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Data Article

Feedback-related potentials in a gambling task with randomised reward

Faisal Mushtaq^{a,*}, Pablo Puente Guillen^{a,b}, Richard M. Wilkie^a, Mark A. Mon-Williams^a, Alexandre Schaefer^c^a School of Psychology, University of Leeds, Leeds, West Yorkshire, United Kingdom^b School of Computing, University of Leeds, Leeds, West Yorkshire, United Kingdom^c School of Business, Monash University, Sunway Campus, Selangor, Malaysia

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ABSTRACT

Event-related potentials (ERPs) time-locked to decision outcomes are reported. Participants engaged in a gambling task (see [1] for details) in which they decided between a risky and a safe option (presented as different coloured shapes) on each trial (416 in total). Each decision was associated with (fully randomised) feedback about the reward outcome (Win/Loss) and its magnitude (varying as a function of decision response; 5–9 points for Risky decisions and 1–4 points for Safe decisions). Here, we show data demonstrating: (a) the influence of Win feedback in the preceding outcome (Outcome_{t-1}) on activity related to the current outcome (Outcome_t); (b) difference wave analysis for outcome expectancy-separating Expected Outcomes (consecutive Loss trials subtracted from consecutive reward) from Unexpected Outcomes (subtracting $\text{Loss}_{t-1}\text{Win}_t$ trials from $\text{Win}_{t-1}\text{Loss}_t$ trials); (c) difference waves separating Switch and Stay responses for Outcome Expectancy; (d) the effect of magnitude induced by decisions (Risk_t vs. Safe_t) on Outcome Expectancy; and finally, (e) expectations reflected by response switch direction (Risk to Safe responses vs. Safe to Risk_t) on the FRN at Outcome_t .

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* Corresponding author.

E-mail address: f.mushtaq@leeds.ac.uk (F. Mushtaq).<http://dx.doi.org/10.1016/j.dib.2015.11.060>2352-3409/© 2015 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

Specifications Table

Subject area	Psychology
More specific subject area	Decision-making, Cognitive Neuroscience, Reward Processing
Type of data	Event-related potentials time-locked to decision outcome.
How data was acquired	Participants completed a two-alternative forced choice decision-making task whilst EEG data were acquired using a 128-channel net connected to a high-input amplifier (Electrical Geodesics, Inc., Eugene, OR; see Fig. 1 for electrode montage) at a rate of 500 Hz (0.01–200 Hz bandwidth) and an impedance ≤ 20 k Ω for frontocentral electrodes. Data were recorded using a Cz reference online and digitally converted to an average mastoids reference offline. After offline filtering (0.1–30 Hz bandwidth), data were segmented into 1000 ms epochs time-locked to feedback onset (200 ms baseline) and corrected for artifacts. Values from electrodes were clustered and mean averages from electrodes surrounding the standard FCz location for the FRN and P3a and electrodes surrounding Pz for the P3 were used for statistical analysis.
Data format	Analysed ERPs.
Experimental factors	Feedback valence was fully randomised.
Experimental features	416 trials per participant ($n=27$).
Data source location	School of Psychology, University of Leeds, Leeds, United Kingdom.
Data accessibility	Within this article.

Value of the data

- Data show feedback-locked potentials on a gambling task when outcomes are fully randomised.
- The FRN, P3a and feedback-related P3 differences for outcome expectancy, switch/stay responses, outcome magnitude and switch direction are reported.
- Results demonstrate that FRN activity does not conform to existing prediction error based accounts.

1. Data, experimental design, materials and methods

EEG data were recorded with a 128-channel net connected to a high-input amplifier (Electrical Geodesics, Inc., Eugene, OR; for electrode montage see Fig. 1) whilst participants engaged in a two-alternative forced choice gambling task (see [1,2] for further details). On each trial, participants decided between a risky and a safe option, presented as different coloured shapes. In this experiment, gamble outcomes were fully randomised across 416 trials. ERPs time-locked to presentation of feedback were analysed as described in [1]. Values from electrodes were clustered and mean averages from electrodes surrounding the standard FCz location for the FRN (EGI electrode numbers: '12', '5', '6', '13', '112', '7', '106', 'Cz', '31', '80' and '55') and P3a and electrodes surrounding Pz for the P3 (EGI electrode numbers: '61', '78', '62', '67', '72', '77', '71' and '76') were used for statistical analysis.

2. Reward positivity difference waves

Difference wave analysis confirmed the FRN was driven by a larger positivity to Win outcomes when preceded by a similarly positive outcome. We found a statistically reliable difference at Outcome_t ($F [1, 26]=5.81, p=.023, \eta_p^2=.19$), with Win_t differences producing greater negativity

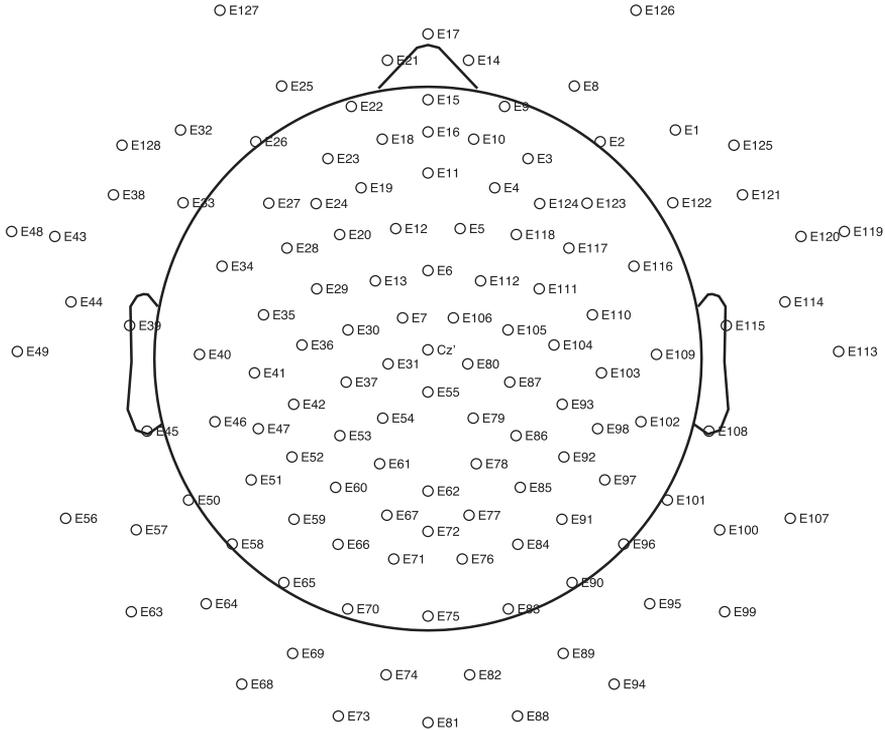


Fig. 1. Electrode locations. Schematic representation of the EGI 128 HydroCel™ Geodesic Sensor Net used to acquire EEG data.

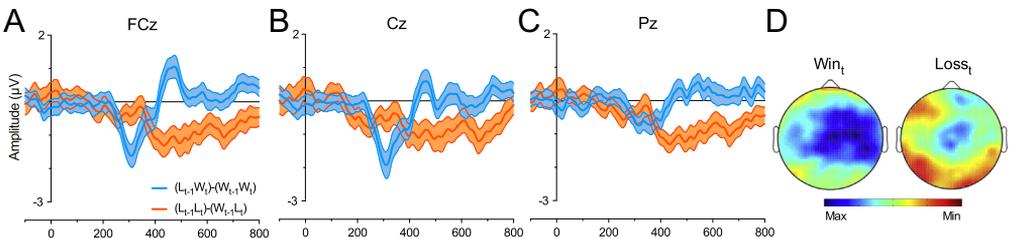


Fig. 2. Win_t and $Loss_t$ FRN difference. Difference waveform computed by subtracting $Win_{t-1}Win_t$ from $Loss_{t-1}Win_t$ trials (blue) and $Loss_{t-1} - Loss_t$ from $Win_{t-1} - Loss_t$ (orange) trials at FCz (A), Cz (B) and Pz (C). Error bars represent SE and abscissa shows time in milliseconds. (D) Topographical maps display mean difference at each electrode site for the FRN time window for Win_t and $Loss_t$ (-1.1 to $0.6 \mu V$).

($M = -1.04 \mu V$, $SE = .3 \mu V$) than $Loss_t$ differences ($M = -.04 \mu V$, $SE = .3 \mu V$) - complementing a significant peak-to-peak amplitude difference for the same comparison ($F [1, 26] = 5.23$, $p = .031$, $\eta_p^2 = .167$). Commensurate with the topographical features of the FRN, Fig. 2D shows a frontocentral scalp distribution of this effect. We also performed peak-to-peak analysis to confirm that the $Win_{t-1}Win_t$ trials were also reliably different from the $Loss_{t-1}Win_t$ trials ($F [1, 26] = 9.03$, $p = .006$, $\eta_p^2 = .258$).

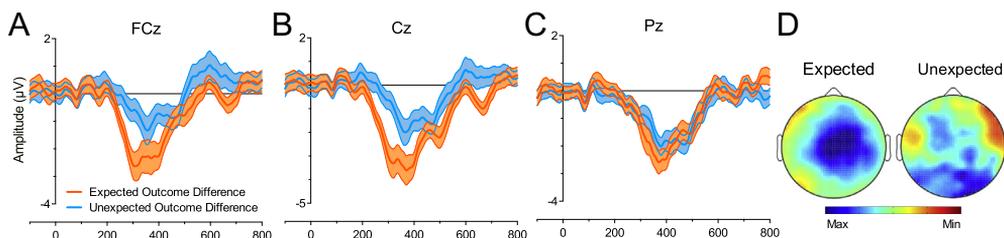


Fig. 3. Expected and Unexpected Outcome Differences. (A) FCz, (B) Cz and (C) Pz. Error bars represent SE and abscissa shows time in milliseconds. (D) Scalp maps show the Expected reward difference was maximal at frontocentral in the time-window for the FRN but no such pattern for the difference in Unexpected Outcomes. Maxima and minima specific to each scalp map; Expected: -2.1 to $0.6 \mu\text{V}$; Unexpected: -2.7 to $0.69 \mu\text{V}$.

3. Difference wave analysis: outcome expectancy

The effect of Outcome Expectancy on the FRN was examined by creating two differences waves: (i) Expected Outcome difference wave calculated by subtracting $\text{Win}_{t-1}\text{Win}_t$ from $\text{Loss}_{t-1}\text{Loss}_t$ trials; and (ii) Unexpected Outcome difference wave calculated by subtracting $\text{Loss}_{t-1}\text{Win}_t$ trials from $\text{Win}_{t-1}\text{Loss}_t$ trials. Fig. 3 shows a significant difference in FRN activity for Expectancy ($F [1, 26]=8.0$, $p=.009$, $\eta_p^2=.236$), with the Expected Outcome difference producing a larger negativity ($M=-1.92 \mu\text{V}$, $\text{SE}=.60 \mu\text{V}$) than Unexpected Outcome difference ($M=-0.59 \mu\text{V}$, $\text{SE}=.36 \mu\text{V}$).

4. Switch vs. Stay: difference wave analysis

4.1. Switch vs. Stay: FRN

The same approach described in Section 3 was adopted for Switch and Stay trials. There was a main effect of Expectancy ($F [1, 26]=25.64$, $p < .0001$, $\eta_p^2=.497$) and the effect of Strategy approached, but did not reach, significance ($F [1, 26]=3.74$, $p=.064$, $\eta_p^2=.126$). These main effects were qualified by a significant Expectancy \times Strategy interaction ($F [1, 26]=27.4$, $p < .0001$, $\eta_p^2=.513$). Visually, consistent with Holroyd and Coles [3], the Unexpected FRN difference ($M=-1.48 \mu\text{V}$, $\text{SE}=.50 \mu\text{V}$) was more negative than Expected ($M=-0.91 \mu\text{V}$, $\text{SE}=.73 \mu\text{V}$) in Stay trials and showed a frontocentral scalp distribution (see Fig. 4B), but this effect was not statistically reliable ($F [1, 26]=0.48$, $p=.495$, $\eta_p^2=.018$). The interaction was driven by Switch trials ($F [1, 26]=52.55$, $p < .0001$, $\eta_p^2=.669$). These trials showed a larger FRN difference for Expected Outcome differences ($M=-5.12 \mu\text{V}$, $\text{SE}=.66 \mu\text{V}$) relative to Unexpected Outcome differences ($M=.82 \mu\text{V}$, $\text{SE}=.51 \mu\text{V}$).

4.2. Switch vs. Stay: P3a

For the P3a there was a significant main effect of Expectancy ($F [1, 26]=28.91$, $p < .001$, $\eta_p^2=.526$) and Strategy ($F [1, 26]=9.11$, $p=.005$, $\eta_p^2=.259$) with Switch trials eliciting a greater negativity ($M=-2.61 \mu\text{V}$, $\text{SE}=.43 \mu\text{V}$) than Stay ($M=-1.11 \mu\text{V}$, $\text{SE}=.43 \mu\text{V}$). These effects were qualified by an Expectancy \times Strategy interaction ($F [1, 26]=46.69$, $p < .0001$, $\eta_p^2=.642$). The effect of Expectancy approached significance in Stay trials ($F [1, 26]=3.57$, $p=.07$, $\eta_p^2=.121$) with Unexpected Outcomes leading to a greater negativity ($M=-1.88 \mu\text{V}$, $\text{SE}=.49 \mu\text{V}$) than Expected ($M=-0.35 \mu\text{V}$, $\text{SE}=.73 \mu\text{V}$), and was significant in Switch trials ($F [1, 26]=58.83$, $p < .0001$, $\eta_p^2=.693$) with Expected Outcomes leading to a greater negativity ($M=-6.76 \mu\text{V}$, $\text{SE}=.78 \mu\text{V}$) than Unexpected ($M=1.54 \mu\text{V}$, $\text{SE}=.59 \mu\text{V}$).

4.3. Switch vs. Stay: feedback-related P3

Consistent with P3a results, there was a significant main effect of Expectancy ($F [1, 26]=33.86$, $p < .0001$, $\eta_p^2=.566$) and Strategy ($F [1, 26]=6.87$, $p=.014$, $\eta_p^2=.209$) with Switch trials eliciting a

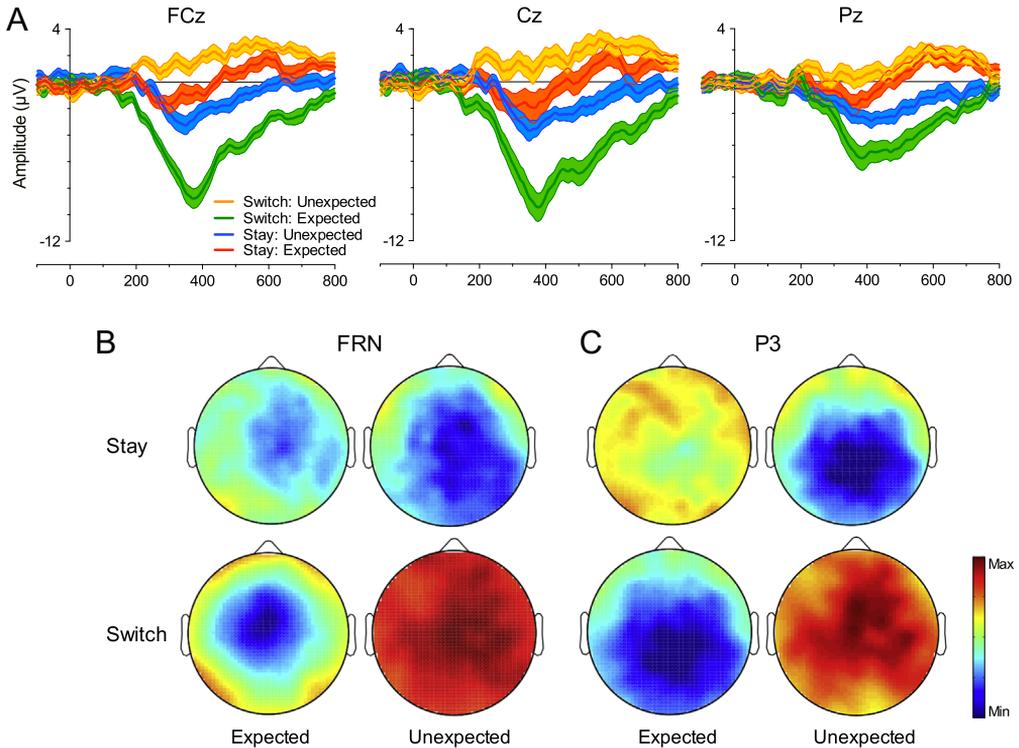


Fig. 4. Switch Stay ERPs. (A) ERPs from FCz, Cz and Pz (left to right). Error bars represent SE and abscissa shows time in milliseconds; (B) for the FRN topographical maps show Unexpected Outcomes elicited a frontocentral negativity (left) in Stay trials – consistent with Holroyd and Coles (2002), but this effect was not statistically reliable. The largest difference was observed for Expected Outcomes in Switch trials (maxima and minima: Stay 1.5 to $-2 \mu\text{V}$; Switch 1.4 to $-5.5 \mu\text{V}$); (C) for the P3, Unexpected Outcomes for Stay responses and Expected Outcomes for Switch responses produced posteriorly distributed feedback-related P3 differences (maxima and minima: Stay 0.8 to $-3 \mu\text{V}$; Switch 1.8 to $-3.0 \mu\text{V}$).

greater negativity ($M = -2.62 \mu\text{V}$, $SE = .44 \mu\text{V}$) than Stay ($M = -1.66 \mu\text{V}$, $SE = .35 \mu\text{V}$). There was a significant Expectancy \times Strategy interaction ($F [1, 26] = 56.11$, $p < .0001$, $\eta_p^2 = .683$). The effect of Expectancy was significant in Stay trials ($F [1, 26] = 12.95$, $p = .0013$, $\eta_p^2 = .333$) with Unexpected Outcomes differences leading to less positivity ($M = -2.62 \mu\text{V}$, $SE = .47 \mu\text{V}$) than Expected ($M = -0.70 \mu\text{V}$, $SE = .42 \mu\text{V}$). There was also a significant effect in Switch trials ($F [1, 26] = 62.31$, $p < .0001$, $\eta_p^2 = .706$) with Expected Outcome differences leading to less positivity ($M = -6.01 \mu\text{V}$, $SE = .74 \mu\text{V}$) than Unexpected ($M = .78 \mu\text{V}$, $SE = .46 \mu\text{V}$).

5. P3a analysis

5.1. $Outcome_{t-2} \times Outcome_{t-1} \times Outcome_t$

There was a main effect of $Outcome_t$ ($F [1, 26] = 4.28$, $p = .049$, $\eta_p^2 = .141$), with Win $_t$ outcomes ($M = 9.72 \mu\text{V}$, $SE = 1.1 \mu\text{V}$) relative to Loss $_t$ outcomes ($M = 8.78 \mu\text{V}$, $SE = 1.03 \mu\text{V}$). No other effects or interactions approached significance (F 's < 1.99 , p 's $> .171$).

5.2. Switch vs. Stay

An $\text{Outcome}_{t-1} \times \text{Outcome}_t$ ANOVA was conducted for Stay and Switch response trials. For Stay responses, there was no statistically reliable effects or interaction (F 's < 2.6, p 's > .12). For Switch trials, there was a main effects for Outcome_t (F [1, 26] = 14.43, p < .0001, η_p^2 = .357) with more positive going amplitude for Win_t (M = 9.01 μV , SE = .96 μV) relative to Loss_t (M = 7.46 μV , SE = .88 μV) and for Outcome_{t-1} (F [1, 26] = 25.42, p < .0001, η_p^2 = .494): Win_{t-1} trials had a greater positive deflection (M = 9.42 μV , SE = 1.1 μV) relative to Loss_{t-1} (M = 7.05 μV , SE = .72 μV). There was also an $\text{Outcome}_{t-1} \times \text{Outcome}_t$ interaction (F [1, 26] = 7.58, p = .011, η_p^2 = .23), but this effect was qualitatively different to the one observed for the FRN. This interaction was driven by differences at Outcome_{t-1} – there was no difference in Outcome_t for Win_{t-1} trials (F [1, 26] = .49, p = .49, η_p^2 = .02), but a substantial effect of Outcome_t when preceded by Loss_{t-1} (F [1, 26] = 35.60, p < .001, η_p^2 = .578) – Win trials following Losses (8.37 μV , SE = .85 μV) were larger than sequential losses (5.74 μV , SE = .65 μV).

6. Risk-related ERPs

The effect of magnitude on individual ERPs was analysed by conducting an $\text{Outcome}_{t-1} \times \text{Magnitude} \times \text{Outcome}_t$ ANOVA for the FRN using a peak-to-peak measure. There was a significant main effect of Magnitude (F [1, 26] = 10.19, p = .004, η_p^2 = .282) but this factor did not interact with Outcomes (F 's < 1.36, p 's > .25). Subsequently, difference wave analyses were conducted by separating the ERPs for Outcome_t for the preceding decision (Risk [producing a large outcome] vs. Safe [producing a small outcome]) and valence at Outcome_{t-1} . Mean amplitude differences were used in a Magnitude (Risk vs. Safe) \times Expectancy (Expected Outcome Difference vs. Unexpected Outcome Difference) ANOVA for the FRN, P3a and P3b.

6.1. FRN

There was a significant main effect of Expectancy (F [1, 26] = 9.33, p = .005, η_p^2 = .264) – with Expected Outcomes giving rise to a greater negativity (M = -1.99, SE = .52 μV) than Unexpected

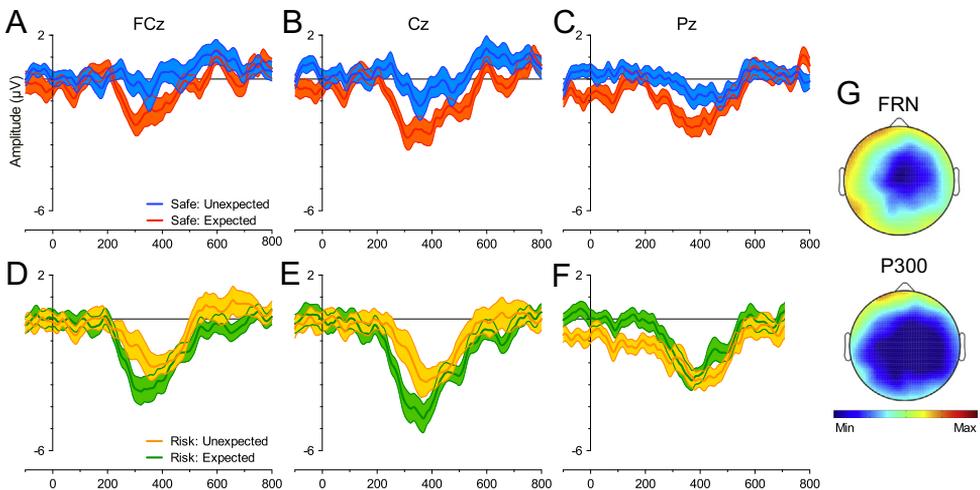


Fig. 5. Expectancy and Magnitude. (A–C) ERPs for Expected and Unexpected Reward difference waveforms from FCz, Cz and Pz (left to right) for Safe choices and (D–F) for Safe responses. Error bars represent SE and abscissa shows time in milliseconds; (G) topographical maps show the effect of Magnitude (Safe-Risk) for the FRN and P3 (maxima and minima +1.0 μV to -2.5 μV).

($M = -.59$, $SE = .379 \mu V$). There was also a significant main effect of Magnitude ($F [1, 26] = 5.42$, $p = .028$, $\eta_p^2 = .172$) – with Risk choices differences leading to a larger negativity ($M = -1.89 \mu V$, $SE = .51 \mu V$) than Safe ($M = -.69 \mu V$, $SE = .43 \mu V$). However, Magnitude did not modulate the differences in Outcome Expectancy – as indicated by the Expectancy \times Magnitude interaction ($F [1, 26] = .015$, $p = .903$, $\eta_p^2 = .001$). To illustrate, difference waveforms for Risk and Safe are plotted separately in Fig. 5.

6.2. P3a

There was a significant main effect of Magnitude ($F [1, 26] = 13.58$, $p = .001$, $\eta_p^2 = .343$) – with Risk choices leading to a larger negativity ($M = -2.3 \mu V$, $SE = .52 \mu V$) than safe ($M = -.52 \mu V$, $SE = .44 \mu V$). However, there was no effect of Expectancy ($F [1, 26] = 2.78$, $p = .107$, $\eta_p^2 = .097$) and no Expectancy \times Magnitude interaction ($F [1, 26] = .08$, $p = .783$, $\eta_p^2 = .003$).

6.3. Feedback-related P3

There was a significant main effect of Magnitude ($F [1, 26] = 11.48$, $p = .002$, $\eta_p^2 = .306$) – with Risk choices leading to a larger negativity ($M = -2.42 \mu V$, $SE = .33 \mu V$) than Safe ($M = -1.35 \mu V$, $SE = .33 \mu V$). However, there was no effect of Expectancy ($F [1, 26] = 1.50$, $p = .232$, $\eta_p^2 = .054$) and the Expectancy \times Magnitude interaction did not reach significance ($F [1, 26] = 1.38$, $p = .251$, $\eta_p^2 = .05$).

7. Switch direction \times Outcome_t analysis

An Outcome_{t-1} \times Outcome_t \times Switch Direction (Risk_{t-1}Safe_t; Safe_{t-1}Risk_t) ANOVA was not possible due to a constraint with the number of trials available for this analysis (only 3 subjects had > 16 trials across the 8 conditions). In order to examine the impact of expectancy reflected by Switch sequence direction on Outcome_t related activity a Switch Direction \times Outcome_t ANOVA was conducted. All 27 subjects had a minimum of 16 artefact-free trials available for this analysis: Risk_{t-1}Safe_t Loss_t (trials $M = 42$, $SD = 11$); Safe_{t-1}Risk_t Loss_t (trials $M = 40$, $SD = 9$); Risk_{t-1}Safe_t Win_t (trials $M = 39$, $SD = 8$); Safe_{t-1}Risk_t Win_t (trials $M = 42$, $SD = 9$).

There was a main effect of Outcome_t ($F [1, 26] = 7.05$, $p = .013$, $\eta_p^2 = .213$) and Switch Direction ($F [1, 26] = 5.38$, $p = .029$, $\eta_p^2 = .171$), with Risk_{t-1}Safe_t ($M = -4.45 \mu V$, $SE = .72 \mu V$; see Fig. 6A) more negative than Safe_{t-1}Risk_t ($M = -3.79 \mu V$, $SE = .70 \mu V$). Although visually, the ERPs indicated differences (Fig. 6B), there was no statistically reliable Outcome_t \times Switch Direction interaction ($F [1, 26] = .01$, $p = .919$, $\eta_p^2 < .001$).

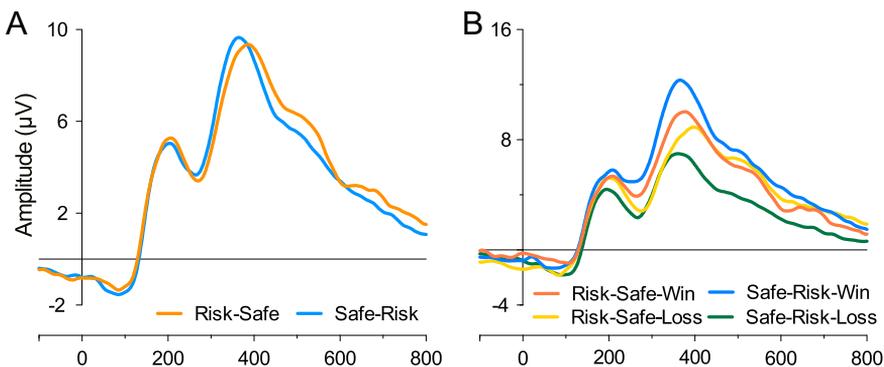


Fig. 6. Switch direction and outcome related activity. (A) ERPs at FCz showed marginally significant peak-to-peak FRN effect with greater negativity for Risk_{t-1}Safe_t responses relative to Safe_{t-1}Risk_t, however, there was no statistically reliable Switch Direction \times Outcome interaction. (B) Abscissa represents time in milliseconds.

Acknowledgements

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