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The cumulative effect of positive and negative feedback on emotional experience

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Abstract

The cumulative effect of positive or negative feedback on subsequent emotional experiences remains unclear. Elucidating this effect could help individuals to better understand and accept the change in emotional experience, irrespective of when they or others receive consecutive positive or negative feedback. This study aimed to examine this effect on 37 participants using self-reported pleasantness and event-related potential data as indicators. After completing each trial, the participants received predetermined false feedback; they were then assessed on a nine-point pleasantness scale. There were 12 false feedback conditions categorized into three valence types. The positive type consisted of three consecutive positive feedbacks and a fourth medium feedback; the medium type contained four consecutive medium feedbacks; the negative type consisted of three consecutive negative feedbacks and a fourth medium feedback. We abbreviated medium false feedback after three positive, medium, and negative false feedbacks as 3pm, 3mm, and 3nm, respectively. The results showed that the score of self-reported pleasantness of 3mm was significantly lower than that of 3pm and higher than that of 3nm. The feedback-related negativity amplitude of 3pm was significantly greater than that of 3mm and 3nm, and the late-positive potential amplitude of 3nm was significantly greater than that of 3pm and 3mm. We found that individuals experienced medium feedback more positively and negatively after continuous positive and negative feedback, respectively. Our findings suggest that individuals should seek continuous positive feedback and avoid continuous negative feedback; this strategy may contribute to increased positive emotional experiences in the future.

Keywords: cumulative effect; emotional experience; success-failure manipulation paradigm; ERPs; FRN; LPP

1. Introduction

Emotional experience refers to subjective feelings (Ledoux, 2012; Perry, Baciadonna & Chittka, 2016) that represent a central and continuous feature of human consciousness that is only abolished during sleep, brain damage, or drug-induced altered states (Nummenmaa, Hari, Hietanen & Glerean, 2018). *Feedback* stimulus affects the personal emotional experience; further, the valence of feedback is an important determinant of the specific induced emotions (Ilies, De Pater & Judge, 2007). Specifically, negative feedback induces unpleasant emotional experiences (Sargeant, Mann, Sinclair, Van der Vleuten & Metsemakers, 2008), while positive feedback, including praise, usually induces positive emotional experiences (Webster, Duvall, Gaines & Smith, 2003). Experimental studies have primarily focused on the effect of a single feedback on emotional experience. For example, Williams and Desteno (2008) reported that after completing a dot estimation task, individuals who received false-positive feedback (acclaim) experienced significantly greater positive emotions than those in the control group (no acclaim). However, in everyday life, humans often receive sequential feedback from different events, which jointly affects emotional experiences. Despite its importance in everyday life, there is limited understanding of how continuous feedback with the same valence affects emotional experience remains. Clarifying this issue could help individuals to better understand and accept the change in emotional experience, irrespective of whether they or others receive consecutive positive or negative feedback.

The present study focuses on whether consecutive feedback of the same valence could form an emotional context and affect the subsequent emotional experience. Previous studies have investigated the effects of emotion on attention allocation (Rothermund, 2003; Rothermund et al., 2011; Schwager & Rothermund, 2014; Wentura et al., 2018) and found an incongruency effect in emotional processing after eliciting a vivid emotion that is sufficiently intense, whereas a congruency effect was found if a person had already adapted to an emotion-eliciting situation and did not experience an emotionally “hot” state (Schwager & Rothermund, 2014). The incongruency effect, also called counter-regulation theory, represents a preferential allocation of attention to stimuli of opposite valence to the current emotional state, whereas the congruency effect represents preferential attention to stimuli of the same valence to the current emotional state (Rothermund, 2011). In addition, in the context of investigations on the effect of emotion on cognitive appraisal, researchers presented different types of emotional pictures to participants for 10 s and found that participants subsequently judged neutral pictures more positively and negatively after exposure to positive and negative pictures, respectively (Palumbo, Dascenzo, Quercia & Tommasi, 2017). Of note, attention to stimuli, cognitive appraisal, and emotional experience are important components of emotional processing, a process ranging from attention to appraisal to emotional experience (Reisenzein, 2020). The above studies focused on the effect of emotion on attention allocation and cognitive appraisal. However, the effect of continuous identical valence feedback as an emotional context on subsequent emotional experience has not been previously investigated. Thus, the present study investigates this issue. We considered the evidence that frequently presenting either positive or negative pictures to individuals did not suffice to establish an intense emotional experience (Smith et al., 2006) and took into account the effect of emotion on cognitive appraisal (participants judged neutral pictures more positively and negatively after exposure to positive and negative pictures, respectively; Palumbo et al., 2017). We assumed that, like the effect of emotion on attention allocation and cognitive appraisal, continuous feedback with positive or negative valence as an emotional context would allow participants to experience subsequent medium feedback more positively or negatively, respectively.

This study also used the event-related potential technique (ERP) to examine the neural processes underlying the behavioral pattern. Considering that emotional experience is induced by feedback, we focused on two ERP components, namely, feedback-related negativity (FRN) and late-positive potential (LPP).

FRN (Gehring & Willoughby, 2002; Miltner, Braun & Coles, 1997*)* is closely associated with feedback and is often used to compare the effects of different valences of feedback on individual neural activity. FRN is a medial frontal negative deflection of the ERP with maximal amplitude approximately 250 ms after feedback onset (Gehring & Willoughby, 2002; Hajcak, Holroyd, Moser & Simons, 2005; Hajcak, Moser, Holroyd & Simons, 2006; Yeung, Holroyd & Cohen, 2005; Yeung & Sanfey, 2004). FRN originates from the dorsal anterior cingulate cortex (Hauser et al., 2014), an important area within the reward network (Rushworth, Noonan, Boorman, Walton & Behrens, 2011), and is thought to have a crucial role in tracing uncertainty (Behrens, Woolrich, Walton & Rushworth, 2007) and response evaluation (Williams, Bush, Rauch, Cosgrove & Eskandar, 2004)

A widely accepted account of FRN is the reinforcement learning error-related negativity theory (Holroyd & Coles, 2002). This theory postulates that FRN is an index of the reward prediction error (RPE; Gheza, Paul & Pourtois, 2018; Walsh & Anderson, 2012). An RPE occurs when an event is inconsistent with an individual's prediction based on previous events. Specifically, a larger FRN results from the event being worse (-RPE; Holroyd & Coles, 2002). An alternative explanation for FRN is the predicted response-outcome (PRO) model (Alexander & Brown, 2011). This model assumes that neurons in the anterior cingulate cortex (ACC) record a history of positive and negative reinforcement prior to specific actions and make predictions regarding the probabilities of future outcomes. In the event that the predicted outcomes do not occur, ACC activation reaches its maximum. According to the PRO model, FRN is valence-independent, and the outcome prediction error determines the FRN size; the prediction error is positively correlated with the FRN size (Talmi, Atkinson & El-Deredy, 2013). Based on the aforementioned findings, Mushtaq, Wilkie, Monwilliams, and Schaefer (2016) suggested that FRN is mainly affected by expectations when stable expectations (the frequency of one condition being stably different from other conditions) can be formed. Otherwise, it is affected by the emotional system. The present study focused on medium feedback following different continuous feedback with a comparable medium feedback frequency across the three conditions. Therefore, we assumed that the FRN mainly reflects the emotional system activity.

Previous studies have involved dynamic positive and negative feedback (Mushtaq, Wilkie, Mon-Williams & Schaefer, 2016; Osinsky, Mussel & Hewig, 2012; Pfabigan et al., 2015; Zhu, Wang, Gao & Jia, 2019). Osinsky et al. (2012) investigated the range of FRN amplitudes in three consecutive outcomes (including win-win-win and loss-loss-loss sequential conditions) and found that two wins followed by a loss or two losses followed by a win were rather unexpected outcomes and resulted in an increased FRN amplitude of the third feedback. However, the study did not focus on the FRN amplitude of medium feedback after consecutive positive or negative feedback. A further study gave explicit cues (gain, loss, zero value) to participants and investigated the FRN of zero value in different contexts, concluding that there were no differences in the FRN amplitudes of zero values between the gain and loss contexts (Pfabigan et al., 2015). In brief, the present study combines the two aforementioned studies and examines whether continuous feedback with the same valence could form an emotional context without explicit cues and affect the FRN amplitude of subsequent medium feedback.

We postulated that the FRN of 3pm would be larger than that of the preceding three consecutive conditions because the three consecutive positive feedbacks induced a positive expectation (i.e., optimistic prediction about future performance), but this expectation was eventually violated by the fourth medium feedback (i.e., worse than expected). It would follow that the FRN of 3nm would be smaller than that of the preceding consecutive negative conditions because 3nm was better than anticipated. We expected that there would be no significant difference between the FRN of 3mm and that of the preceding three medium conditions. According to previous studies, FRN is reliably greater for negative than positive feedback (Gheza, Paul & Pourtois, 2018;

Holroyd & Coles, 2002; Walsh & Anderson, 2012). Hence, we hypothesized that the FRN of 3pm would be greater than that of 3nm and 3mm because, compared to the preceding positive triplets, 3pm was a more negative feedback stimulus.

LPP (Cuthbert, Schupp, Bradley, Birbaumer & Lang, 2000; Hajcak, MacNamara & Olvet, 2010) is a widely distributed positive deflection in the midline of the brain that becomes apparent at approximately 300 ms after stimulation presentation. It is associated with emotion, which reflects the individual's motivational attention to emotional content. Stimuli involving greater emotional arousal induce a larger LPP, which represents the allocation of more neural resources to prominent emotional stimuli (Hajcak, Dunning & Foti, 2009; Keifer, Hauschild, Nelson, Hajcak & Lerner, 2019; Schupp, Junghöfer, Weike & Hamm, 2004). Positive and negative pictures and words, rather than neutral stimuli, have been reported to induce greater LPP (Cuthbert et al., 2000; Dillon, Cooper, Grent, Woldorff & LaBar, 2006; Foti & Hajcak, 2008; Foti, Hajcak & Dien, 2009; Hajcak & Nieuwenhuis, 2006; Hajcak & Olvet, 2008; Schupp et al., 2000). Compared with neutral stimuli, increased LPP of emotional stimuli does not generate habituation with repeated stimuli. Even with repeated stimuli, emotional stimuli induce a larger LPP than neutral stimuli (Hajcak et al., 2010). We hypothesized that after receiving continuous feedback with different valences, individuals would experience 3pm and 3nm as more emotional stimuli than 3mm. This would be reflected in the LPP signal as the LPPs of 3pm and 3nm would be larger than that of 3mm. Moreover, according to negative bias theory (Rozin & Royzman, 2001), 3nm may evoke a larger LPP than 3pm as it is a more negative stimulus.

In summary, the aim of the present study is to examine the cumulative effect of positive or negative feedback on subsequent emotional experience using self-reported pleasantness, FRN, and LPP as indicators.

2. Method

2.1 Participants

We conducted a power analysis using G*Power (Version 3.1; Faul, Erdfelder, Lang & Buchner, 2007) and found that 36 participants were required in our with-participants design to detect an estimated medium effect size at a power (β) of 0.95. Ultimately, time and resources constrained the sample size to N=37 (20 female participants). All participants were healthy college students without an educational background in psychology recruited through an online advertisement. The average age of the participants was 20 years (*SD* = 1.826, range: 17-24 years). Participants were right-handed, not color-blind, and had a normal or corrected-to-normal vision. They independently completed the tasks in a separate quiet cubicle and received financial compensation at the end of the experiment.

2.2 Paradigm

We used the success-failure manipulation paradigm (SFM; Nummenmaa & Niemi, 2004; Williams & DeSteno, 2008) where participants were presented with ambiguous stimuli that limit the precise evaluation of their own performance (accuracy and reaction time as performance indicators), followed by false feedback of positive or negative valence. The paradigm is designed to disguise the true intention of the study and is considered to have lower demand characteristics because the emotion-eliciting aspect of the stimulus material is less obvious (Schuch & Pütz, 2021). Additionally, the SFM has strong ecological validity and strongly induces numerous emotion types, including pleasantness, pride, anxiety, and shame (Nummenmaa & Niemi, 2004).

In addition, previous studies always used three tasks in a row to investigate the dynamics of feedback negativity or reward positivity (Mushtaq et al., 2016; Osinsky et al., 2012). Our study mainly focused on the cumulative effect of positive and negative feedback on the subsequent emotional experience. Furthermore, considering that there were vast numbers of trials in our study, one type of task might lead to the participants feeling fatigued. Hence, we adopted four different tasks used in previous studies. We also set different degrees of difficulty: simple, medium, and difficult. Medium difficulty was primarily used to avoid making the experiment so simple that the participants doubted the performance feedback, as well as to avoid making it so difficult that they were discouraged from completing the experiment and possibly interrupting the feedback effect on emotion. In summary, to make participants trust the false feedback, we used the SFM paradigm, with multiple types of tasks and different task difficulties.

2.3 Procedure

The participants were greeted by a male experimenter upon arrival and asked to comfortably sit in front of the lab computer. Before starting the experiment, the participants were allowed to familiarize themselves with the keyboard position (0 to 9) to reduce eye-blink and head movement during electroencephalogram (EEG) data acquisition. The following sentence, “Please follow the instructions to complete the keystroke task without checking the keyboard,” appeared at the screen center. Subsequently, 10 numbers, from 0 to 9, randomly appeared where participants were required to press the corresponding button on the number pad when a number was presented. The participants were only allowed to continue the experiment after an accuracy > 90% was achieved.

Next, the participants were informed that the experiment involved cognitive ability, and tasks were selected from several common tests, including the Wechsler Intelligence Test and Cultural Equity Test since these cognitive tasks could enhance motivation for active participation in the experiment (Williams & DeSteno, 2008). The participants were informed that their data would be recorded in a database, and therefore were expected to respond carefully. There were four different tasks (dot estimation, duration estimation, quantity estimation, and perceptual ability) with different rules that participants were required to understand. Once participants had a clear grasp of the processes and contents of the four tasks, they completed two exercise trials for each task for familiarization. In each trial (Figure 1 presents the flow chart of a single trial), first, a fixation point appeared in the center of the screen for a random duration of 800-1200 ms. Subsequently, one of the four tasks was presented. Four tasks were pseudo-randomly presented, and the same task was not sequentially repeated. After completing each task, a blank screen appeared for a random duration of 800-1200 ms. Next, participants received false feedback for 1,500 ms, and the EEG data were recorded when false feedback appeared. The positive, medium, and negative false feedbacks were represented by an upward, upward-downward, and downward arrow, respectively. Unbeknownst to the participants, the outcome of each trial was predetermined and pseudo-random. The order in which participants received feedback was divided into 12 conditions: positive-positive-positive-medium false feedback (p1-p2-p3-m); medium-medium-medium-medium false feedback (m1-m2-m3-m), and negative-negative-negative-medium false feedback (n1-n2-n3-m). For convenience, we used the abbreviation "m" after three positive, medium, and negative false feedbacks as 3pm, 3mm, and 3nm, respectively. Finally, participants rated pleasantness from 1 (unpleasant) to 9 (pleasant) after receiving each feedback (Thiruchselvam et al., 2012). Self-reported pleasantness was considered to be an indicator of emotional experience since pleasantness is a core effect of emotion (Barrett, Mesquita, Ochsner & Gross, 2007).

After completing the exercise session, participants either chose to repeat the practice or start the formal experiment. The trials in the exercise session were identical to those in the formal experiment. There were 480 trials in the formal experiment divided into 12 conditions (p1, p2, p3, 3pm, m1, m2, m3, 3mm, n1, n2, n3, 3nm), with 40 trials for each condition. Furthermore, four different tasks were used in the experiment, so each task contained 120 trials and 10 trials for each task for each condition. The formal experiment was divided into four blocks containing 120 trials, each with a between-block interval of at least 30 s.

After completing all the trials, participants immediately rated the degree of task difficulty of the four tasks from 1 (not at all) to 7 (extremely) and also attributed their performance to four aspects (ability, effort, fortune, and task) on a scale of 1 (not at all) to 7 (extremely). Knowledge of performance attribution served to indirectly check whether participants believed that the feedbacks they received were based on their own performance, as feedbacks were all false and predetermined. Although we tried to make feedback more authentic by mixing different tasks and different difficulties, the possibility remained that participants might suspect that feedback was predetermined rather than based on their present performance. Shepperd, Malone, and Sweeny (2008) thought that the internal-external distinction reflected a difference in controllability, which meant that loss of feedback controllability would lead participants to perceive the causes of their undesired outcomes as outside their personal control and attribute their performance to external factors, such as fortune and circumstances. Therefore, participants were informed that their performance had been attributed to internal factors and external factors at the end of the experiment to verify their trust in the false feedback they had received. Hence, we assumed that, in cases where external attribution scores (fortune and task) were significantly higher than internal attribution scores (ability and effort), participants might doubt the authenticity of the received feedback, and their self-reported pleasantness may be unreliable.

[Please insert Figure 1 here]

2.3.1 Dot estimation task. In the dot estimation task, a red and blue square dot matrix was displayed on the computer screen. Participants were instructed to report the number of red dots after browsing for 2,000 ms; further, their accuracy and response time were recorded as performance indicators (Williams & DeSteno, 2008; see Figure 1.a for a sample item). It was difficult for participants to judge their own accuracy in this task; furthermore, upon inclusion of the response time, participants became uncertain about their task performance.

There were 120 trials of the dot estimation task. This task mixed three difficulty types: simple, medium, and difficult. An increase in the number of red dots was associated with the increased difficulty of the task. Simple matrixes comprised 5 to 7 red dots, and there were 10 trials each for red dots “5,” “6,” and “7.” Consequently, there were 30 trials of simple matrixes. Medium matrixes comprised 8 to 10 red dots, and there were 20 trials each for red dots “8,” “9,” and “10,” resulting in 60 trials of medium matrixes. Difficult matrixes comprised 11-14 red dots, and there were 10 trials each for red dots “11” and “12” and five trials each for red dots “13” and “14.” Therefore, there were 30 trials of difficult matrixes.

2.3.2 Duration estimation task. In the duration estimation task (Hetherington, Dennis & Spiegler, 2000; see Figure 1.b for a sample item), when the clue stated “please estimate 1 s,” participants readied to press button 1 on the number pad. Once they did, three dots (“...”) appeared on the screen, indicating that they were estimating. Thereafter, participants pressed button 1 again to complete the trial. The only action required for duration estimation was pressing button 1. Participant estimation of “1 s” was taken as the appearance duration of the three dots. There were 120 trials of duration estimation in which participants were asked to estimate the duration of “1 s” (simple trial), “2 s” (medium trial), and “3 s” (difficult trial) 40 times each. The smaller the error, the better the performance.

2.3.3 Quantity estimation task. In the quantity estimation task (Gino, Norton & Ariely, 2010; see Fig 1.c for a sample item), a rectangular image divided by a diagonal was presented, and participants were asked to report the diagonal side with more red dots after browsing for 1,000 ms. There were two types of diagonals: bottom left-top right and top left-bottom right. There were 120 trials, and each diagonal type was half occupied. The quantity estimation task was divided into three difficulty types. In the simple, medium, and difficult trials (40 trials each), the difference between the number of red dots on the left and right was 3, 2, and 1, respectively. The number of unilateral red dots was 6-15. For example, the presence of 7 and 6 dots on the left and right, respectively, was considered a difficult trial. In contrast, the presence of 14 and 11 dots on the left and right, respectively, was considered a simple trial.

2.3.4 Perceptual ability task. In the perceptual ability task (Raftery & Bizer, 2009; see Figure 1.d for a sample item), a square representing a piece of paper was displayed. Participants were asked to envision the paper being “folded in half” several times. The last image showed a circle/semicircle hole being punched through all the layers of the now-folded piece of paper. Thereafter, participants were asked to identify which of the five presented images below best represented the paper if it were to be unfolded. Participants pressed buttons 1 to 5 on the number pad to react. The task picture was displayed for a maximum of 8,500 ms, and participants were allowed to make a choice at any time. If participants did not react within 8,500 ms, the picture disappeared, and the screen went blank. The experiment did not resume until a response was given. This was common across all 120 trials of the perceptual ability task. Moreover, this task consisted of three difficulty types with the simple, medium, and difficult types (40 trials each), indicating that the squares were folded once, twice, and thrice, respectively. The circle and semicircle hole positions were balanced.

2.4 False feedback

Brain activity was recorded when participants viewed false feedback. Participants were informed of three types of false feedback (positive, medium, and negative) before starting the exercise trials. In the dot estimation, quantity estimation, and perceptual ability tasks, the positive false feedback was represented by an upward arrow, indicating that participants completed the trial correctly and had a reaction time that was faster than that of > 88% of participants. The medium false feedback was represented by an upward-downward arrow, indicating that the participants correctly completed the trial but had an ordinary reaction time. The negative false feedback was represented by a downward arrow, indicating that the participants performed the task incorrectly.

In the duration estimation task, three arrow types represented three types of false feedback; however, their meanings differed. Positive/medium/negative false feedback indicated that the error was small/medium/big, respectively. To ensure that participants trusted that the received feedback was due to their own responses rather than being predetermined when introducing the tasks, participants were informed as follows: "according to a previous database, the trial of each task in our study had corresponding criterion of bad or good. For example, in the duration estimation task, 210 ms of error was considered small at the 8th trial while 100 ms of error might be considered small at the 20th trial." Given that tasks contained different difficulty types, it was difficult for the participants to doubt the false feedback and guess the true study objective.

2.5 Behavior data analysis

SPSS Statistics 20.0 (IBM Corp., Armonk, NY) was used for statistical analysis. A one-way repeated measures analysis of variance (ANOVA) was used to test differences in the scores of performance attribution and degree of task difficulty. A repeated measures ANOVA used valence (positive, medium, and negative) and sequence (first, second, third, and fourth) as with-subject factors to test the difference in pleasantness among 12 conditions. Post-hoc tests were used to determine the direction of the significant main effects ($p < 0.05$). The p-values were corrected using Greenhouse-Geisser correction for non-sphericity; further, p-values for all post-hoc tests were adjusted using the Bonferroni correction.

2.6 EEG recording and analysis

The EEG was recorded using a 64-channel fabric cap using Brain Product (Brain Products GmbH, Munich, Germany). Electrodes were arranged according to the 10-20 system, with the grounding electrode being placed at AFz. Data were recorded using an

FCz reference online. The electrooculograms (EOGs) generated from vertical eye movements and blinks were recorded using an electrode placed approximately 1 cm below the right eye. The difference between the right and left orbital margin activity was considered as horizontal EOG. Both EEG and EOG signals were amplified using a band-pass of 0.05-100 Hz and continuously sampled at 500 Hz. All electrode impedances were maintained below 10 kΩ for online recording.

Brain Vision Analyzer 2.1 (Brain Products GmbH, Munich, Germany) was used to perform the EEG offline processing. The EEG signals were re-referenced to the averaged mastoid electrodes, and electrode FCz was reinstated. Then, data below 0.1 Hz and above 30 Hz were filtered with IIR Filters, and the Notch was filtered at 50 Hz. Eye movement-related artifacts were removed using a semi-automatic ocular correction based on independent component analysis. Subsequently, the ERP waveforms were time-locked to the onset of the feedback stimuli and segmented into epochs of 200–1,000 ms (-200–0 ms signified 200 ms before the feedback presentation; 0–1,000 ms signified 1,000 ms after the onset of feedback presentation). Trials with EEG voltage values exceeding ± 80 μV were considered artifacts and were excluded from the analysis. Finally, mean trial numbers (±SD, max trials, min trials) for the 12 conditions after artifact rejection were as follows: p1, 37.68 (2.935, 40, 30); p2, 38.05 (2.828, 40, 31); p3, 38.19 (2.295, 40, 32); 3pm, 38.35 (2.452, 40, 29); m1, 38.11 (2.481, 40, 32); m2, 37.95 (2.516, 40, 31); m3, 37.62 (3.04, 40, 27); 3mm, 37.81 (3.044, 40, 27); n1, 37.59 (3.175, 40, 24); n2, 37.95 (2.953, 40, 29); n3, 37.41 (3.905, 40, 22); 3nm, 37.38 (2.802, 40, 31).

FRN amplitude was defined as the difference between the most negative peak in the 250-350 ms time window after feedback stimulus onset and its preceding positive peak (Moser & Simons, 2009; Mushtaq et al., 2016; Yeung & Sanfey, 2004) at electrode FCz, where FRN amplitudes reached maximum values (Holroyd, Larsen & Cohen, 2004; Von Borries, Verkes, Bulten, Cools & De Bruijn, 2013; Walsh & Anderson, 2011). According to the grand-average ERP waveforms of conditions and their topographical maps (Fig.5), we calculated mean amplitudes for 20-ms time windows around these positive and negative peaks. The FRN was quantified as the difference between the mean amplitudes around the negative and preceding positive peaks (Osinsky et al., 2012). Additionally, we computed the average value of nine electrodes (C3, Cz, C4, CP3, CPz, CP4, P3, Pz, P4) within the 350–600-ms window to define LPP (Moser, Hajcak, Bukay & Simons, 2006).

Statistical analyses were performed using SPSS Statistics 20.0 (IBM Corp., Armonk, NY). To assess amplitude differences among 12 conditions, we performed a repeated measures ANOVA with valence (positive, medium, and negative) and sequence (first, second, third, and fourth) as the within-subject factors for FRN and LPP. The direction of significant main effects ($p < 0.05$) was determined using post-hoc tests. Greenhouse-Geisser corrections and Bonferroni corrections were applied, as appropriate.

3. Results

3.1 Performance attribution

One-way repeated measures ANOVA revealed a significant main effect of performance attribution, $F(2.324, 83.651) = 5.731$, $p = 0.003$, $\eta^2 = 0.137$. Post-hoc tests revealed that the scores for ability ($t(36) = 2.836$, $p = 0.007$, Cohen's d = 0.468) and effort ($t(36) = 3.389$, $p = 0.002$, Cohen's d = 0.557) were significantly higher than those for fortune (Figure 2.a).

[Please insert Figure 2 here]

3.2 Degree of task difficulty

One-way repeated measures ANOVA revealed a significant main effect of degree of task difficulty, $F(3, 108) = 5.084$, $p = 0. 002$, $\eta^2= 0. 124$. Post-hoc tests revealed that the score for perceptual ability was significantly higher than that for dot ($t(36) = 3.375$, $p = 0.002$, Cohen's d = 0.555) and duration estimation ($t(36) = 3.399$, $p = 0.002$, Cohen's d = 0.560; Figure 2b).

3.3 Pleasantness

[Please insert Table 1 here]

A repeated measures ANOVA revealed that the main effect of valence was significant ($F(1.146, 41.271) = 97.193$, $p < 0.001$, $\eta^2 = 0.730$), the main effect of sequence was not significant ($F(1.721, 61.963) = 0.459$, $p = 0.605$), and the interaction between valence and sequence was significant ($F(1.528, 54.996) = 62.430$, $p < 0.001$, $\eta^2 = 0.634$). Post-hoc tests revealed that there were significant differences in the scores for pleasantness among valence in the first, second, third, and fourth self-reports (all ps < 0.001, η^2s > 0.542). Specifically, as shown in Figure 3, the score of 3pm was significantly higher than that of 3mm ($t(36) = 5.391$, $p < 0.001$, Cohen's d = 0.888) and 3nm ($t(36) = -6.523$, $p < 0.001$, Cohen's d = 1.07). Furthermore, the score of 3mm was significantly higher than that of 3nm ($t(36) = 4.346$, $p < 0.001$, Cohen's d = 0.710).

[Please insert Figure 3 here]

The score of 3pm was significantly lower than those of p1 ($t(36) = 6.004$, $p < 0.001$, Cohen's d = 0.988), p2 ($t(36) = 7.238$, $p < 0.001$, Cohen's d = 1.189), and p3 ($t(36) = 7.964$, $p < 0.001$, Cohen's d = 1.310), and the score of 3nm was significantly higher than those of n1 ($t(36) = -7.152$, $p < 0.001$, Cohen's d = 1.176), n2 ($t(36) = -8.278$, $p < 0.001$, Cohen's d = 1.361), and n3 ($t(36) = -8.841$, $p < 0.001$, Cohen's d = 1.452). Also, the score of 3mm was significantly higher than that of m1 ($t(36) = 4.310$, $p < 0.001$, Cohen's d = 0.698), but not significantly higher than those of m2 and m3 (ps > 0.14).

In addition, the score of p3 was significantly higher than those of p2 ($t(36) = 4.332$, $p < 0.001$, Cohen's d = 0.709) and p1 ($t(36) = 5.296$, $p < 0.001$, Cohen's d = 0.874), and the score of p2 was significantly higher than that of p1 ($t(36) = 4.819$, $p < 0.001$, Cohen's d = 0.788). The score of m1 was significantly higher than those of m2 ($t(36) = 2.783$, $p = 0.009$, Cohen's d = 0.458) and m3 ($t(36) = 2.94$, $p = 0.006$, Cohen's d = 0.483), but the scores of m2 and m3 were not significantly different ($t(36) = 0.54$, $p = 0.593$). Meanwhile, the score of n1 was significantly higher than those of n2 ($t(36) = 4.073$, $p < 0.001$, Cohen's d = 0.676) and n3 ($t(36) = 3.986$, $p < 0.001$, Cohen's d = 0.660), but there were no significant differences in the scores of n2 and n3 ($t(36) = 0.748$, $p = 0.459$).

3.4 FRN

A repeated measures ANOVA revealed that there was a significant main effect of valence ($F(1.362, 49.024) = 4.368$, $p = 0.031$, $\eta^2 = 0.108$) and a significant main effect of sequence ($F(1.706, 61.407) = 9.260$, $p = 0.001$, $\eta^2 = 0.205$), as well as a significant two-way interaction effect ($F(6, 216) = 5.318$, $p < 0.001$, $\eta^2 = 0.129$). Post-hoc tests revealed a significant difference in first ($F(2, 35) = 8.217$, $p = 0.001$, $\eta^2 = 0.320$), second ($F(2, 35) = 4.017$, $p = 0.027$, $\eta^2 = 0.187$), and fourth ($F(2, 35) = 4.086$, $p = 0.025$, $\eta^2 = 0.189$) among three valences, but not in third ($F(2, 35) = 0.095$, $p = 0.174$). The significant differences meant that there were different FRN amplitudes among three valences in those sequences.

Figure 4 shows that, particularly in the fourth sequence, the FRN amplitude of 3pm was significantly larger than that of 3mm ($t(36) = -2.422$, $p = 0.021$, Cohen’s d = 0.398) and 3nm ($t(36) = -2.688$, $p = 0.011$, Cohen’s d = 0.441), but the difference in FRN amplitudes between 3mm and 3nm was not significant ($t(36) = -0.095$, $p = 0.925$).

[Please insert Figure 4 here]

Post-hoc tests revealed a significant difference among sequences in positive ($F(3, 34) = 6.592$, $p = 0.001$, $\eta^2 = 0.368$) and medium sequences ($F(3, 34) = 3.663$, $p = 0.022$, $\eta^2 = 0.244$), but not in negative sequence (($F(3, 34) = 1.762$, $p = 0.173$). Specifically, as shown in Figure 5, in positive sequence, the FRN amplitude of 3pm (i.e. the fourth) was significantly larger than that of p1 ($t(36) = -3.960$, $p < 0.001$, Cohen’s d = 0.651), p2 ($t(36) = -4.558$, $p < 0.001$, Cohen's d = 0.749), and p3 ($t(36) = -4.075$, $p < 0.001$, Cohen's d = 0.670), but other differences were not significant (*p*s = 1). In medium sequence, only the FRN amplitude of m1 was significantly larger than that of m3 ($t(36) = -2.880$, $p = 0.007$, Cohen's d = 0.474), but other differences were not significant (*p*s > 0.321). Hence, only the FRN amplitude of 3pm was significantly larger than that of prior consecutive three positive feedbacks. There were no significant differences between FRN amplitudes of 3mm and 3nm and previous medium and negative sequences, respectively.

[Please insert Figure 5 here]

3.5 LPP

A repeated measures ANOVA revealed that there was a significant main effect of valence ($F(2, 72) = 14.552$, $p < 0.001$, $\eta^2 = 0.288$) and a significant main effect of sequence ($F(2.453, 88.325) = 4.157$, $p = 0.013$, $\eta^2 = 0.104$), as well as a significant two-way interaction effect ($F(6, 216) = 7.396$, $p < 0.001$, $\eta^2 = 0.170$). Post-hoc tests revealed a significant difference in first ($F(2, 35) = 12.476$, $p < 0.001$, $\eta^2 = 0.416$), third ($F(2, 35) = 9.982$, $p < 0.001$, $\eta^2 = 0.363$) and fourth ($F(2, 35) = 28.121$, $p < 0.001$, $\eta^2 = 0.616$) among three valences, but not in second ($F(2, 35) = 1.755$, $p = 0.188$). The significant differences meant that there were different LPP amplitudes among three valences in those sequences.

Figure 6 shows that, particularly in the fourth sequence, the LPP amplitude of 3nm was significantly larger than that of 3pm ($t(36) =5.668$, $p < 0.001$, Cohen's d = 0.930) and 3mm ($t(36) = 7.363$, $p < 0.001$, Cohen's d = 1.213), and the amplitude of 3pm was significantly higher than that of 3mm ($t(36) = 2.857$, $p = 0.007$, Cohen's d = 0.471).

[Please insert Figure 6 here]

4. Discussion

At the behavioral level of the task-performance attribution, we found that scores for effort and ability were significantly higher than those for fortune. This indicated that participants attributed their performance more to internal factors (i.e., effort and ability) and did not doubt the received feedback. Regarding self-reported pleasantness, as we predicted, compared to continuous medium feedback, the emotional experience of medium feedback was significantly higher and lower after receiving continuous positive and negative feedback, respectively. The results in our study were inconsistent with the counter-regulation theory (Rothermund, 2003; Rothermund et al., 2011; Schwager & Rothermund, 2014). First, this may be due to the fact that in counter-regulation theory, there is a preferential allocation of attention to stimuli of opposite valence to the current emotional state. However, our study focused on subsequent medium feedback after continuous positive or negative feedback. The difference in stimulus valence may explain this discrepancy. Second, as shown in previous studies (Palumbo et al., 2017; Smith et al., 2006), repeated feedback may not induce an intense emotional experience and result in participant bias toward the same valence of previous feedback in subsequent medium feedback. This suggests that upon reception of multiple multi-valence feedbacks, only continuous positive feedbacks can improve the positive emotional experience of subsequent medium feedbacks.

Due to the use of false feedback, medium feedback is more unpredictable than are positive and negative feedback and induces the maximal FRN (see more details in Supplementary material II). More importantly, the 3pm condition induced the most negative FRN. According to the PRO model (Alexander & Brown, 2011), the FRN is valence-independent and is dependent on the prediction error. Hence, in our study, 3pm and 3nm had the same occurrence frequency, which was supposed to reflect similar FRN between 3pm and 3nm. However, the FRN amplitude of 3pm was significantly larger than that of 3nm. This demonstrates that the present findings are inconsistent with the PRO model. Based on the reinforcement learning theory (Holroyd & Coles, 2002), a more negative FRN is induced when the results are worse than expected. In our study, the FRN amplitude of 3pm was significantly larger than that of the other two conditions (3mm and 3nm). Consistent with this, 3pm was significantly lower than p1, p2, and p3 in pleasantness scores with respect to behavioral data, indicating that three consecutive positive feedbacks induced a positive expectation. However, this expectation was eventually violated by the fourth medium feedback, leading to the largest FRN when 3pm was worse than expected. This finding is consistent with those of previous studies indicating that a larger FRN was induced by more negative feedback (Gheza, Paul & Pourtois, 2018; Holroyd & Coles, 2002; Walsh & Anderson, 2012). The pleasantness score of 3pm was higher than that of 3mm and 3nm. This may suggest that after consecutive positive feedback, participants may become more positive to subsequent medium feedback, even though medium feedback was worse than expected.

These results were different from the findings of Eldar et al. (2016) attributing self-reported pleasantness to ‘reward prediction errors.’ In particular, positive surprises (+RPEs) would result in a higher mood, whereas negative surprises (-RPEs) would result in a lower mood. However, some outcomes in our study were not consistent with their opinion. For example, even though the 3pm was worse than expected (the FRN of 3pm was larger than those of 3mm and 3nm), the pleasantness score of 3pm was the highest. In addition, the pleasantness scores from p1 to p3 were significantly increased, but the FRN amplitudes of the three conditions (p1, p2, p3) were not different. Similarly, there were no differences in FRN amplitudes between n1 and n2, and n1 and n3, but the pleasantness scores significantly decreased. This indicated that, in our study, RPEs were not the only determinants of emotional experience. The differences between our findings and those reported by Eldar et al. may be explained as follows. First, this may be due to different tasks. Eldar et al. focused on reward outcomes in the form of monetary gains and losses, while in the present study, we used cognitive tasks, and participants received performance feedback. Cognitive abilities are regarded as a relevant domain for self-conceptions (Williams & DeSteno, 2008), which may have a deeper impact on participant emotional experiences than monetary gains and losses. Hence, while the 3pm pleasantness score was worse than expected, considering that the prior three feedbacks were positive, the positive impact may continue to 3pm resulting in higher participant pleasantness. Differences in timescales of emotion and mood may also affect results. In our study, the cumulative effect was restricted to three feedbacks. However, according to Eldar et al., ‘moods’ differed from ‘emotions’ as they typically last longer and emotions were typically related to a single stimulus, while moods were less closely linked to particular events and can reflect the cumulative impact of multiple stimuli. Hence, the outcome of our study is different from the findings reported by Eldar et al. but also complements their views, revealing that the cumulative effect of emotions with different durations had different impacts on subsequent emotional experience.

This study found that the LPP amplitudes at 3pm and 3nm were significantly higher than those at 3mm. Previous studies have reported that both positive and negative stimuli induced larger LPP than those induced by neutral stimuli (Ito, Larsen, Smith & Cacioppo, 1998; Schupp et al., 2000). Therefore, our study participants could have regarded 3pm and 3nm as stronger emotional feedback stimuli compared to 3mm, although they were signaled via the same visual feedback indicated by an upward-downward arrow. Additionally, the average LPP amplitude at 3nm was significantly larger than those at 3pm and 3mm. Ito et al. (1998) reported that negative images induced larger LPP than those induced by positive ones. Consistent with the behavioral data of 3nm, the self-reported pleasantness score was also the most negative. Therefore, we inferred that participants regarded 3nm as a negative feedback stimulus and were negatively biased toward it. Norris (2021) interpreted negative bias as negative information has a stronger effect on attention, perception, memory, physiology, emotion, behavior, motivation, and decision-making than positive information of the same degree and arousal. Negative bias has a theoretical evolutionary advantage (Rozin & Royzman, 2001) since for individual survival, it is more important to avoid harmful stimuli than to pursue potentially beneficial stimuli; therefore, negative information can obtain more neural resources on LPP.

5. General discussion

Our behavioral and ERP findings indicate that when receiving multiple multi-valence feedback, individuals experience medium feedback more positively after continuous positive feedback, although medium feedback was worse than expected. Individuals experienced medium feedback more negatively after continuous negative feedback. These findings are consistent with animal studies. From a biological naturalism perspective, emotion is a consciousness state, and consciousness is an inherently subjective biological phenomenon that is only experienced by humans and other animals (Barrett et al., 2007). The most basic requirement for consciousness generation is possessing subjective experience. The brain structure of insects exhibits similar functions as the midbrain structure of vertebrates and can support subjective experience (Barron & Klein, 2016). Since emotion–cognition interactions have an adaptive value, invertebrates may possess emotion-like systems (Mendl & Paul, 2016). Perry, Baciadonna, and Chittka (2016) repeatedly administered sucrose solution (water as the control) to invertebrates (bees) as a reward to induce positive emotions. The bees presented subsequent ambiguous stimuli that were more positive and reinitiated foraging more quickly after being attacked by explicitly simulated predators. Thus, receiving repetitive positive stimuli appeared to have a positive bias in cognitive appraisals with reduced influence of negative stimuli, which increased the positive emotional experience. Although humans probably have far more rich emotional lives than insects (Perry, Barron & Chittka, 2017), the consistency between previous animal reports and our findings suggests that repeatedly receiving positive stimuli could induce a more positive experience of ambiguous or medium stimuli, which may reflect a basic and general phenomenon across species.

Moreover, the findings of cognitive studies in humans are consistent with our results. In the field of perception, the aftereffects of prolonged exposure to a stimulus are well-known. There have been studies on the aftereffects of simple stimuli properties, including shape (Suzuki & Cavanagh, 1998), size (Blakemore & Sutton, 1969), color (Mccollough, 1965), and orientation (Dekel & Sagi, 2015). To determine whether the aftereffects occur for more complex properties, Palumbo, Dascenzo, Quercia, and Tommasi (2017) investigated whether previously shown positive or negative images may cause an adaptation and affect the perceived valence of complex images. They found that participants judged neutral tests more positively and negatively following positive and negative adapters, respectively, supporting our hypothesis. Previous studies focused on the aftereffects on physical features and perceived valence of stimuli, while our study further proved assimilative aftereffects on emotional experience. This suggests that this phenomenon may exist across both cognitive and emotional processes.

One implication of our study is that individuals should extensively pursue and avoid continuous positive and negative stimuli, respectively, in real life. A positive stimulus can yield positive emotions, which reduces social anxiety (Cohen & Huppert, 2018), prevents/treats depression (Santos et al., 2013), and promotes longevity (Carstensen et al., 2011). Our findings further suggest that continuous positive feedback could help individuals experience subsequent feedback better and improve future pleasantness, which suggests that pursuing present continuous positive stimuli could provide an umbrella for positive emotions even though one may live an ordinary life in the future. In contrast, negative feedback threatens an individual’s self-esteem and induces negative emotions (Ilies et al., 2007); moreover, continuous negative feedback reduces the perception of the positive attributes of subsequent medium feedback, which renders future emotional experience worse.

6. Limitations and prospects

This study has several limitations. First, although we balanced the valence of bogus feedback and the types of tasks, one task was significantly more difficult than the other three tasks. Future studies should use different tasks with comparable difficulty to eliminate the influence of other factors, including task difficulty. Second, there may be differences between different kinds of ratings which can be difficult to interpret in some cases. For instance, we cannot guarantee that a score of seven on fortune has the same subjective meaning as a score of seven on effort. To improve this, we may adopt the forced choice method in which, for example, participants allot 12 points of performance attribution to four factors. Accordingly, factor scores are comparable, and participants largely attribute their performance to the factor with the highest score. Third, our participants were normal persons with healthy emotional experiences. There are numerous individuals with bipolar disorder, generalized anxiety disorder, etc. (Grande, Berk, Birmaher & Vieta, 2016; Wittchen, 2002) who do not experience emotions normally. Therefore, it is important to assess individuals with emotional disorders and to determine the underlying reason for their different emotional experiences.

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Conflict of Interest:

The authors have no conflicts of interest to declare.

Table 1. Self-reports of pleasantness under 12 conditions (*M*±*SD*)

	First	**Second**	**Third**	**Fourth (m)**
p	6.136 (1.495)	6.374 (1.515)	6.553 (1.493)	5.209 (1.220)
m	4.961 (1.220)	4.886 (1.219)	4.869 (1.233)	4.808 (1.227)
n	3.475 (1.462)	3.269 (1.425)	3.241 (1.417)	4.564 (1.256)

Figure Captions

Figure 1. Flow chart of a single trial. First, a fixation point appeared at the center of the screen for a random duration of 800-1200 ms. Second, one of the four tasks was presented (no repetition of the same task for four consecutive tasks). After the completion of each task, a blank screen appeared for a random duration of 800-1200 ms. Next, the participants received false feedback that lasted 1,500 ms, and EEG data were recorded when false feedback appeared. There were three types of false feedback: positive, medium, and negative, with a predetermined presentation sequence. Finally, participants reported their “pleasantness” using a 9-point Likert scale without a time limit from 1 (*unpleasant*) to 9 (*pleasant*). The hand coin represented the button action.

Figure 2. (a) Participant appraisal scores for performance attribution. (b) Participant appraisal scores by task difficulty. (Error bars represent the standard error of the mean).

**p* <.05; ***p* <.01; ****p* <.001.

Figure 3. Differences in participant pleasantness scores among the three conditions: 3pm, 3mm, and 3nm. (Error bars represent the standard error of the mean).

**p* <.05; ***p* <.01; ****p* <.001.

Figure 4. FRN induced by 3pm, 3mm, and 3nm. (a) Average FRN amplitude at FCz in three conditions. (b) Scalp maps display FRN topography according to conditions (darker blue indicating more negative amplitude). (c) Grand-average ERP waveforms of the three conditions at FCz. The abscissa represents the time window between -200 ms and 1,000 ms with 0 ms as the onset of feedback presentation. The ordinate represents the ERP amplitude with negative numbers inverted traditionally. (Error bars represent the standard error of the mean).

*p <.05; **p <.01; ***p <.001.

Figure 5. The amplitude of FRN of each condition at FCz. (a) The FRN amplitude in four conditions: p1, p2, p3, 3pm. (b) The FRN amplitude in four conditions: m1, m2, m3, 3mm. (c) The FRN amplitude in four conditions: n1, n2, n3, 3nm.

Figure 6. LPP induced by 3pm, 3mm, and 3nm. (A) Average LPP amplitude at nine electrodes (C3, Cz, C4, CP3, CPz, CP4, P3, Pz, P4) in three conditions. (B) Scalp maps display LPP topography according to the conditions, with the darker red indicating the more positive amplitude. (C) Grand-average ERP waveforms of three conditions at Cz. The time window ranged from 350 ms to 600 ms. The abscissa represents a time window from -200 ms to 1,000 ms with 0 ms as the onset of feedback presentation. The ordinate represents the ERP amplitude with negative numbers inverted traditionally. (Error bars represent the standard error of the mean).

*p <.05; **p <.01; ***p <.001.