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Dissociable effects of reward magnitude on fronto-medial theta and FRN during performance monitoring

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Abstract
Reward processing is influenced by reward magnitude, as previous EEG studies showed changes in amplitude of the feedback-related negativity (FRN) and reward positivity (RewP), or power of fronto-medial theta (FMθ). However, it remains unclear whether these changes are driven by increased reward sensitivity, altered reward predictions, enhanced cognitive control, or a combination of these effects. To address this question, we asked 36 participants to perform a simple gambling task where feedback valence (reward vs. no-reward), its magnitude (small vs. large reward), and expectancy (expected vs. unexpected) were manipulated in a factorial design, while 64-channel EEG was recorded concurrently. We performed standard ERP analyses (FRN and RewP) as well as time-frequency decompositions (FMθ) of feedback-locked EEG data. Subjective reports showed that large rewards were more liked and expected than small ones. At the EEG level, increasing magnitude led to a larger RewP irrespective of expectancy, whereas the FRN was not influenced by this manipulation. In comparison, FMθ power was overall increased when reward magnitude was large, except if it was unexpected. These results show dissociable effects of reward magnitude on the RewP and FMθ power. Further, they suggest, that although large reward magnitude boosts reward processing (RewP), it can nonetheless undermine the need for enhanced cognitive control (FMθ) in case reward is unexpected. We discuss these new results in terms of optimistic bias or positive mood resulting from an increased reward magnitude.

KEYWORDS
motivation, reward, RewP, theta

1 | INTRODUCTION

There is a long research tradition on how humans perceive, process, and pursue external rewards such as a delicious meal, a comforting social interaction, or a simple monetary compensation. Because rewards are valuable sources of pleasure, its prospect motivates us to seek them, with effects visible during the anticipation and prediction of reward (Berridge, Robinson, & Aldridge, 2009). If a reward is predicted but eventually not achieved (i.e., reward prediction error), this deviation is swiftly processed and fuels reinforcement learning (Holroyd & Coles, 2002; Schultz, 2015; Sutton & Barto, 1998). Reward processing is therefore not only determined by the valence of the outcome but also by contextual factors, including expectations. Reward magnitude is another source of contextual modulation during reward processing (for a review, see Sambrook & Goslin, 2015). Neuroeconomics studies showed that both reward probability and magnitude shape reward processing via the so-called expected value (Glimcher, Camerer, Fehr, & Poldrack, 2009). Consider two simple gambles where the probability of winning is constant (e.g., 25%), but reward is either small (€1) or large (€10). In both cases, a different expected value is generated, namely, €0.25 in the small reward condition (25% × €1), and €2.5 in the large one (25% × €10). Hence, the expected value translates the integration of probability with magnitude. As a result, reward prediction errors scale with the expected value, whereby if a large reward is expected but not met, the neural processing of this deviation is stronger than if this reward is small (Rolls, McCabe, & Redoute, 2008; Tobler, Fiorillo, & Schultz, 2005). However, at the electrophysiological level, discrepant results have been reported regarding amplitude modulation of specific ERP components as a function of reward magnitude (for an overview of existing EEG studies, see Table 1). Moreover, when amplitude changes were reported, it often remained unclear if they occurred because reward expectation, or adjustment in cognitive control more generally (or perhaps both), was altered by reward magnitude.

Reward processing has been studied extensively in the past using the ERP method and, more specifically, the feedback-related negativity (FRN) or, alternatively, the reward positivity (RewP) component. Although both ERP components share overlapping time courses, they can be dissociated from each other at the electrophysiological level (see Gheza, Paul, & Pourtois, 2018, for a recent demonstration). In many ways, these two ERP components show opposite characteristics: While the FRN is a phasic negative ERP component peaking around 250 ms after negative feedback onset at fronto-central sites (Holroyd & Coles, 2002; Miltner, Braun, & Coles, 1997; Ullsperger, Fischer, Nigbur, & Endrass, 2014; Walsh & Anderson, 2012), the RewP is a broad positive deflection elicited at fronto-central sites for reward (Holroyd, Pakzad-Vaezi, & Krigolson, 2008; Proudfit, 2015). Importantly the FRN's amplitude is the largest for negative compared to positive outcomes, while the RewP's amplitude is the largest for positive compared to negative outcomes. Moreover, both components are differently sensitive to prediction errors. The FRN appears to reflect negative reward prediction errors (i.e., worse-than-expected outcomes, e.g., unexpected no-reward feedback; Holroyd & Coles, 2002; Sambrook & Goslin, 2015; San Martín, 2012; Ullsperger, Danielmeier, & Jocham, 2014; Walsh & Anderson, 2012). In comparison, the RewP appears to reflect positive reward prediction errors (i.e., better-than-expected outcomes, e.g., unexpected reward feedback; Frömer, Stürmer, & Sommer, 2016; Meadows, Gable, Lohse, & Miller, 2016; Weinberg, Riesel, & Proudfit, 2014).

These ERP components are obtained after a standard averaging procedure, where the time- and phase-locked components of the EEG signal elicited by the feedback are retained. However, the EEG activity, which is not phase locked to the onset of the feedback, can carry relevant information about reward processing (Cohen, Wilmes, & van de Vijver, 2011; Fell et al., 2004; Makeig et al., 2002). Using a time-frequency decomposition of the EEG data, the power of 4–8 Hz (theta) oscillations over frontal-medial electrodes following evaluative feedback onset has been identified as a reliable electrophysiological marker of surprise, ultimately triggering cognitive control (Cavanagh, Figueroa, Cohen, & Frank, 2012; Cavanagh, Frank, Klein, & Allen, 2010; Cavanagh & Shackman, 2015; Cohen, Elger, & Ranganath, 2007; Glazer, Kelley, Pornpattananangkul, Mittal, & Nusslock, 2018; Luft, 2014; Mas-Herrero & Marco-Pallarés, 2014; Osinsky, Seeger, Mussel, & Hewig, 2016). Unlike the FRN or RewP, fronto-medial theta (FMθ) power usually increases for any unexpected outcomes (Cavanagh et al., 2012; Hajihosseini & Holroyd, 2013; Hauser et al., 2014; Mas-Herrero & Marco-Pallarés, 2014). Given that the detection of prediction errors is crucial for goal-adaptive behavior (Ullsperger, Danielmeier, et al., 2014), FMθ activity has been interpreted as reflecting the need for enhanced cognitive control when facing difficult, new, or challenging situations (Cavanagh & Frank, 2014; Cavanagh & Shackman, 2015). This assumption is not only supported by the observation of increased FMθ activity for unexpected, novel, or negative outcomes but also by covariations seen at the behavioral level following conflict or error processing (Cavanagh, Cohen, & Allen, 2009; Nigbur, Ivanova, & Stürmer, 2011) as well as translational research on adaptive control (Narayanan, Cavanagh, Frank, & Laubach, 2013; Womelsdorf, Johnston, Vinck, & Everling, 2010).

As can be seen in Table 1, previous ERP studies have observed a larger (i.e., more positive) RewP for rewards of large as compared to small magnitude (Hajcak, Moser, Holroyd, & Simons, 2006; Holroyd, Larsen, & Cohen, 2004; Meadows et al., 2016; San Martín, Manes, Hurtado, Isla, & Ibañez, 2010), suggesting that increasing magnitude likely augmented reward processing or sensitivity, even though subjective ratings were usually not used to corroborate this conclusion (with the exception of Kreussel et al., 2012; Luo & Qu, 2013; San Martín et al., 2010, who reported either effects of expectancy, pleasure, or satisfaction). In comparison, a missed (large) reward or a loss of large magnitude seemed to decrease the FRN component (Banis & Lorist, 2012; Goyer, Woldorff, & Huettel, 2008; Gu et al., 2017). However, it should be noted that many studies failed to reveal any modulatory effect on the FRN component (Sato et al., 2005; Yeung & Sanfey, 2004). Moreover, very few EEG studies have explored changes in FMθ power as a function of reward magnitude, and, similarly to the FRN, no clear picture emerged regarding the direction of the effect created by this variable (see Table 1). Whereas some studies showed FMθ power increases for larger rewards (Andreou et al., 2015; HajiHosseini & Holroyd, 2015; Leicht et al., 2013), others failed to show any significant modulation of FMθ activity as a function of magnitude (Bernat, Nelson, & Baskin-Sommers, 2015; Doñamayor, Marco-Pallarés, Heldmann, Schoenfeld, & Münte, 2011; Sambrook & Goslin, 2016). Moreover, only one of them previously explored the effect of reward magnitude in relation to feedback valence and expectancy but

TABLE 1 Overview of existing EEG studies examining the effect of reward magnitude on performance monitoring

				Magnitude effects on …				
Publication	Task (sample size)	Conditions	FRN/RewP quantification	FRN (neg. FB)	RewP (pos. FB)	P3	Theta	Delta
Goyer et al. (2008)	Choice of magnitude (20)	Gain–loss Large–small Chosen–alternative	Mean (200–300)	↓		↑		
Luo and Qu (2013)	Choice of magnitude (18)	Gain–loss Low–high (context) Small–large (relative)	Mean (200–250)	↓	↑	↑		
Sambrook and Goslin (2015)	Meta analysis (45)	Good–bad Large–small Expected–Unexpected	Mean (228–344)	↓	↑			
Banis and Lorist (2012)	Choice of options (guessing) (32)	Gain–loss Large–small	Mean (230–300) Mean-to-mean (P2P3)	↓	↑			
Gu et al. (2017)	Choice of options (guessing) (sequential FB) (26)	Gain–loss Large–small Certain–ambiguous	Mean (250–350)	↓	↑	↑		
Wu and Zhou (2009)	Choice of options (guessing), magnitude announced (19)	Gain–loss Large–small Expected–unexpected (magnitude)	Mean (250–350)	↓	↑	↑		
HajiHosseini et al. (2012)	Choice of options (guessing), magnitude announced (26)	Gain–loss Large–small Expected–unexpected	Mean around peak	↓	↑		(↑)	
Gu et al. (2011)	Choice of options (guessing), sequential FB (24)	Gain–loss Large–small	Peak-to-peak (P2)	↓	↑	↑		
Kreussel et al. (2012)	Choice of options (learning) (24)	Gain–loss Large–small Expected–unexpected	Mean (250–350)	(↓)	↑	↑		
Holroyd et al. (2004)	Choice of options (guessing) (16)	Gain–loss Best–zero–worst (relative)	Peak	(↓)	↑			
Kamarajan et al. (2009)	Choice of magnitude (50)	Gain–loss Large–small	Mean (200–275)	(↓)	(↑)	↑		

(Continues)

TABLE 1 (Continued)

				Magnitude effects on …				
Publication	Task (sample size)	Conditions	FRN/RewP quantification	FRN (neg. FB)	RewP (pos. FB)	P3	Theta	Delta
Pedroni, Langer, Koenig, Allemand, and Jäncke (2011)	Choice of options (guessing), magnitude announced (16)	Gain–no gain Large–small	TANCOVA over entire waveform	(=)	(↑)			
Andreou et al. (2015)	Choice of magnitude (23)	Gain–loss Large–small (bipolar–healthy)	Peak-to-peak (P2)	(↓)	(↑)		↑	
Marco-Pallares et al. (2008)	Choice of magnitude (25)	Gain–loss Large–small	Mean (200 –300)	=	↑		=	
Doñamayor et al. (2011)	Choice of magnitude (16)	Gain–loss Large–small	Nonparametric permutation testing	↑	=		=	
Bellebaum et al. (2010)	Choice of options (learning), magnitude announced (20)	Gain–no gain Large–medium–small	Peak-to-peak (P2)	↑	=	↑		
Meadows et al. (2016)	Speeded reaction (20)	Gain–no gain Large–…–Small	Mean (230–330)	=	↑	↑		
San Martín et al. (2010)	Choice of options (guessing) (22)	Gain–loss Large–small Expected	Mean (240–310)	=	↑			
Santesso et al. (2011)	Choice of magnitude (20)	Gain–loss Large–small (risk magnitude)	Peak (200–400)	=	↑			
Zottoli and Grose-Fifer (2012)	Choice of magnitude options (learning) (18)	Gain–loss Large–small	Peak-to-peak (P2)	=	↑			
Schuermann, Endrass, and Kathmann (2012)	Choice of magnitude (50)	Gain–loss Large–small	Peak-to-peak (P2)	=	↑	↑		
Hajcak et al. (2006)	Choice of options (guessing) (16)	Gain–loss Large–small	Peak-to-peak (P3)	=	(↑)			
Leicht et al. (2013)	Choice of magnitude (22)	Gain–loss Large–small	Peak-to-peak (P2)	=	=	=	↑	↑
Sato et al. (2005)	Choice of options (guessing), magnitude announced (18)	Gain–loss Large–small	Peak-to-peak (P2)	=	=	↑		

(Continues)

TABLE 1 (Continued)

				Magnitude effects on …				
Publication	Task (sample size)	Conditions	FRN/RewP quantification	FRN (neg. FB)	RewP (pos. FB)	P3	Theta	Delta
Yeung and Sanfey (2004)	Choice of options (guessing), sequential FB magnitude announced (16)	Gain–loss Large–small	Peak-to-peaks (P2P3)	=	=	↑		
Padrón Fernández-Rey Acuña & Pardo-Vazquez (2016)	Perceptual discrimination (15)	Gain–loss Large–small Easy–difficult	Single trial ROC and latency	=	=	↑		
Doñamayor, Schoenfeld, and Münte (2012)	Speeded reaction (MID) (20)	Reward–no reward Large–medium–small (expected–unexpected)	Nonparametric permutation testing				↑	
Bernat et al. (2015)	Choice of magnitude (149)	Gain–loss Large–small	Peak				=	↑
Janssen, Poljac, and Bekkering (2016)	Choice of options (guessing), magnitude announced (25)	Gain–loss Large–small (Expected–unexpected)	Peak-to-peak (P2)	=	=		=	=

Note: ↑ and ↓indicate a reported increase or decrease of the ERP component for a larger compared to a smaller reward magnitude, respectively. Equal sign (=) refers to no statistical difference between these two conditions. Results in parentheses were not statistically tested, but mean amplitudes indicate this trend.

Abbreviation: FB, feedback/outcome.

focused on other frequency bands than FMθ (HajiHosseini, Rodríguez-Fornells, & Marco-Pallarés, 2012).

The goal of our study was to use a multicomponent approach to assess changes in reward processing at the neurophysiological level depending on reward magnitude. More specifically, we set out to establish whether increasing reward magnitude led to a general boost in reward processing (RewP) or was also accompanied by specific changes in reward expectation (FRN/RewP, FMθ). To this aim, we used a simple gambling paradigm devoid of learning or risk evaluation (adapted from Paul & Pourtois, 2017), in which feedback valence (reward vs. no-reward), expectancy, and reward magnitude were manipulated using a factorial design. We capitalized on state-of-the-art neurophysiological markers of reward processing (RewP) and reward prediction error (FRN/RewP, FMθ), supplemented with subjective ratings informing about how evaluative feedback was processed by participants along the valence and expectancy dimensions.[1] Based on the literature reviewed above (see also Table 1), we hypothesized that FRN and RewP could show dissociable effects during reward processing: the amplitude of the RewP should be enhanced for large versus small rewards (irrespective of expectancy), whereas we did not expect to find a clear effect of magnitude on the FRN for no-reward outcomes (see Table 1). However, we conjectured that the FRN should translate signed (negative) reward prediction errors, with a larger difference between expected and unexpected outcome when it was no-reward compared to rewarding. With regard to FMθ, we surmised that its power should be larger for no-reward than for reward feedback, unexpected compared to expected feedback, and for large compared to small outcome (Cavanagh et al., 2012; Hajihosseini & Holroyd, 2013; Kamarajan et al., 2009; Luo & Qu, 2013; Meadows et al., 2016; Sambrook & Goslin, 2015; Santesso, Dzyundzyak, & Segalowitz, 2011).

2 | METHOD

2.1 | Participants

Forty undergraduate students gave written informed consent and received €30 for participating in this study approved by the local ethics committee. They had normal or corrected-to-normal vision and no history of neurological or psychiatric disorders. They all reported to be right-handed. Three participants were excluded due to technical problems during data acquisition or noisy data, and another one due to poor performance (i.e., less than 50% correct responses, see catch trials below). Hence, 36 participants ($M_{\text{Age}} = 23.6$ years, $SD = 2.7$; 24 female) were eventually included in the analyses. Post hoc sensitivity analysis showed that, with a final sample size of 36, the study had a power ($1 - \beta$) of 0.8 to detect a large-sized effect at an α level of .05.

2.2 | Task

A modification of a previously used gambling task was administered (Hajcak, Moser, Holroyd, & Simons, 2007; Paul & Pourtois, 2017), where participants had to select the correct door in order to win a monetary reward. At the beginning of each trial, participants were informed about reward probability with a cue (1,000 ms). The cue was presented as a small circle filled up to one third or two thirds (black/white) announcing a reward probability of 33% or 66%, respectively. Afterward, a horizontal array of three doors was presented. Participants chose a door by pressing with their right index finger the corresponding key on a response box. After a fixation dot (800 ms), this choice was followed by either a green plus sign (+) indicating a monetary reward or a red circle (o; 1,500 ms), indicating no reward was obtained. Unknown to participants, feedback was related only to the objective reward probabilities, ending up with a preset winning of 4,500 points for all subjects (irrespective of their choices), which was translated into a fixed €10 payoff. Importantly, a systematic manipulation of reward magnitude was introduced in a blockwise fashion (i.e., participants were informed beforehand that they could win either 5 or 45 points for choosing the correct [rewarding] door on every trial). Reward magnitude (being either large or small) was manipulated across blocks to avoid unwanted carryover effects of changing reward magnitude across successive trials. To make sure participants processed evaluative feedback as a function of the prospect of either low or high payoff, the reward probability cue was surrounded by either a simple (small reward) or jagged (large reward) circle (see Figure 1). Further, the size of the feedback was also modified (becoming three times larger when reward magnitude was large).

To ensure participants paid attention to the cue and the feedback, different catch trials were included every now and then. To assess if participants correctly processed reward probability at the cue level before making a choice, they were asked about their winning chance ("How many doors contain a prize?"), answered with the corresponding number on the keyboard. After the feedback was presented, they were also occasionally asked about how (un)expected the given outcome was or how much they (dis)liked it, answered on a visual analog scale (VAS, ranging from *not at all* to *a lot*). These two questions were used to assess if the manipulations of reward expectancy and magnitude produced significant effects at the subjective level. Each question was asked

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[1] Besides the FRN/RewP and FMθ, reward magnitude can also influence the P300 component and delta power (1–4 Hz) at posterior leads, although these neurophysiological effects are usually less related to reward prediction errors but to the salience of the outcome instead. For the sake of completeness, we also analyzed these complementary electrophysiological markers of performance monitoring in this study but present these results in the online supporting information.

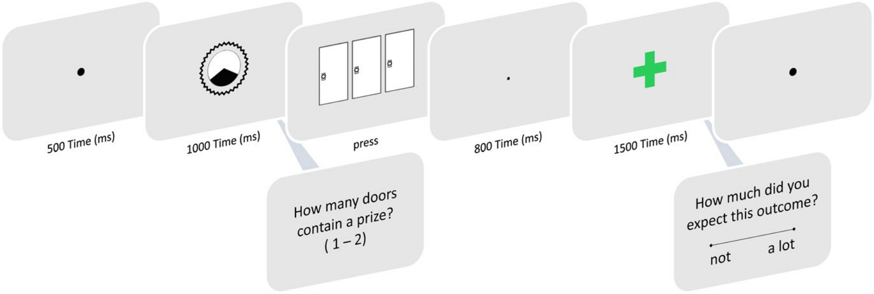

FIGURE 1 Overview of the trial structure. At the beginning of each trial, participants were informed about the actual reward probability (black or white part of the circle, 33% or 66%). After they chose one door, they received either reward or no-reward feedback. Additionally, in some trials, participants had to report, using a specific scale (see Method), the objective reward probabilities and/or the expectancy or liking of the given feedback

64 times, and in 46% of the trials, one (or two) questions were asked. Questions regarding the cue were asked equally often for each magnitude and reward probability condition (16 times). Unexpected feedback was probed six times for each condition and question, while expected feedback was probed 10 times. All stimuli were shown against a gray background on a 21-in. CRT screen (60 Hz refresh rate) and implemented in E-Prime (V 2.0.10, Psychology Software Tools Inc., Sharpsburg, PA).

2.3 | Procedure

Participants started with instructions and six practice trials. The experiment consisted of four blocks of 90 trials each. Two blocks had large reward magnitude while the other two had low reward magnitude. Block order was counterbalanced across subjects. The two possible reward probability cues were presented equally often but in random order within each block. After each block, participants were informed about their current winning (in points, converted to euros), and they had to rate (general ratings) how much they expected and liked each feedback type (reward and no-reward). These two ratings were answered using the same VAS probes for the catch trials (see above). Each block was briefly interrupted after 45 trials (half of the block) for a short break. A subset of the sample ($n = 17$) was also asked to provide mood ratings at this point. To this aim, these 17 participants indicated their current mood state on four VAS probes, ranging from *neutral* to *as happy/pleasant/awake/lively as I can imagine*.

2.4 | Recording and preprocessing of EEG data

EEG was recorded using a 64-channel BioSemi ActiveTwo system (http://www.biosemi.com) according to the extended 10-20 EEG system, with two other electrodes placed at the mastoids and four additional electrodes to measure eye movements. EEG was sampled at 512 Hz and preprocessed offline with EEGLAB 13.5.4b (Delorme & Makeig, 2004) implemented in MATLAB R2013b. The preprocessing included 0.03/35 Hz high/low-pass filtering and linked-mastoid rereferencing. For data cleaning, the algorithmic preprocessing line for EEG (APPLE; Cavanagh, Napolitano, Wu, & Mueen, 2017) was applied, which combines custom algorithms and functions from the open source toolboxes FASTER (Nolan, Whelan, & Reilly, 2010) and EEGLAB to automatically identify the most likely independent component associated with eyeblinks, to interpolate bad channels, and to remove bad epochs. On average, 2.5 ($SD = 0.7$) components were removed by ICA (independent component analysis), 2.1 ($SD = 1.0$) channels interpolated, and 4.1% ($SD = 2.3$) of epochs rejected. Epochs were extracted starting from −1,000 to 2,700 ms around feedback onset and baseline corrected to the −250 to 0 ms interval before feedback onset. For each subject separately, the EEG data corresponding to eight conditions (i.e., 2 Valence × 2 Expectancy × 2 Magnitude) were extracted. To account for different signal-to-noise ratios between conditions, a limited (randomly sampled) number of trials of the expected conditions (originally $M = 57$, $SD = 1.4$) was used to match the unexpected conditions for each subject individually ($M = 26$, $SD = 2.3$).

A review of previous studies revealed that, depending on the ERP of interest (either the FRN or the RewP), different quantification methods have often been used (see Table 1). Similarly, in a previous study (Gheza, Paul, et al., 2018), we found that a peak-to-peak measurement was able to capture the short-lived negative deflection after no reward (i.e., N200), resembling the FRN, while a mean amplitude measurement was better suited to capture the large positivity following rewards and hence resembling the RewP. Therefore, depending on the ERP component of interest (either FRN or RewP), these two quantification methods can reveal different results. For the sake of consistency and transparency, we used and reported them both, to assess possible changes of either the FRN (to no-reward) or the RewP (to reward) to valence, expectancy, and magnitude. The FRN component is usually defined as the difference between the largest peak in the time window of the negative component (N2) and its base (i.e., the peak of the

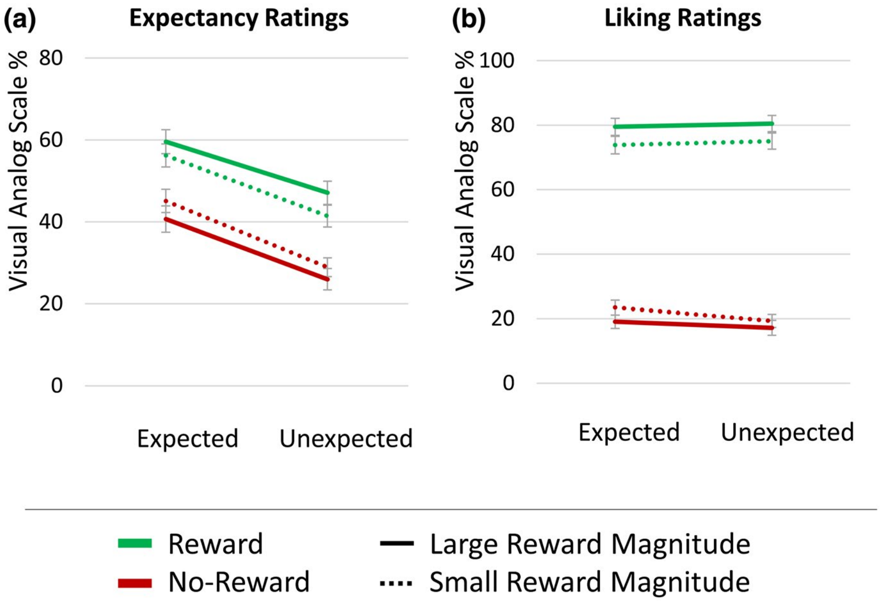

FIGURE 2 Subjective ratings of feedback (catch trials), separately for expectancy and liking

preceding positivity, P2; e.g., Bellebaum, Polezzi, & Daum, 2010; Gu et al., 2011; Zottoli & Grose-Fifer, 2012, see Table 1). This peak-to-peak method has been shown to be more adequate to capture subtle amplitude modulations of the FRN by expectancy, compared to a more conservative mean-amplitude approach (see also Gheza, Paul, et al., 2018). Therefore, the FRN component was quantified at FCz as the difference between the most negative peak (within 150–300 ms, i.e., N200) and the preceding positive peak (i.e., P200). The amplitude difference between these two consecutive peaks resulted in a negative value, reflecting the FRN and being typically larger for unexpected no-reward than reward. These peaks were selected manually, separately for each subject and condition. Nevertheless, a close review of existing studies exploring the effects of reward magnitude on the FRN/RewP component (see Table 1) suggests that the ERP component under scrutiny was more often the RewP (as opposed to FRN) and was usually quantified as a mean activity computed within a predefined time window (around 200–300 ms postfeedback onset). This approach has often been put forward to score the RewP component in the existing literature (e.g., Foti, Weinberg, Bernat, & Proudfit, 2015; Frömer et al., 2016; Meadows et al., 2016). This in turn provides a measure of the RewP rather than the FRN per se (for a similar approach, see Gheza, Paul, et al., 2018). Therefore, we also performed a mean amplitude measurement around the peak (230–280 ms postfeedback onset at electrode FCz). This time window was selected based on the maximum of the difference between no-reward and reward feedback across all conditions (i.e., 255 ms) and was identical to our previous study (Paul & Pourtois, 2017). Importantly, although the use of difference scores between reward and no-reward feedback has been recommended in the past (Krigolson, 2018; Luck & Gaspelin, 2017), we refrained from using this approach here. This choice was motivated by our previous study (Gheza, Paul, et al., 2018) and other independent results (see Fouragnan, Retzler, Mullinger, & Philiastides, 2015) showing that partly nonoverlapping neural networks underpin the processing of reward and no-reward feedback.

The time frequency analysis was done using EEGLAB built-in *std_ersps* function (2.4 to 9 cycles, 0.8 to 10 Hz, 60 log-spaced frequencies, 400 time points per epoch). The time interval from −500 to −200 ms before feedback onset was used for baseline correction. The mean FMθ activity (4–8 Hz) was extracted in the 200–400 ms interval following feedback onset at FCz. This electrode position was chosen based on the local maximum (mean power values) of the difference between no-reward and reward feedback (see Figure 3) as well as on previous EEG studies using the same site and data analysis (Gheza, Paul, et al., 2018; Paul & Pourtois, 2017).[2]

2.5 | Subjective ratings

Ratings on the VAS regarding the feedback liking/expectancy as well as the mood ratings were transformed into percentage scores, arbitrarily setting the extreme end (*not at all*) to 0 and the other one (*a lot*) to 100.

2.5.1 | Catch trials

Accuracy for the reward probability cue (i.e., the percentage of correct responses) was computed for each reward probability and reward magnitude separately. For the VAS

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[2] To ensure that the results reported for the FMθ activity (total power) were not influenced by the superimposed FRN/RewP component (evoked activity), we also performed additional analyses where we subtracted the evoked component from the total power to reveal the selective contribution of induced effects to this mean FMθ activity; see supporting information for details and results.

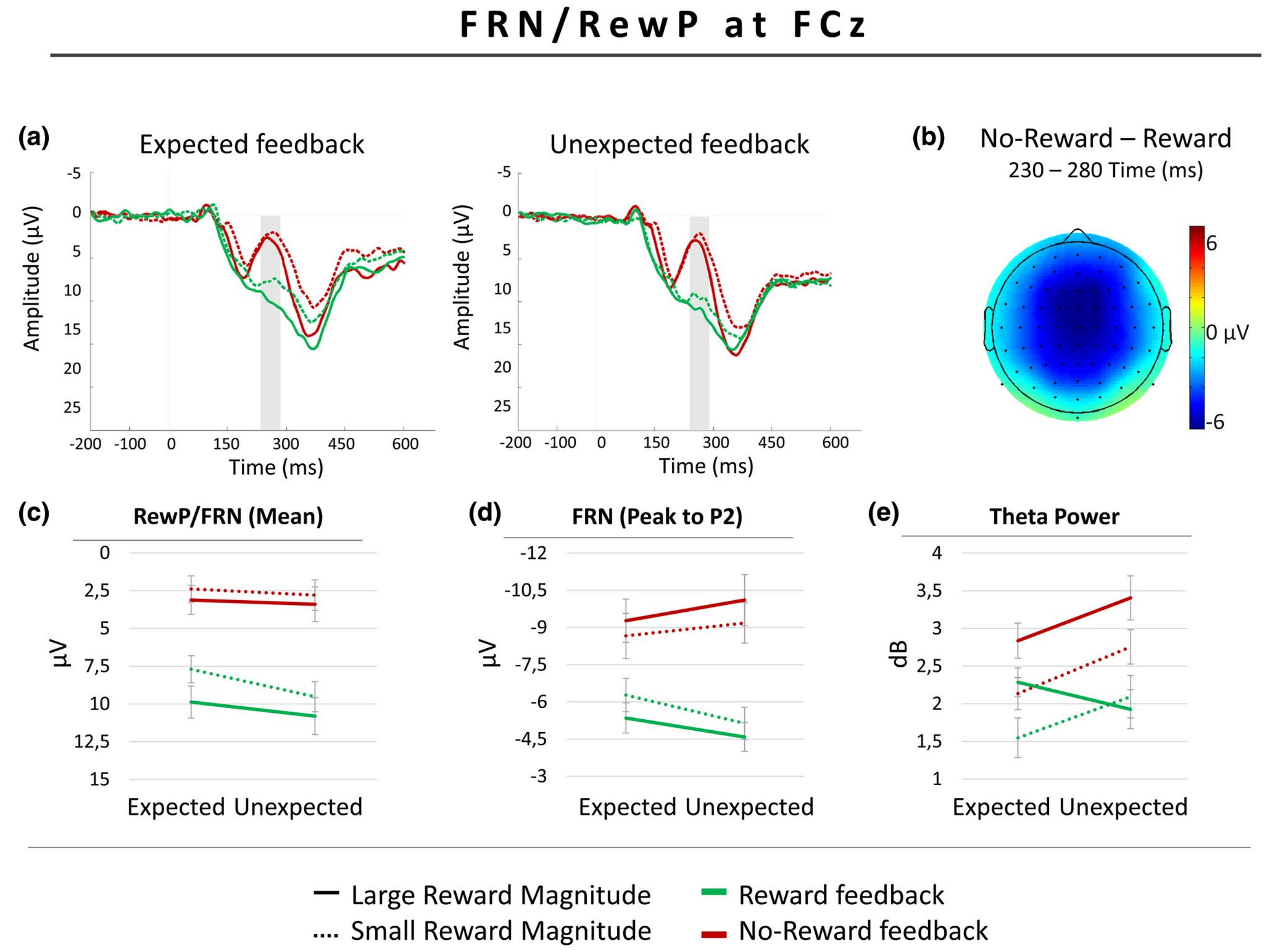

FIGURE 3 ERP results. (a) Grand-averaged ERP waveforms at electrode FCz. Time point 0 corresponds to feedback onset and negativity is plotted upward. (b) Horizontal topographical map of the FRN component (computed as the difference wave between no-reward and reward feedback during the 230–380 ms postfeedback onset interval), confirming a predominant fronto-central scalp distribution for it. (c,d,e) Mean amplitudes/power, separately for each condition (± standard error of the mean). (c) Overview of the mean amplitudes of the RewP/FRN component, defined as the mean between 230 and 280 ms after feedback onset at FCz. (d) Peak-to-peak FRN amplitudes at FCz, quantified as the difference between the N2 and the preceding P2. (e) Mean FMθ power at electrode FCz

ratings obtained for the feedback, mean answers were computed separately for each of the eight possible conditions (2 Valence × 2 Expectancy × 2 Magnitude).

2.5.2 | General ratings

For each of the two VAS probes (i.e., expectancy, liking), the mean answers were computed separately for each of the four possible conditions (2 Valence × 2 Magnitude). Mood ratings (asked within each block) were averaged separately for each item but across the corresponding magnitude blocks.

2.6 | Statistical analysis

For all analyses, the significance alpha cutoff was set to 0.05. Data analysis was carried out in JASP (0.8.2., JASP Team, 2017). The main and interaction effects were reported first, followed by post hoc tests computed on the estimated marginal means of the dependent variables and their standard errors as implemented in SPSS EMMEANS syntax (22, IBM statistics) whenever applicable. Materials, data, and analysis scripts are publicly available on the Open Science Framework (https://osf.io/gwhp6/).

2.6.1 | Catch trials

Accuracy was analyzed using a 2 × 2 repeated measures analysis of variance (ANOVA) with the within-subject factors reward probability (low/high) and feedback magnitude (small/large). For the feedback, the data obtained for each scale (i.e., liking, expectancy) were submitted to a 2 × 2 × 2 repeated measures ANOVA with the within-subject factors feedback valence (reward/no-reward), expectancy (expected/unexpected), and magnitude (small/large).

2.6.2 | General ratings

For each scale separately (i.e., liking, expectancy) a 2 × 2 repeated measures ANOVA was performed, with the within-subject factors feedback magnitude and valence. For each of the four affective dimensions, mood levels were compared between small and large reward magnitude conditions using paired *t* tests. To control for multiple comparisons, a Bonferroni correction (0.0125) was applied.

2.6.3 | EEG components

The extracted FRN amplitudes (peak-to-peak analysis), RewP amplitudes (mean amplitude measurement), and FMθ power values were analyzed using separate 2 × 2 × 2 repeated measures ANOVAs, with the within-subject factors feedback valence, expectancy, and magnitude.

3 | RESULTS

3.1 | Catch trials

3.1.1 | Cue-level

The accuracy was very high ($M = 95\%–97\%$, $SD = 4$) and did not yield significant main or interaction effects, all $F\text{s} \le 2.8$, $p\text{s} \ge .10$, $\eta^2\text{s} \le .074$.

3.1.2 | Feedback level

For expectancy (see Figure 2a), the ANOVA revealed significant main effects of expectancy, $F(1, 35) = 43.4$, $p < .001$, $\eta^2 = .55$, and valence, $F(1, 35) = 24.0$, $p < .001$, $\eta^2 = .41$. Additionally, the interaction between feedback valence and magnitude was significant, $F(1, 35) = 17.2$, $p < .001$, $\eta^2 = .33$. Other effects were not significant, all $F\text{s} \le 64.2$, $p\text{s} \ge .34$, $\eta^2\text{s} \le .027$. Reward was more expected than no-reward ($p < .001$), and expected feedback was more expected than unexpected feedback ($p < .001$). The significant interaction showed that, while reward feedback was more expected in the large compared to the small reward blocks ($p = .003$), the opposite was true for no-reward feedback ($p = .021$; see Figure 2a and Table 2).

For liking (see Figure 2b), the ANOVA revealed a significant main effect of valence, $F(1, 35) = 213$, $p < .001$, $\eta^2 = .86$) and a significant interaction between expectancy and valence, $F(1, 35) = 5.13$, $p = .030$, $\eta^2 = .13$) as well as between magnitude and valence, $F(1, 35) = 14.98$, $p < .001$, $\eta^2 = .30$. No other interactions or main effects reached significance, all $F\text{s} \le 2.75$, $p\text{s} \ge .11$, $\eta^2\text{s} \le .072$. Reward was more liked than no-reward ($p < .001$). The interaction between expectancy and valence was explained by a drop in liking unexpected no-reward compared to expected no-reward feedback ($p = .015$), without such a change for reward ($p = .25$). Moreover, the other significant interaction showed that reward feedback was liked more for large compared to small magnitude feedback ($p = .002$), while the opposite was seen for no-reward feedback ($p = .004$).

3.2 | General ratings

3.2.1 | Feedback

For expectancy ratings, the ANOVA revealed a significant interaction between valence and magnitude, $F(1, 35) = 5.91$, $p = .020$, $\eta^2 = .15$. No other main effects were significant,

TABLE 2 Overview of means (standard deviations) per condition

Condition	Liking	Expectations	RewP/FRN (mean)	FRN/RewP (Peak-P2)	FMθ total
Large magnitude					
No-reward					
Expected	19.08 (19.42)	40.68 (12.39)	4.88 (6.38)	−9.27 (5.24)	2.84 (1.40)
Unexpected	17.20 (15.72)	25.96 (13.87)	5.64 (8.17)	−10.11 (6.19)	3.41 (1.76)
Reward					
Expected	79.51 (17.71)	59.58 (15.87)	12.75 (7.22)	−5.35 (3.68)	2.29 (1.15)
Unexpected	80.51 (17.07)	47.09 (14.98)	13.63 (8.18)	−4.58 (3.48)	1.93 (1.54)
Small magnitude					
No-reward					
Expected	23.44 (17.14)	45.10 (13.76)	3.81 (5.95)	−8.66 (5.48)	2.13 (1.27)
Unexpected	19.35 (13.70)	28.92 (12.12)	4.56 (6.70)	−9.18 (4.91)	2.75 (1.36)
Reward					
Expected	73.82 (16.77)	56.21 (16.50)	9.84 (6.39)	−6.28 (4.06)	1.55 (1.58)
Unexpected	75.06 (16.00)	41.41 (14.97)	11.82 (6.76)	−5.13 (3.89)	2.09 (1.69)

all $Fs \le 1.67$, $ps \ge .21$, $\eta^2s \le .05$. Post hoc tests showed that, while no-reward feedback was rated as equally (un) expected for both magnitudes ($p = .27$, $M_{small} = 51.4\%$, $SD = 23.9$, $M_{large} = 47.2\%$, $SD = 21.5$), reward feedback was more expected in the large compared to the small reward blocks ($p = .002$, $M_{small} = 45.6\%$, $SD = 21.0$, $M_{large} = 54.6\%$, $SD = 21.7$).

For the liking ratings, the ANOVA revealed significant main effects of valence, $F(1, 35) = 316$, $p < .001$, $\eta^2 = .90$, and magnitude, $F(1, 35) = 6.69$, $p = .014$, $\eta^2 = .24$. More importantly, the interaction between valence and magnitude was significant as well, $F(1, 35) = 11.2$, $p = .002$, $\eta^2 = .240$. Post hoc tests revealed more liking for reward over no-reward feedback ($p < .001$) as well as for large than small feedback ($p = .014$). However, this was only the case for reward feedback ($p < .001$, $M_{small} = 82.3\%$, $SD = 14.6$, $M_{large} = 87.2\%$, $SD = 13.6$), without any significant modulation of liking for no-reward depending on magnitude ($p = .10$, $M_{small} = 12.6\%$, $SD = 12.5$, $M_{large} = 10.6\%$, $SD = 13.6$).

3.2.2 | Mood ratings

Significantly higher ratings of happiness, $t(15) = 2.87$, $p = .012$, $d = 0.72$, and pleasantness, $t(15) = 3.11$, $p = .007$, $d = 0.78$, were found for large ($M_{happy} = 40.6\%$, $SD = 28.6$, $M_{pleasant} = 38.9\%$, $SD = 26.5$) compared to small reward magnitude blocks ($M_{happy} = 34.6\%$, $SD = 26.51$, $M_{pleasant} = 32.9\%$, $SD = 26.0$). Arousal did not differ between these two conditions, $t(15) \le 1.65$, $p \ge .12$, $d \le 0.41$ ($M_{awake\ small} = 41.5\%$, $SD = 25.4$, $M_{awake\ large} = 43.9\%$, $SD = 27.1$; $M_{lively\ small} = 30.5\%$, $SD = 16.9$, $M_{lively\ large} = 34.1\%$, $SD = 21.0$).

3.3 | EEG components

3.3.1 | FRN (peak-to-peak)

The ANOVA revealed a significant main effect of valence, $F(1, 35) = 33.8$, $p < .001$, $\eta^2 = .49$. Moreover, the interactions between expectancy and valence, $F(1, 35) = 6.69$, $p = .014$, $\eta^2 = .16$, as well as between valence and magnitude, $F(1, 35) = 4.35$, $p = .044$, $\eta^2 = .11$, were both significant. No other effect reached significance, all $Fs \le 0.32$, $ps \ge .58$, $\eta^2s \le .009$. The FRN component was larger for no-reward compared to reward feedback ($p < .001$). Consistent with its sensitivity to reward prediction errors, this difference was larger for unexpected compared to expected feedback ($p = .014$) as well as for large compared to small rewards ($p = .044$). However, a closer look at the waveforms (see Figure 3a and Table 2) suggested that these effects were mostly driven by a systematic modulation of the reward feedback, as opposed to the no-reward one. Post hoc comparisons confirmed this assumption. For reward feedback, the FRN's amplitude was more positive after unexpected compared to expected feedback ($p = .016$); while for no-reward feedback, the component's amplitude was slightly more negative after unexpected compared to expected feedback, although this difference was not significant ($p = .23$). A similar dissociation was found for magnitude, albeit remaining nonsignificant, as the FRN's amplitude was slightly more positive for large compared to small rewards ($p = .10$), while it seemed to be more negative for large compared to small no-reward feedback ($p = .14$).

3.3.2 | RewP/FRN (mean)

This dissociation between the FRN and RewP was further corroborated when we scored these ERP components using a more stringent mean amplitude measurement (see Figure 3a,c and Table 2). The ANOVA revealed significant main effects of valence, $F(1, 35) = 69.78$, $p < .001$, $\eta^2 = .67$, magnitude, $F(1, 35) = 9.02$, $p = .005$, $\eta^2 = .21$, and expectancy, $F(1, 35) = 7.54$, $p = .009$, $\eta^2 = .18$. The interaction between valence and magnitude was significant, too, $F(1, 35) = 4.18$, $p = .048$, $\eta^2 = .018$. No other effects reached significance, all $Fs \le 1.15$, $ps \ge .29$, $\eta^2s \le .032$. The RewP was larger (i.e., more positive) for reward compared to no-reward feedback ($p < .001$), for unexpected compared to expected feedback ($p = .002$), and for large compared to small magnitude ($p < .001$). This latter difference was clearly more pronounced for reward feedback ($p = .001$) compared to no-reward feedback ($p = .11$).

3.3.3 | FMθ power

The ANOVA revealed significant main effects of valence, $F(1, 35) = 21.36$, $p < .001$, $\eta^2 = .38$, expectancy, $F(1, 35) = 5.75$, $p = .022$, $\eta^2 = .14$, and magnitude, $F(1, 35) = 12.0$, $p = .001$, $\eta^2 = .26$. Interestingly, unlike the FRN/RewP, these main effects were qualified by significant interaction effects with expectancy. This analysis showed significant two-way interactions between expectancy and valence, $F(1, 35) = 5.06$, $p = .031$, $\eta^2 = .13$, as well as between expectancy and magnitude, $F(1, 35) = 4.99$, $p = .032$, $\eta^2 = .13$. Importantly, the three-way interaction was also significant, $F(1, 35) = 5.09$, $p = .030$, $\eta^2 = .13$. The interaction between valence and magnitude was not significant, $F(1, 35) = 2.76$, $p = .089$, $\eta^2 = .081$. FMθ activity was substantially larger for no-reward compared to reward feedback ($p < .001$), for large compared to small magnitude ($p = .001$), and unexpected compared to expected feedback ($p = .004$). To follow up the significant three-way interaction, we ran two separate ANOVAs for each magnitude level. When small rewards were at stake, main effects of feedback valence, $F(1, 35) = 7.43$, $p = .010$,

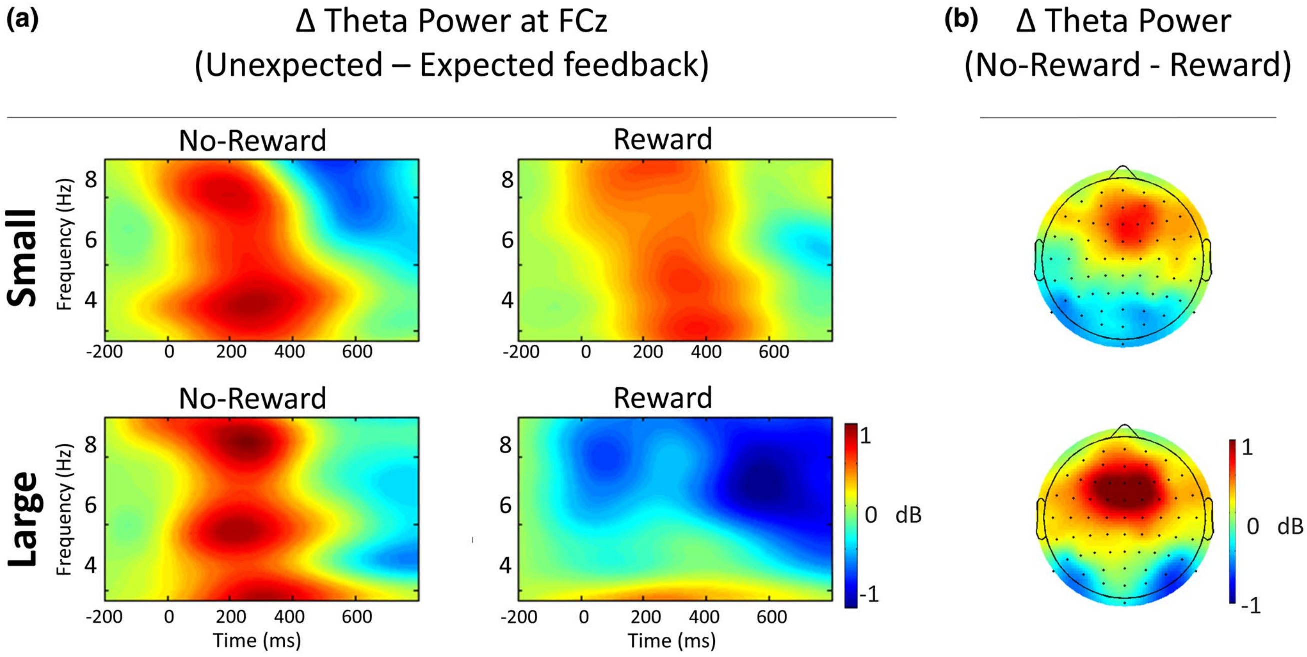

FIGURE 4 FMθ power results at electrode FCz. (a) FMθ power was larger for unexpected than expected feedback, especially for no-reward feedback. By comparison, for reward feedback, if reward magnitude was large (second row), this difference vanished, as confirmed by a significant three-way interaction. (b) Horizontal topographical maps of FMθ power (difference between no-reward and reward feedback) computed during the 200–400 ms postfeedback onset interval, separately for large and small rewards, confirming a predominant fronto-central scalp distribution for this specific oscillation

η^2 = .18, and expectancy, *F*(1, 35) = 11.95, *p* = .001, η^2 = .25, were significant, without a significant interaction effect between them, *F*(1, 35) = 0.098, *p* = .76, η^2 = .003. FMθ activity was larger for no-reward compared to reward feedback ($p < .001$) and for unexpected compared to expected feedback, irrespective of feedback valence (no-reward: *p* = .002; reward: *p* = .023). A different picture emerged for the ANOVA on large magnitude trials. There was a significant main effect of valence, *F*(1, 35) = 28.99, $p < .001$, η^2 = .45, but not of expectancy, *F*(1, 35) = 0.32, *p* = .58, η^2 = .009. Importantly, the interaction between feedback valence and expectancy was significant, too, *F*(1, 35) = 7.61, *p* = .009, η^2 = .18. No-reward led to increased FMθ activity compared to reward ($p < .001$). Although FMθ activity was larger for unexpected compared to expected large no-reward feedback (*p* = .033), this difference was actually absent for large reward feedback (i.e., FMθ activity did not differ between unexpected and expected large reward; *p* = .16; see Figures 3e and 4 and Table 2). When comparing all levels of the two factors (expectancy, magnitude) against each other, results showed that FMθ activity was consistently larger for unexpected compared to expected outcomes ($p \leq .033$), with the notable exception of large rewards (*p* = .16). Moreover, FMθ activity increased for large compared to small outcomes ($p \leq .007$), except when reward was unexpected (*p* = .57).

4 | DISCUSSION

Previous EEG studies showed that reward magnitude influences reward processing yet with different effects found for the FRN and RewP component (see Table 1). Moreover, it remains unclear whether these changes actually translated increased reward processing per se, altered reward predictions, or a combination of both. To address this question, we recorded 64-channel EEG in 36 participants who carried out a gambling task, where the valence, expectancy, and magnitude of the outcome were manipulated using a factorial design. Importantly, we used a multicomponent approach enabling us to assess possible changes in reward processing at different neurophysiological levels depending on these three factors. Accordingly, we could clarify whether reward magnitude mostly influences reward processing (RewP) or reward predictions (FRN/RewP, FMθ).

Subjective ratings showed that participants were sensitive to feedback valence and expectancy. Moreover, they were also influenced by reward magnitude: Large rewards led to an increase in the liking and expectancy of the feedback compared to small rewards. At the EEG level, reward magnitude showed dissociable effects for the FRN, RewP, and FMθ activity. More specifically, irrespective of expectancy, the RewP amplitude for reward outcome was increased for large compared to small rewards, suggesting that large magnitude increased reward processing. Intriguingly, no similar effect was found at the FRN level when no-reward was considered, confirming that magnitude influenced reward processing selectively. Further, reward magnitude also boosted FMθ activity, except for unexpected large rewards. Hence, large magnitude probably led to a complex change in motivation or affect (see below), besides the general gain in reward processing or pleasure. Hereafter, we discuss the possible implications of these new results.

When scored using a peak-to-peak measurement, the FRN/RewP component showed a larger difference between no-reward and reward when the outcome was unexpected compared to expected, in agreement with the tenets of reinforcement learning (Chase, Swainson, Durham, Benham, & Cools, 2011; Hajcak et al., 2006; Holroyd & Coles, 2002). However, this interaction effect between valence and expectancy was not influenced by reward magnitude. Instead, reward magnitude influenced the RewP component (measured as a mean activity) and the processing of reward selectively, which was larger overall (i.e., more positive) for large compared to small rewards, as previously reported (Meadows et al., 2016; San Martín et al., 2010; see also Table 1). Given this dissociation, it appears parsimonious to conclude that large rewards were associated with an increased reward processing, occurring irrespective of the expectancy of the outcome, however.

Interestingly, effects of reward magnitude were clearly different when considering FMθ activity compared to these ERP components. As expected, FMθ power increased for no-reward, unexpected outcome, and large magnitude feedback (Andreou et al., 2015; Cavanagh et al., 2012; HajiHosseini & Holroyd, 2015; Leicht et al., 2013). Moreover, FMθ activity, similar to the RewP, was influenced by expectancy and captured prediction errors. However, in the large magnitude condition, FMθ did not discriminate between expected and unexpected rewards, while it still did for no-rewards. Further, control analyses (see online supporting information) confirmed that these results were specific to induced FMθ activity and could not be explained by the mere superposition of the ERP effects. As the post hoc tests indicated, this three-way interaction was driven by the response to (unexpected) large rewards: FMθ power captured (unsigned) prediction errors for all conditions but large reward. Given this specific pattern, we therefore concluded that large reward interfered with the standard expectancy coding reflected by FMθ power. Moreover, FMθ power was consistently larger for high compared to low magnitude, with the notable exception of unexpected reward. This last result therefore suggests that, at the FMθ level, unexpected large reward was not processed as such (Cavanagh et al., 2012; Gheza, De Raedt, Baeken, & Pourtois, 2018; Hajihosseini & Holroyd, 2013). Tentatively, we suggest that this lack of FMθ power increase when large reward was unexpected could reflect indirectly an optimistic bias (Kress & Aue, 2017; Sharot, 2011; Weinstein, 1980), according to which participants tended to overestimate reward probability. This interpretation, albeit speculative, is in line with the subjective ratings, confirming that large rewards were more expected than no reward (Sharot, Korn, & Dolan, 2011; Windschitl, Smith, Rose, & Krizan, 2010). Given this optimistic bias, it is conceivable that unexpected large rewards were actually perceived as relatively expected or certain, thereby blurring the differential FMθ increase as a function of (un)expectancy in this condition. Presumably, the normal increase at the FMθ level was attenuated because participants did not perceive this outcome as unexpected and/or challenging.

Strikingly, the current findings for FMθ also mirror the results obtained in a previous study where positive mood was elicited and compared to neutral mood (Paul & Pourtois, 2017). Similarly to the use of a large reward magnitude, positive mood was associated with a blunted discrimination at the FMθ level between expected and unexpected reward (Paul & Pourtois, 2017). Hence, positive mood and reward magnitude appear to each produce comparable modulations of FMθ during reward processing. In this earlier study, we interpreted these results as reflecting an optimistic bias created by positive mood, leading to an overestimation of the likelihood of positive events (Eldar, Rutledge, Dolan, & Niv, 2016; Loewenstein & Lerner, 2003; Mayer, Gaschke, Braverman, & Evans, 1992). Moreover, positive mood can be conceptualized in terms of changes in approach motivation (see Cacioppo & Gardner, 1999; Lang, Bradley, & Cuthbert, 1998). Approach motivation is usually evoked by rewards (Kim, 2013; Novak & Foti, 2015; Simon et al., 2010; Threadgill & Gable, 2016) and is generally manipulated by rewards of different magnitude (Avlar et al., 2015; Meadows et al., 2016). Hence, it seems plausible to assume that the affective or motivational state of the participants was actually altered by the reward magnitude manipulation used in the current study, and this change influenced reward processing in a mood-congruent manner (Paul & Pourtois, 2017). This interpretation is also supported indirectly by the results obtained for delta activity and the P300 ERP component (see supporting information), showing both an amplitude increase when a large reward was at stake, irrespective of valence. Because these two neurophysiological components have previously been related to the processing of the motivational significance of the evaluative feedback (Bernat et al., 2015; Glazer et al., 2018; Wu & Zhou, 2009), it seems therefore plausible to assume a general gain in the motivational significance of the feedback, besides reward processing per se, when reward magnitude was large. Moreover, mood ratings collected in a subsample of 17 participants confirmed that participants experienced more happiness and pleasantness in large compared to small reward blocks. Hence, it is possible that the observed changes seen here eventually stemmed from an affective or motivational state created by the use of a large reward magnitude.

Importantly, Cavanagh and Frank (2014) proposed that FMθ activity is not only evoked by unexpected or challenging events but is closely related to cognitive control more generally. According to this framework, the current results can be interpreted as reflecting a lack to leverage cognitive control level when the reward was large but unexpected. This weakening of cognitive control at the FMθ level by reward magnitude accords well with earlier models available in the literature, which assume that positive affect and approach motivation can tip the balance in favor of using updating and reactive control flexibly over a stable and robust maintenance of the task set (Chiew & Braver, 2014; Goschke & Bolte, 2014). In this framework, the absence of FMθ power increase for unexpected reward, when a large magnitude was used specifically, would therefore reflect a dynamic change in the motivational state of the participants who did not treat this outcome as necessarily challenging and thus requiring a swift increase in cognitive control. Whether this change in cognitive control with large magnitude (FMθ) was independent of, caused by, or was even a prerequisite for the boost in reward processing (RewP) could not be established with the current design. To address this question, additional EEG studies are needed to explore further the actual interplay between these separate neurophysiological signals during reward processing.

Some limitations warrant comment. First, some subjective ratings for the feedback did not perfectly align with FMθ results. Nevertheless, given how these ratings were administered, it is likely that objective reward probability rather than subjective perception contributed to increase this discrepancy (Windschitl et al., 2010). Presumably, using more appropriate measures of subjective predictions could reveal more comparable results with FMθ. Second, the size of the feedback stimulus was different for the two reward magnitude conditions, being larger for large compared to small feedback. Given that size or visual salience has been shown to influence FRN/RewP amplitudes previously (Pfabigan, Sailer, & Lamm, 2015), we cannot rule out the possibility that some of the effects observed (e.g., main effect of magnitude on the RewP) were partly explained by this low-level factor. However, since FMθ power was modulated by the three factors in an interactive fashion, it appears unlikely that size only was responsible for the systematic change in feedback processing seen across the different conditions. An uncontrolled variation of the feedback size cannot explain the lack of FMθ power change for unexpected compared to expected large reward feedback seen in this study, because in both cases the size of the feedback was identical. Third, reward magnitude was manipulated using a block design, and, as such, uncontrolled changes in the affective or motivational state of the participants may have occurred and even obscured the effect of reward magnitude on these neurophysiological results. Therefore, it appears important to consider possible changes in the affective or motivational state of the participants, besides reward magnitude only, when interpreting these new results. However, we opted for a block design to avoid carryover effects of changing reward magnitude across successive trials. It appears important to assess whether similar effects (especially for FMθ and RewP) could be replicated, when reward magnitude is manipulated at the single trial level. Last, it would be extremely valuable in future EEG studies to assess whether similar RewP/FRN and FMθ results could be obtained, when loss instead of reward are used as incentive. This change would promote loss-avoidance motivation and likely influence, in turn, the expression of these electrophysiological manifestations.

To sum up, the present findings show that reward magnitude produces dissociable effects during reward processing at the EEG level, which likely inform about complex and dynamic changes in the motivational state of the participants. Increasing reward magnitude led to a boost in reward processing at the RewP level, though occurring irrespective of expectancy. This change was confined to reward and did not alter no-reward and the FRN. Intriguingly, this boost in reward processing as a function of increasing magnitude was accompanied by a transient decrease in cognitive control (FMθ), as if magnitude actually blurred the processing of expectancy during reward processing. We suggest that either an optimistic bias or increase in positive mood can account for these flexible changes in reward processing at the EEG level as a function of reward magnitude.

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