consistency of the instruments was evaluated using Cronbach's Alpha. To examine participants' risk-taking behavior, we assessed their betting choices, distinguishing between a "safe" bet of 5 coins and a “risky” bet of 25 coins. We specifically focused on these two bet amounts, excluding the 10-coin bet (available bet on the slot machine); this choice was made to maximize the contrast between low- and high-risk conditions and to avoid interpretive ambiguity associated with the middle option, in line with our objective to examine clear differences in risk-taking propensity. This approach ensured that our analysis captured decisions that reflected distinct levels of risk-taking. We calculated a risky bet ratio by dividing the number of risky choices by the total of risky and safe choices made after each slot-machine outcome (i.e., Number of risky choices/(Number of risky choices + Number of safe choices)). Additionally, we investigated participants' decision times following each outcome.

Concerning the VR task, we conducted a 3 × 4 mixed ANOVA with Group (positive, negative, neutral) as a between-subjects factor and Outcome (i.e., Win, Loss, Near-miss, and Tie) as a within-subjects factor. We used the same ANOVA design for both participants' bet amount (BET) choice and decision time (DT). For the DT, we considered outliers the decision times higher and lower than 3 SD from the individual mean in order to remove the slowest and fastest responses from the analysis.

Concerning the ERP analysis, the RewP and P300 amplitudes were analyzed by using a 3 × 4 mixed ANOVA with Group (i.e., positive, negative, and neutral MIP condition) as a between-subjects factor, and Outcome (i.e., Win, Loss, Near-miss, and Tie) as a within-subjects factor.

To further isolate the differential activity between wins and the two loss outcomes (i.e., Full-losses and Near-misses) and inspect the processes underlying the evaluation of gains while reducing the noise related to other processes common to the different outcomes, we compared Win minus Full-losses and Win minus Near-misses difference-waves across conditions, analyzing mean amplitudes in the same temporal windows and channel location (i.e., 250–350 ms at FCz; 400–500 ms at Cz). Thus, the mean amplitudes were analyzed by using a 3 × 2 mixed ANOVA with Group (i.e., positive, negative, and neutral MIP condition) as a between-subjects factor, and Difference Wave (i.e., Win minus Full-Loss, Win minus Near-miss) as a within-subjects factor.

For all the ANOVAs, the Greenhouse–Geisser correction was applied in case of significant violation of sphericity, and post-hoc comparisons were Bonferroni-corrected.

Results

MIP procedure results

To assess the effectiveness of the MIP procedure, we conducted separate one-way ANOVAs with Group as a between-subjects factor on the percentage change in each PANAS dimension score: *(post–pre)/pre × 10*0. We found a significant main effect of the Group for both positive affect, $F(2, 55) = 3.29$, $p = .045$, and negative affect, $F(2, 55) = 3.55$, $p = .035$. Pairwise comparisons revealed that the positive mood group showed a greater increase in positive affect (M = 12.04, SD = 16.68) compared to the negative group (M = −4.07, SD = 17.58; $p = .040$), but not compared to the neutral group (M = 2.26, SD = 21.08; $p = .355$). Similarly, the negative mood group reported a greater increase in negative affect (M = 6.25, SD = 26.46) than the positive group (M = −13.41, SD = 18.32; $p = .036$), but not significantly more than the neutral group (M = −6.24, SD = 21.53; $p = 1.00$).

Behavioral results

A 3 (Group: Positive, Negative, Neutral) × 4 (Outcome: Win, Near-Miss, Full-Loss, Tie) mixed ANOVA on participants' bet choices revealed a significant main effect of Outcome, $F(2.33, 128.30) = 15.77$, $p < .001$, $\eta p^2 = .223$. Participants placed lower bets after winning outcomes (M = 0.39, SE = 0.04) compared to near-misses (M = 0.52, SE = 0.04; $p = .001$, Cohen's d = −0.52), full-losses (M = 0.48, SE = 0.04; $p = .042$, d = −0.37), and ties (M = 0.58, SE = 0.04; $p < .001$, d = −0.75). Further comparisons indicated that bets placed after full-losses were lower than those placed after ties ($p < .01$, d = −0.51) and near-misses ($p = .045$, d = −0.36), although bets following near-misses and ties did not significantly differ ($p = .236$, d = −0.28). These findings confirm that participants were less risk-prone after wins than after any other outcome.

The effect of mood on betting behavior was not statistically significant. Neither the main effect of Group ($F(2, 55) < 1$, $p = .391$, $\eta p^2 = .034$) nor the Group × Outcome interaction ($F(4.67, 128.30) < 1$, $p = .724$, $\eta p^2 = .020$) reached significance. Nonetheless, a numerical trend suggested that participants in the positive and negative mood groups (M = 0.52 and M = 0.54, respectively, SE = 0.07 for both) tended to make slightly riskier choices than those in the neutral group (M = 0.42, SE = 0.06).

A parallel ANOVA on decision times revealed a significant main effect of Outcome, $F(1.62, 89.33) = 127.4$, $p < .001$, $\eta p^2 = .698$. Consistent with the Post-Reinforcement Pause effect (Dixon et al., 2013), participants took more time to place a bet after a win (M = 4.52 s, SE = 0.22) than after full-losses (M = 2.43 s, SE = 0.13), near-misses (M = 2.55 s, SE = 0.14), or ties (M = 2.45 s, SE = 0.12), with all comparisons reaching significance at $p < .001$ (Cohen's d values between 1.56 and 1.75). No other comparisons among the non-winning outcomes were statistically significant (p > .20). Again, neither the main effect of Group ($F(2, 55) < 1$, $p = .47$, $\eta p^2 = .027$) nor the Group × Outcome interaction ($F(3.25, 89.33) < 1$, $p = .567$, $\eta p^2 = .025$) was significant. However, participants in the negative mood condition responded somewhat faster (M = 2.76 s, SE = 0.23) than those in the positive (M = 3.13 s, SE = 0.25) or neutral (M = 3.07 s, SE = 0.22) groups.

In addition, in order to explore a possible effect of gender on behavioral outcomes (i.e., risky choice ratio and decision time), we also conducted a 2 × 4 (Gender x Outcome) ANOVA. There was no statistically significant interaction effect of Gender x Outcome ($F = .574$, $p = .590$), and Gender main effect ($F = .680$, $p = .413$). Similarly, there was no statistically significant interaction effect of Gender x Outcome on Decision Time ($F = .689$, $p = .477$), and Gender main effect ($F = .866$, $p = .356$).

Event-related potential feedback-evaluation results

Analysis of the RewP component revealed a robust main effect of Outcome, $F(2.48, 136.37) = 47.02$, $p < .001$, $\eta p^2 = .461$, while neither the interaction between Outcome and Group ($F(4.96, 136.37) = 0.12$, $p = .987$, $\eta p^2 = .004$) nor the main effect of Group ($F(2, 55) = 1.10$, $p = .341$, $\eta p^2 = .038$) reached statistical significance. Bonferroni-corrected comparisons showed that the RewP was significantly higher following wins (M = 5.32 µV, SE = 0.45) than after near-misses (M = 2.49 µV, SE = 0.30; $p < .001$, d = 0.97), full-losses (M = 0.92 µV, SE = 0.19; $p < .001$, d = 1.30), and ties (M = 2.69 µV, SE = 0.33; $p < .001$, d = 0.81). Additionally, full-losses elicited lower amplitudes than both near-misses and ties ($p < .001$), whereas near-misses and ties did not significantly differ ($p = 1.00$, d = −0.09).

Figure 2 illustrates this pattern of neural responses across conditions at FCz. The ERP waveform shows a clearly enhanced RewP peak following win outcomes, relative to all others, particularly full-losses, which elicited relatively minimal positivity. Near-misses and ties produced intermediate responses, suggesting engagement of the brain's reward evaluation system. This pattern aligns with the idea that near-misses are processed as more salient than full-losses, despite the lack of actual reward.

As for the P300 component, a significant main effect of Outcome was observed, $F(2.46, 135.36) = 60.27$, $p < .001$, $\eta p^2 = .523$. Neither the interaction between Outcome and Group ($F(4.92, 135.36) = 0.30$, $p = .910$, $\eta p^2 = .011$) nor the main effect of Group ($F(2, 55) = 0.22$, $p = .803$, $\eta p^2 = .008$) were significant. P300 amplitude was highest following wins (M = 6.30 µV, SE = 0.68), significantly exceeding that observed for near-misses ($p < .001$, d = 0.67), ties ($p < .001$, d = 0.95), and full-losses (M = −1.49 µV, SE = 0.29; $p < .001$, d = 1.41). The amplitude for near-misses (M = 3.40 µV, SE = 0.52) was also significantly higher than for ties (M = 1.63 µV, SE = 0.51; $p = .008$, d = 0.46).

Figure 3 provides a clear visual representation of these outcome-related differences in P300 amplitude at Cz. As

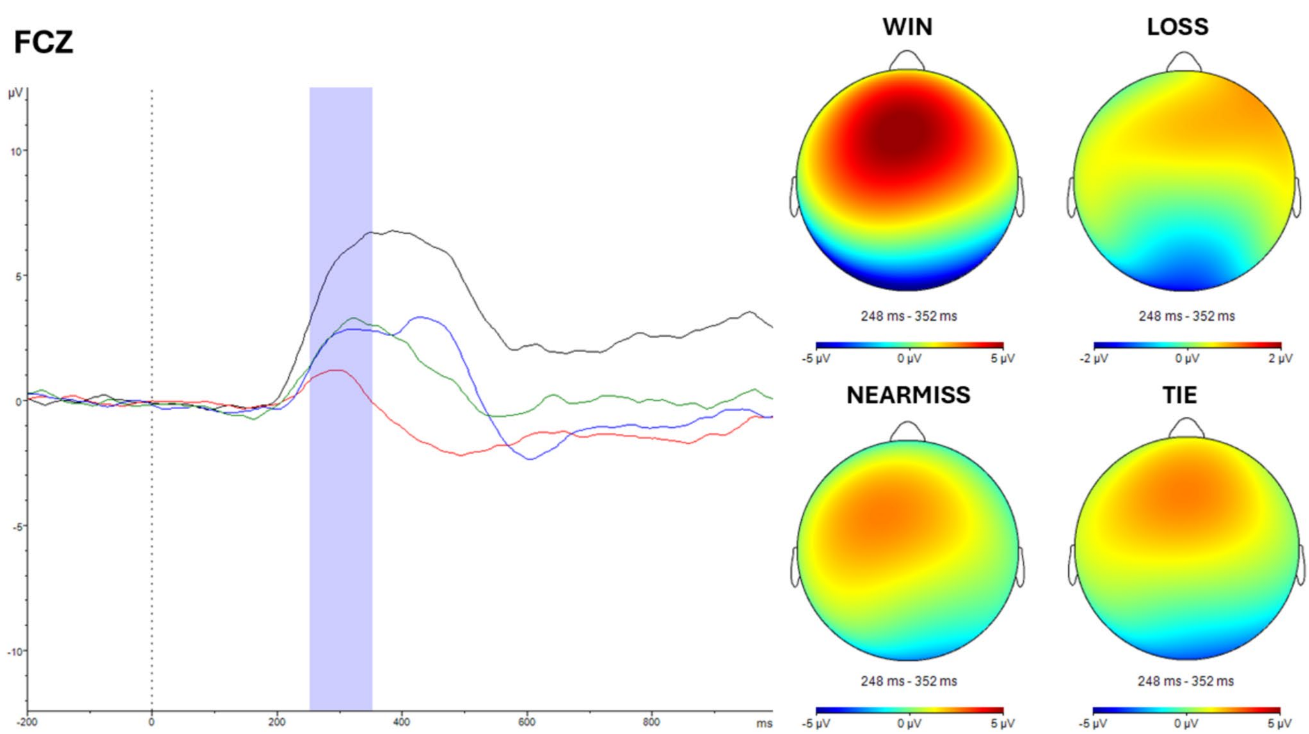

Fig. 2 Event-related potential average waveform in FCz. Note: Black line = Win outcome; Red Line = Full-Loss outcome; Blue Line = Near-Miss outcome; Green Line = Tie outcome. The shaded area depicts the temporal window for Reward Positivity

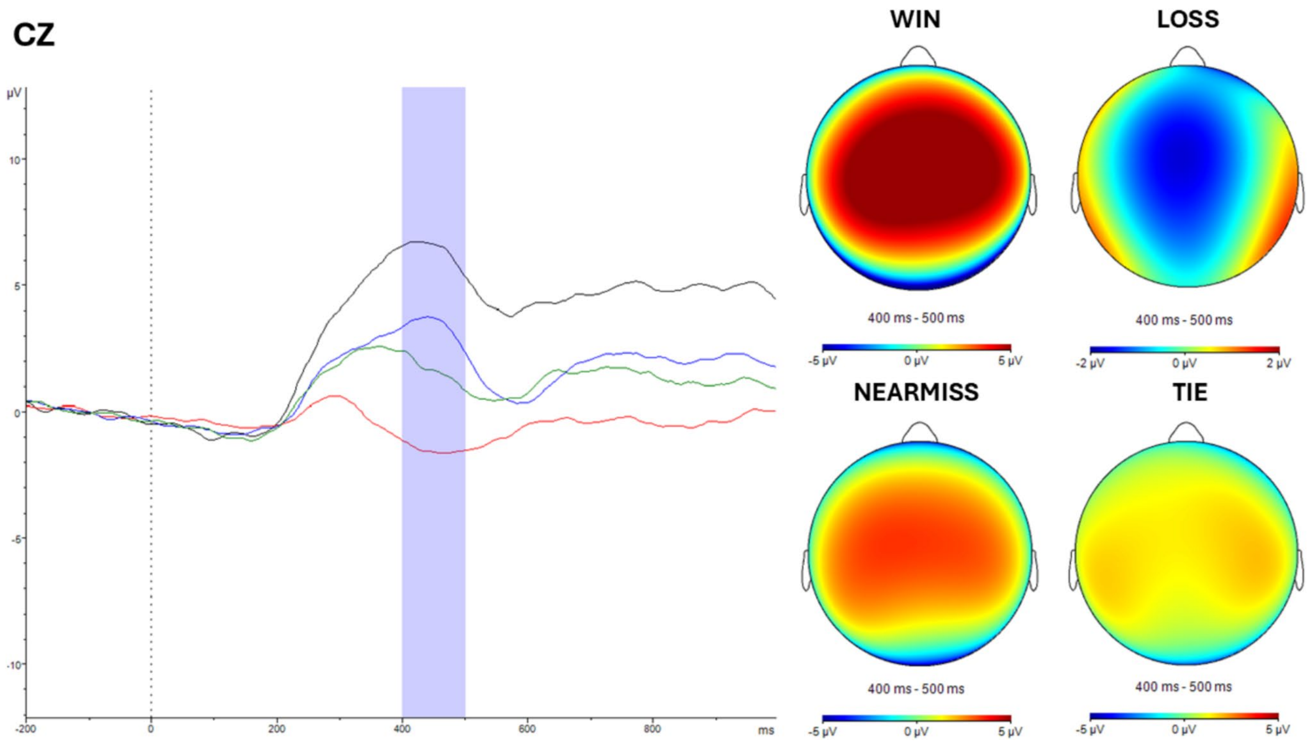

Fig. 3 Event-related potential average waveform in Cz. Note: Black line = Win outcome; Red Line = Full-Loss outcome; Blue Line = Near-Miss outcome; Green Line = Tie outcome. The shaded area depicts the temporal window for P300

shown, wins elicited a strong positive deflection, suggesting heightened attentional allocation to rewarding outcomes. Near-misses, while not associated with actual gain, evoked a moderate P300 response, reflecting their affective salience and perceived proximity to a win. In contrast, full-losses produced a markedly diminished or even negative-going deflection. The intermediate amplitude observed for ties falls between near-misses and full-losses, suggesting a graded sensitivity of the P300 component to outcome subjective valence.

The analyses of difference-waves provided further support for these effects. At FCz, in the RewP time window (250–350 ms), a significant main effect of Difference Wave was found, $F(1, 55) = 23.70$, $p < .001$, $\eta p^2 = .301$. The amplitude of the Win minus Near-Miss wave (M = 2.83 μV, SE = 0.39) was lower than that of the Win minus Full-Loss wave (M = 4.41 μV, SE = 0.46). There was no significant interaction with Group ($F(2, 55) = 0.042$, $p = .959$, $\eta p^2 = .002$), and the main effect of Group was also non-significant ($p = .798$).

Figures 6 and 7 (see the Supplementary Materials) visually highlight this distinction in reward-related neural processing. The greater amplitude of the Win–Full-Loss difference wave reflects a stronger contrast in the brain's response to highly rewarding versus clearly unrewarding outcomes. In contrast, the smaller Win–Near-Miss difference suggests that near-misses share some reward-related characteristics with wins, eliciting partial activation of reward-related ERP components. This supports the idea that near-misses are not evaluated as complete full-losses at the neural level, aligning with behavioral evidence of their motivational salience.

At Cz, in the P300 time window (400–500 ms), the main effect of Difference Wave was again significant, $F(1, 55) = 102.22$, $p < .001$, $\eta p^2 = .650$. The Win minus Near-Miss difference wave (M = 2.90 μV, SE = 0.58) was significantly smaller than the Win minus Full-Loss wave (M = 7.79 μV, SE = 0.74). The interaction with Group was not significant ($F(2, 55) = 1.30$, $p = .281$, $\eta p^2 = .045$), nor was the main effect of Group ($p = .977$).

As shown in the supplementary 6 and 7 figures, the same pattern is evident in the P300 time window: the Win–Loss contrast yields a markedly larger positivity than the Win–Near-Miss contrast. This indicates that near-misses continue to be cognitively differentiated from full-losses even in later stages of outcome evaluation.

In line with behavioral analyses, we also conducted the same gender exploratory analyses for ERP data (i.e., RewP, P300, and difference waves). For the RewP, there was no statistically significant interaction effect of Gender x Outcome ($F = .663$, $p = .576$), and Gender main effect ($F = .018$, $p = .895$). Similarly, there was no statistically significant interaction effect of Gender x Outcome on P300 ($F = .571$, $p = .635$), and Gender main effect ($F = .001$, $p = .973$).

Discussion

In line with our initial behavioral hypothesis and previous literature, participants tended to take more risks after negative outcomes than positive ones (Raghunathan & Pham, 1999; Juergensen et al., 2018). Specifically, participants showed lower risk-taking after wins compared to all other outcomes, and higher risk-taking after near-misses than after full-losses. This latter result is consistent with findings suggesting that near-misses and full-losses, despite identical monetary consequences, are processed differently at the psychological and neural levels (Ulrich & Hewig, 2014). The increased risk-taking following near-misses may reflect enhanced gambling motivation driven by their affective salience. In addition, replicating previous findings (Dixon et al., 2013; Quaglieri et al., 2024), participants exhibited longer decision times after wins, consistent with the Post-Reinforcement Pause (PRP) effect.

At the neurophysiological level, results showed a fronto-central distribution for the RewP, consistent with previous studies (e.g., Proudfit, 2015; Myles et al., 2024), and a more central P300 distribution, which contrasts with the parietal dominance often reported (Wu & Zhou, 2009). As expected, both the RewP and P300 amplitudes were largest following wins and smallest following full-losses, with near-misses eliciting intermediate responses.

Interpreting these results within the approach-motivated framework (Threadgill & Gable, 2018), the RewP may reflect more than a binary good–bad evaluation. Instead, it may represent a performance monitoring signal associated with goal-oriented behavior (Yin et al., 2024). In this view, near-misses could be interpreted as partially successful attempts that elicit dopaminergic responses from the cortico-striatal circuit (Holroyd & Coles, 2002; Proudfit, 2015). This interpretation could be consistent with the greater RewP amplitude observed for near-misses compared to full-losses.

The P300 component, in turn, showed a gradual pattern, with amplitudes decreasing from wins to near-misses, ties, and full-losses. Rather than merely reflecting the value of the outcome, the P300 likely signals the integration of cognitive and motivational information, as well as the subjective relevance of the outcomes. This interpretation aligns with the view that the P300 indexes motivational updating in response to feedback (Nieuwenhuis et al., 2005). The elevated P300 response to near-misses supports their classification as emotionally and cognitively engaging events, possibly through counterfactual thinking and the feeling of having "almost won" (Forgas, 2013; Dores et al., 2020).

While the RewP may reflect early, rapid evaluation of feedback, the P300 may represent a later stage of integration, capturing expectations, motivation, and attention. In our findings, this was evidenced by the differentiation between near-misses and ties in the P300, but not in the RewP. This could suggest that near-misses are processed similarly to neutral outcomes during early evaluation but acquire distinct meaning during later cognitive processing. Outcomes sharing similar initial visual features (e.g., two matching symbols) can be initially processed as a single perceptual category, before being semantically differentiated during later stages of evaluation. The lack of RewP differentiation could reflect shared early processing, while the different P300 may result from subsequent recognition of the near-miss as a missed opportunity.

Moreover, the way near-misses are presented, before or after the payline, can shape the direction of counterfactual processing (Wu et al., 2018). Near-misses before the payline, as used in our study, tend to evoke additive counterfactuals, which may promote continued play through increased motivational engagement. This is consistent with our finding that near-misses elicited larger P300 amplitudes than full-losses and ties, aligning with models positing that counterfactuals dynamically shape emotional and behavioral adjustment in sequential risk environments (Forgas, 2013; Dores et al., 2020).

Notably, these ERP components are sensitive to expectancy. In our study, wins accounted for 14% of total outcomes, while near-misses represented 38% of negative outcomes. Prior research has shown that lower reward expectancy can reduce FRN negativity and increase P300 amplitude for near-misses compared to full-losses, a pattern consistent with our results (Yin et al., 2024).

The difference wave analysis supported the overall ERP findings. Greater amplitude differences between wins and full-losses, compared to wins and near-misses, were observed in both the RewP and P300 time windows. This suggests that near-misses partially activate reward-related systems, generating responses possibly tied to frustration and continued engagement (Clark et al., 2009; Chase & Clark, 2010).

As regards mood effects, we did not observe statistically significant differences in behavioral or ERP measures. These null findings should be interpreted with caution, particularly considering the modest sample size and the exploratory nature of the study. Importantly, our results are not necessarily inconsistent with prior literature. While components such as the RewP and P300 are generally sensitive to affective and motivational states, several studies have reported null effects when mood is manipulated incidentally and remains unrelated to task goals (Paul et al., 2020; Hajcak et al., 2006). For example, Paul et al. (2020) found that a positive mood induction procedure did not alter RewP amplitude due to the lack of task relevance and motivational engagement. In our study, the mood induction was also incidental to the gambling task and may have lacked the motivational salience needed to modulate feedback-related ERPs. Further research employing stronger or more task-relevant mood manipulations is needed to clarify these effects.

Another possible explanation for the null findings of our mood manipulation can be traced back to the temporal aspects of the MIP. While the MIP was developed to be as varied as possible, including diverse auditory, visual, and verbal materials, its effects might have been subtle and short-lived, since they were not simultaneous to the task. In particular, the VR-based gambling task might have led participants to divert their attention away from the MIP materials, minimizing its enduring impact on behavioral and electrophysiological components. In this regard, recent literature has suggested VR-based MIPs to be simultaneous to task performance, as previous studies have not yet clarified how long mood alterations persist after induction and which component plays an influential role (Kako et al., 2023).

Therefore, consistent with the considerations above, factors such as the task relevance of mood, its intensity and temporal persistence may represent boundary conditions under which mood fails to modulate outcome evaluation processes and subsequent risk-taking behavior. These factors could be meaningfully integrated into broader theoretical frameworks such as the Mood Maintenance Theory or the Affect Infusion Model, which already posit that the influence of mood depends on contextual and cognitive features of the task (for a review, see Saka & Yildirim, 2024). Thus, the current findings may help to specify the effectiveness of mood-based modulations on outcome evaluation and risk-taking.

Thus, future research employing more sustained and task-relevant MIP on larger samples is warranted to further clarify the role of mood states in modulating behavioral and electrophysiological components of risk-taking in a VR-based environment. Nevertheless, these null findings are informative and suggest that similar affective manipulations may not consistently influence early and late stages of feedback processing.

In addition, although not a primary aim, we also explored gender differences in risk-taking and feedback processing, motivated by prior research suggesting such effects (Byrnes et al., 1999). However, no significant effects of gender or interactions were found, and the pattern and strength of the main findings remained unchanged. While our sample size limits power for subgroup analyses, these results suggest that the effects reported here are not strongly modulated by participant gender. Future research with larger and more stratified samples is needed to clarify the potential role of gender differences in mood-influenced decision-making and feedback sensitivity, especially in ecologically valid contexts such as immersive gambling scenarios.

Some limitations should be noted. The sample consisted of university students, which limits generalizability. In addition, the VR gambling task, although immersive, imposed fixed betting options that do not fully mirror real-world gambling behavior. Finally, future studies should examine whether near-miss effects are amplified or reduced in clinical populations, such as individuals with gambling disorders (Yücel et al., 2017), and whether mood-related effects become more evident in such groups.

In conclusion, this study represents the first attempt to investigate the effects of incidental mood on near-miss in virtual reality to examine decision-making and its neural correlates. The use of VR enhanced ecological validity, and the multisensory MIP procedure allowed for more effective affect manipulation than traditional methods (Diniz Bernardo et al., 2021). This study offers new insights into the neurocognitive mechanisms underlying risky decision-making, highlighting the role of near-misses and outcome evaluation in shaping behavior. It supports the integration of VR-based methods in psychological research to better understand risk-related processes and their modulation by emotional states. Future studies could use immersive paradigms to explore how affective and cognitive components interact in high-risk decision contexts, informing both theoretical models and intervention strategies aimed at reducing maladaptive gambling behaviors.

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Author contributions **Alessandro Quaglieri**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Pierandrea Mirino**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Sara Mercuri**: Validation, Visualization, Writing – review & editing. **Clarissa Cricenti**: Methodology, Validation, Visualization. **Giulia Lausi**: Methodology, Validation, Visualization. **Emanuela Mari**: Project administration, Resources, Visualization. **Jessica Burrai**: Project administration, Resources, Visualization. **Anna Maria Giannini**: Funding acquisition, Project administration, Resources, Supervision, Validation, Visualization. **Pierpaolo Zivi**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.
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Data availability The data that support the findings of this study are available from the corresponding author, A.Q. upon reasonable request.

Declarations

Institutional review board The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of Department of Psychology, Faculty of Medicine and Psychology, "Sapienza" University of Rome (protocol number 0000272 of 17.02.2022).

Informed consent Informed consent was obtained from all subjects involved in the study.

Conflicts of interest The authors declare no conflict of interest.

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