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Temporal dynamics and potential neural sources of goal conduciveness, control, and power appraisal[☆]

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ABSTRACT

A major emotion theory, the Component Process Model, predicts that emotion-antecedent appraisal proceeds sequentially (e.g., goal conduciveness > control > power appraisal). In a gambling task, feedback manipulated information about goal conduciveness (outcome: win, loss), control (perceived high and low control), and power appraisals (choice options to change the outcome). Using mean amplitudes of event-related potentials, we examine the sequential prediction of these appraisal criteria. Additionally, we apply source localization analysis to estimate the neural sources of the evoked components of interest. Early ERPs (230–300 ms) show main effects of goal conduciveness and power but no interaction effects suggesting *goal obstructiveness assessment* of task-relevant feedback information. Late ERPs (350–600 ms) reveal main effects of all appraisals and interaction effects representing the *integration of all appraisal information*. Source localization analysis suggests distinct neural sources for these appraisal criteria.

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1. Introduction

An important area of emotion research concerns the neural mechanisms of emotion elicitation and differentiation. The fact that similar events elicit different emotions in different people or in the same person at different times and in varying intensities renders the study of the underlying mechanism of emotion elicitation and differentiation highly challenging. Appraisal theories (for an overview, see Moors, Ellsworth, Scherer, & Frijda, 2013; Scherer, Schorr, & Johnstone, 2001) defend their view that the way people evaluate an event determines the type of elicited emotion. They conceptualize a specific cognitive process – *appraisal* – through which events are evaluated on a number of different criteria (e.g., novelty, relevance, pleasantness, goal congruence, agency, and cop-

ing potential). The combination of appraisal results for different criteria determines the type of emotion and its intensity.

The organization and neural correlates of appraisal processes remain largely unexplored. Urgent need for empirical clarification concerns (a) whether appraisal criteria are processed sequentially or in parallel, and (b) to what extent the processing of different criteria is tied to specific neural substrates (e.g., goal obstructiveness appraisal might be related to cognitive processes reflected by an event-related potential [ERP] component ~230–300 ms after stimulus onset) (cf. Moors et al., 2013). To date, only a few electroencephalography (EEG)-ERP studies have investigated the temporal organization of appraisal processes (Gentsch, Grandjean, & Scherer, 2013; Grandjean & Scherer, 2008; van Peer, Grandjean, & Scherer, 2014). These studies examined the temporal structure of appraisal processes as specified by the Component Process Model (CPM, Scherer, 1984, 2001, 2009). The results indicate that EEG-ERP measures of event processing can indeed be related to the operation of particular appraisal criteria such as novelty, goal/task relevance, intrinsic pleasantness, goal conduciveness, and power. Consistent with the prediction of the CPM, the results also indicate that appraisal criteria were processed sequentially (indicated by sequential effects on subsequent ERP components and sequentially organized distinct spatiotemporal scalp maps) and presumably also in parallel (suggested by separate main effects on the same ERP component in the absence of interaction effects) immediately

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after stimuli onset. Nonetheless, it remains inconclusive whether sequential appraisal effects on ERP components also occur for other appraisal criteria such as control appraisal and whether these appraisal processes have distinct markers, and to what extent they are tied to specific neural sources or networks.

In the present study, control appraisal (i.e., assessment of perceived situational control) is added to the manipulation of goal conduciveness (motivational valence or goal congruency evaluation of an event, e.g., a win is goal conducive/congruent and a loss is goal obstructive/incongruent) and power appraisals (i.e., assessment of choice options) in an experimental gambling task for the first time. To date, these appraisal criteria have not been jointly investigated in ERPs and their potential neural sources have not been explored. We applied the traditional ERP approach to investigate their temporal dynamics and we added source localization analysis to estimate the neural sources of the ERPs. The central research issues are reviewed in the subsequent paragraphs.

2. Appraisal processes

The CPM (Scherer, 1984, 2009) hypothesizes a fixed sequential and cumulative operation of appraisal checks (*sequence hypothesis*). These predictions are established on the notion of limited information processing resources and on phylogenetic, ontogenetic, and micro-genetic (logical) considerations (see Scherer, 1984, 2001, 2009; Scherer, Zentner, & Stern, 2004 for more details). While appraisal theories largely agree on the types of appraisal criteria, there is disagreement on whether all criteria are always implicated in appraising events and to what extent they are processed sequentially (e.g., Roseman, 2001; Smith & Ellsworth, 1985; Smith & Kirby, 2009a; Smith & Lazarus, 1993). Experimental data are needed to solve these issues. In the present study, we will focus on the sequential organization of processed appraisal information related to the appraisals of goal conduciveness, control, and power.

Despite the long tradition of appraisal theories, only a few studies have been designed to examine the temporal organization of appraisal criteria and the related cognitive processes using EEG–ERP recordings (Gentsch et al., 2013; Grandjean & Scherer, 2008; van Peer et al., 2014). Results of these studies support the view of a sequential organization of appraisal processes immediately following event onset. Grandjean and Scherer (2008) manipulated novelty, goal/task relevance, intrinsic pleasantness, and goal conduciveness appraisal in a modified visual Oddball task using affective pictures. They found a sequential order of these appraisal criteria and identified specific time intervals for each criterion: (a) novelty (~0–130 ms), (b) intrinsic pleasantness (~100–130 ms), (c) goal/task relevance (~130–380 ms), and (d) goal conduciveness appraisal (~250–380 ms). Furthermore, single and cumulative effects of sequential appraisal processing of novelty (~200–300 ms) and intrinsic pleasantness (~300–400 ms) were investigated in more detail in a visual Oddball task (van Peer et al., 2014), indicating that the processing of intrinsic pleasantness depends on the preceding processing of novelty. Gentsch et al. (2013) used feedback to manipulate goal conduciveness and power appraisal in a gambling task. The results suggest that goal conduciveness (~230–300 ms) is initially appraised and is followed by power appraisal (~350–600 ms). To sum up, these studies consistently found converging evidence for sequential processing of appraisal criteria in EEG–ERP recordings. However, potential neural sources of these effects have not yet been addressed, for example, by applying a source localization analysis.

3. Control and power appraisal

In appraisal theories, determining the degree of situational control (control appraisal) and personal resources (power appraisal,

e.g. available options to change an event or its consequences) are important for discriminating among unpleasant affective states such as anger, sadness, disgust, frustration, and fear (e.g. Lazarus, 1991; Roseman, Antoniou, & Jose, 1996; Scherer, 2001; Smith & Ellsworth, 1985). The CPM conceptualizes three separate appraisal criteria for the assessment of coping potential (Scherer, 2001, 2009): (1) Control appraisal evaluates the extent to which an event or its outcome can be controlled by agents (people or animals). For example, the weather and the lottery are usually uncontrollable, whereas the behavior of a friend or the duration of a meeting is relatively controllable. If control is possible, (2) power appraisal subsequently assesses the options to act on the event and the available resources to attain or maintain current goals or needs. Resources can be knowledge, physical strength, money, other people, or rational analysis (French & Raven, 1968; Klein, 1998). If control is impossible, (3) adjustment appraisal evaluates how well one can adjust to the consequences. In the present study, we investigate the processing of control and power appraisals in ERPs.

4. Processes underlying goal conduciveness, control, and power appraisals

The neural mechanisms that underlie the processing of control and power appraisals are not well understood. The results of our previous study (Gentsch et al., 2013) indicate that high power appraisal could be related to cognitive processes of context updating, mental resource investment, and enhanced encoding that operate between 350 and 600 ms after event onset (cf. Kok, 2001; Olofsson, Nordin, Sequeira, & Polich, 2008; Polich & Kok, 1995). Previous studies on perceived personal ability (e.g., Pecchinenda & Smith, 1996; Smith & Kirby, 2009b) and power appraisal (van Reekum, 2000) have manipulated task difficulty or shooting power in a computer game, respectively. For example, Pecchinenda and Smith (1996) demonstrated that in the most difficult task condition of an anagram task, low power appraisal was related with task disengagement and reduced skin conductance activity. Also van Reekum (2000) showed that low power appraisal lead to task disengagement and prolonged reaction times. In our previous study, low power appraisal showed less positive P300 amplitudes compared to high power appraisal. Less positive P300 amplitudes may reflect reduced processing depth, which indirectly indicates disengagement in the presence of low power appraisal. To date, only one EEG–ERP study investigated power appraisal (Gentsch et al., 2013), but there is no published EEG–ERP study which investigated control evaluation as it is conceptualized by appraisal theories.

Neural correlates associated with goal conduciveness appraisal are usually investigated in the form of motivational valence evaluation in monetary gambling tasks (e.g., Gehring & Willoughby, 2002; Hajcak, Moser, Holroyd, & Simons, 2006; Nieuwenhuis, Yeung, Holroyd, Schurger, & Cohen, 2004; Pfabigan, Alexopoulos, Bauer, & Sailer, 2011; Piliastides, Biele, Vavatzanidis, Kazzer, & Heekeren, 2010). In these tasks, feedback stimuli convey information about the motivational valence (e.g., win or loss) and the magnitude of the outcome (small or large). Two ERP components are commonly investigated in this context. (1) The FN, which is a negative deflection occurring in feedback-locked ERPs between approximately 200 and 300 ms after feedback onset over medial-frontal electrode sites, and (2) the P300/P3b, which is a positive deflection, maximal over parieto-occipital electrode sites between 350 and 600 ms after feedback onset.

Depending on the task and research focus of the study, the FN is labelled differently (e.g., feedback[-related] negativity, F[R]N; [feedback] error-related negativity, [f]ERN; or medial-frontal negativity, MFN). Despite these labels, similar cognitive processes might underlie these negative peaks (Nieuwenhuis et al., 2004), pre-

sumably located in the dorsal or medial anterior cingulate cortex (ACC, e.g., Alexander & Brown, 2011; Gehring & Willoughby, 2002; Hauser et al., 2014; Nieuwenhuis et al., 2004). A considerable number of experimental studies and a few model-simulation studies (e.g., Alexander & Brown, 2011; Botvinick, Braver, Barch, Carter, & Cohen, 2001) have been conducted to identify the cognitive process and likely neural generators of this ERP component (for a review, see Walsh & Anderson, 2012; Yeung, 2004). Although several theories have been formulated (e.g., the reinforcement learning theory by Holroyd & Coles, 2002 or the salience-prediction error by Talmi, Atkinson, & El-Deredy, 2013), a single theoretical framework could not be established that reconciles and accounts for the variety of results (Alexander & Brown, 2011). It is argued that cognitive/computational (e.g., Gehring, Goss, Coles, Meyer, & Donchin, 1993; Holroyd & Coles, 2002; Yeung, Botvinick, & Cohen, 2004) and affective (e.g., Gehring & Willoughby, 2002) explanations of this ERP component complement rather than oppose each other since they seem to conceptualize the same class of processes (Yeung, 2004). In the present study, we use the FN as a guiding ERP component to quantify and investigate the appraisal effects between 200 and 300 ms since we manipulated appraisal information in feedback stimuli that were presented in a gambling task.

The findings on the P300 differ across gambling task studies. Consistently, P300 amplitudes were sensitive to the monetary magnitude information of the feedback (e.g., Hajcak, Holroyd, Moser, & Simons, 2005; Pfabigan et al., 2011; Sato et al., 2005; Yeung & Sanfey, 2004). Less frequently, the motivational valence of the feedback (e.g., Hajcak, Moser, Holroyd, & Simons, 2007) or the degree of power to decide on the outcome (Gentsch et al., 2013) affected the P300. It remains unclear which of these processes specifically affects P300 amplitude deflections. Potential sources of the feedback-related P300 effects could be the posterior cingulate gyrus and the ACC (Zhou, Yu, & Zhou, 2010).

Whether the FN and P300 are elicited by distinct processes related to motivational valence, saliency (i.e., context-dependent task relevance of stimulus information), and outcome magnitude is controversial. A recent study separating these processes (Gu et al., 2011) showed that both ERP components were sensitive to valence and magnitude information of the feedback. The authors proposed a flexible content-independent evaluative system that encodes feedback information as a function of the saliency of feedback information. Hence, the FN may reflect the processing of contextually most relevant features of stimulus information and the P300 might constitute the processing and integration of all stimulus information.

Outside of cognitive neuroscience, studies on the perception of control investigated the phenomenon of *illusion of control* (e.g., Langer, 1975; Langer & Roth, 1975; Thompson, Armstrong, & Thomas, 1998; Wohl & Enzle, 2002). Increased frequencies of action-outcome contingencies augmented participants' evaluation of the controllability of pure chance tasks. However, the question of how different degrees of perceived control are reflected in EEG-ERPs remains open.

5. The present study

Similar to our previous study (Gentsch et al., 2013), in each trial feedback stimuli manipulated goal conduciveness and power appraisal. The important methodological change of the task design concerns the added operationalization of control appraisal. It was operationalized via the occurrence rate of free and no choice options across trials within a block. Prior to each block, participants were informed about the degree of situational control in order to prevent confounding effects of trial-to-trial contingency learning on the ERPs. The present study is the first to investigate control

appraisal in ERPs. It is a direct extension of our previous study (Gentsch et al., 2013) in which we demonstrated the validity of the new manipulation of power appraisal in the form of available choice options.

To summarize, the research questions we addressed in the present study are (a) whether adding a control appraisal manipulation equally results in sequential effects of goal conduciveness, control, and power appraisals in ERPs, and (b) whether these appraisal criteria can be tied to specific neural sources. We expected to replicate sequential effects of goal conduciveness and power appraisal in ERPs. In particular, we predicted goal conduciveness effects in the time interval of the FN (230–300 ms) to show a motivational valence effect (i.e., more negative amplitudes following losses than following wins). We expected effects of power appraisal on P300 amplitudes (350–600 ms after feedback-stimulus onset) in the form of more positive amplitudes in high power than in low power trials. We also predicted control appraisal main effects on P300 amplitudes. Given the CPM prediction that power appraisal is only meaningful when control has been appraised as sufficiently high, we expected an interaction effect of control and power appraisals on P300 amplitudes. Notably, in high control blocks, high power trials should elicit larger P300 amplitudes than low power trials; whereas in low control blocks, P300 amplitudes in high and low power trials should be similar.

6. Method

6.1. Participants

Twenty-four healthy and right-handed (mean of Edinburgh Handedness Inventory = 88.93, SD = 12.27) female students of the University of Geneva participated for payment. Participants were paid 25CHF (Swiss francs) for their participation. Depending on their task performance, they could additionally win up to 16CHF. Participants ranged in age from 18 to 30 years ($M = 21.38$, $SD = 0.66$).

6.2. Procedure

After participants arrived at the laboratory, they read and signed an informed consent form and filled out questionnaires about their current health and demographic characteristics. Participants sat in a semi-dark and sound-attenuated room in front of a computer screen (17", resolution 1280 × 1024, refresh rate 60 Hz, LED monitor) and a standard keyboard to perform the computerized gambling task. The distance between participants' eyes and the screen was 60 cm.

In order to familiarize participants with the gambling task, they completed a practice session (48 trials, 5–7 min). When their performance reached the criterion (>80% of correct responses: accepting wins and rejecting losses) they started the experimental task, otherwise, they had to run another practice session.

The amount of bonus money won during the experimental task depended on the participant's performance. Participants were instructed to maximize the amount of bonus money, without the maximum bonus amount being mentioned to them (16CHF). They were assured that they would not end up losing money or owing money to the experimenter. Participants were not informed that the type of feedback on each trial was independent of their choice; they were told only that they would play a gambling task. At the end of the experiment, participants were paid their participation fee, as well as the bonus money, and were debriefed about the experimental manipulations.

6.3. Gambling task and experimental conditions

The structure of a gambling task trial is illustrated in Fig. 1. Each trial started with a fixation cross (randomized duration: 300–700 ms; 1° high, 1° wide) in the center of the screen, followed by two horizontally aligned circles (Fig. 1, Choice of circle, 3.8° high, 4.6° wide). Participants were told that the outcomes of a trial (win: +0.05CHF; or loss: −0.05CHF) were concealed under these circles. No cues were provided to indicate which circle hid the win. To choose the left or the right circle, participants pressed number 1 or 3 on the numeric keypad, respectively. The chosen circle was highlighted (500 ms), and then the feedback stimulus appeared at its center (Fig. 1, Feedback, 500 ms).

On each trial, feedback stimuli presented appraisal information from both goal conduciveness (outcome: win vs. loss) and power appraisal (power: high [two choice options] vs. low [no choice option to decide about the outcome]). Goal conduciveness appraisal was manipulated by using different geometric shapes (e.g., hexagon and diamond); power appraisal was manipulated through the color of these shapes (solid gray or black fill). The respective associations were counterbalanced across participants. Across different gambling blocks, control appraisal was manipulated by varying the frequency of high and low power feedback.¹ In high control blocks, 75% of the trials indicated high power (25% low power feedback) and these blocks were expected to be perceived as high in control. In low control blocks, 75% of the trials presented low power feedback (25% high power feedback); these blocks were expected to be perceived as low in control. In and across gambling blocks (three high control and three low control blocks) the percentage of wins and losses occurred equally often (50:50). Across all blocks, low and high power feedback was presented equally often.

In total, there were eight experimental conditions: (1) *high control, high power, loss* (162 trials); (2) *high control, high power, win* (162 trials); (3) *high control, low power, loss* (54 trials); (4) *high control, low power, win* (54 trials); (5) *low control, high power, loss* (54 trials); (6) *low control, high power, win* (54 trials); (7) *low control, low power, loss* (162 trials); and (8) *low control, low power, win* (162 trials).

After feedback presentation, the screen went black (1 s), followed by a screen having one letter to the left and one to the right side (Fig. 1, Choice about outcome, A = accept, R = reject; 0.8° high, 6.6° wide; Arial font, size 28). Here, participants decided about the final outcome of that trial. In high power trials, they had the choice between the options of accepting or rejecting the outcome (presentation of “A R” or “R A”: randomized order with the same number of presentations). Here, participants were certain to be able to accept a win and to reject a loss. In contrast, in low power trials, they had no choice, that is, they had to accept the option of either rejecting (presentation of “R R”) or accepting (“A A”) the outcome (randomized selection with the same number of presentations). Then, the participant's decision was highlighted and the total monetary outcome was presented (Fig. 1, Monetary outcome and response feedback, 300 ms; Arial font, size 52 bold). The next trial started immediately. In total, 864 trials were presented in six blocks (three high and three low control blocks) in randomized order. The duration of the gambling task was about 50 min.

In addition, at the end of each gambling block, participants were asked to rate how much they felt (a) positive or negative

(valence), (b) calm or aroused (arousal), (c) that the gambling task was uncontrollable or controllable (potency-control), and (d) that the occurrence of the feedback stimuli was predictable or unpredictable (unpredictability). Participants gave their answer by placing a mark at the appropriate position on a continuous horizontal line (1° high, 18° wide), anchored from −100 (left side) to 100 (right side).

6.4. Data acquisition

Practice session, gambling task, and behavioral data acquisition were administered by using E-Prime 2.0 (Psychology Software Tools, Inc., Pittsburgh, PA). Electroencephalography (EEG 64-channel electrode cap) and facial electromyography (EMG)² data were recorded (bandwidth 0.1–417 Hz, sampling rate: 2048 Hz) with a BIOSEMI Active-Two amplifier system (BioSemi Biomedical Instrumentation, Amsterdam, the Netherlands).

The EEG data were preprocessed offline. First, with the BioSemi *decimeter* software package (BioSemi Biomedical Instrumentation, Amsterdam, Netherlands) the data were downsampled to 256 Hz. Next, in EEGLAB 11.0.4.3b (Delorme & Makeig, 2004), implemented in Matlab R2012a (The MathWorks, Inc., Natick, MA), the data were high-pass filtered (0.1 Hz), noisy channels were removed, and horizontal and vertical eye movements were corrected (based on individual component maps, extracted by Infomax independent component analysis implemented in EEGLAB, cf. Delorme, Sejnowski, & Makeig, 2007). Then the data were exported to Brain Vision Analyzer software (BVA, Brain Products, Gilching, Germany). In BVA, removed channels were interpolated by spherical splines (Perrin, Pernier, Bertrand, & Echallier, 1989). Subsequently, the data were average re-referenced based on the average of all 64 channels, low-pass filtered (30 Hz, roll-off 24db/octave), and segmented (200 ms baseline period and 1.5 s after-stimulus-onset period). Next, trials were removed in which artifacts exceeded $\pm 110 \mu\text{V}$ in all channels (2.62% total amount of excluded trials across all participants). Eventually, the segmented data were baseline corrected (200 ms) and averaged for each experimental condition. The mean activity values (μV) of the two time intervals (FN: 230–300 ms, P300: 350–600 ms) time intervals were exported for data analyses.

6.5. Data analyses

6.5.1. Behavioral data

Participants' task performance and their reaction times (RTs) were investigated when participants decided on the outcome of that trial (Fig. 1, Choice about outcome). A 2 (goal conduciveness) $\times$ 2 (control) $\times$ 2 (power) repeated measures analysis of variance (ANOVA) was calculated on these averaged RTs. Moreover, to examine the differential impact of high and low control blocks on the participants, the average of each rating dimension (i.e., valence, arousal, potency-control, and unpredictability, evaluated by the participants at the end of each gambling block) was analyzed with a univariate repeated measures ANOVA.

6.5.2. ERP mean amplitudes

The ERP analyses were based on grand averaged mean amplitudes within two time intervals (FN: 230–300 ms and P300: 350–600 ms). The FN was evaluated at the channels Fz and FCz, and the P300 at Pz and POz. For each ERP component a 2 (goal conduciveness) $\times$ 2 (control) $\times$ 2 (power) $\times$ 2 (channel location) repeated measures ANOVA was calculated.

¹ In the beginning of each block, participants read “Try to find the circle that brings you the money”. In order to make the multiple-information equally salient – about the outcome and the degree of control – they also read prior to high control blocks “In this block, you decide most of the time on the final outcome.”, and they read prior to low control blocks “In this block, the computer decides most of the time on the final outcome.”

² Facial EMG was concurrently recorded over the forehead, brow, and cheek region. The EMG data are reported in Gentsch, Grandjean, and Scherer (2015).

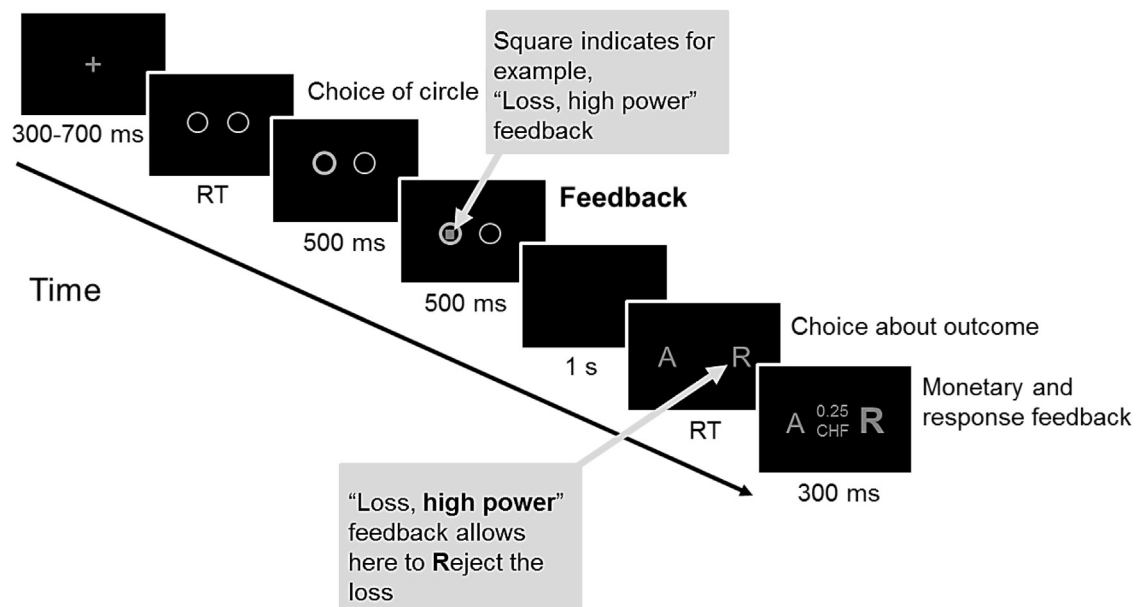


Fig. 1. Trial structure of the gambling task. Presentation time of each event is indicated below the corresponding screen. At feedback onset, goal conduciveness and power appraisal information were simultaneously presented via gray- or black-colored filled geometric shapes. Control appraisal was manipulated within experimental blocks. RT = reaction time. See text for details.

6.5.3. Statistical analyses

Statistical analyses of the behavioral data and the ERP mean amplitudes were carried out with IBM SPSS Statistics 22. All statistical tests were two-tailed and performed at an alpha level of 5%. Holm's stepwise correction procedure (Holm, 1979) was applied to consider the possibility of an increased Type I error due to multiple testing in the planned comparisons and post hoc analyses (corrected p values are labeled as p_{adj}). All reported effect sizes are partial η^2 .

6.5.4. Source localization

To identify the brain regions which were most probably involved in producing the significant scalp ERP amplitude deflections in the two time intervals (FN: 230–300 ms and P300: 350–600 ms), their source activity was estimated using the standardized low-resolution brain electromagnetic tomography (sLORETA version v20150415, Pascual-Marqui, 2002; Pascual-Marqui, Michel, & Lehmann, 1994). SLORETA is a discrete, three-dimensional distributed, linear imaging method based on specific electrophysiological and neuroanatomical constraints (Pascual-Marqui, 2002; Pascual-Marqui et al., 1994). In sLORETA the cortex (limited to the cortical gray matter and both hippocampi) is modeled in the form of voxels as defined by the Montreal Neurological Institute (MNI) reference brain (i.e., MNI152 template comprising of 6239 voxels with a spatial resolution of 5 mm $\times$ 5 mm $\times$ 5 mm). The MNI coordinates were converted to corrected Talairach coordinates. Voxels were retrained that were unambiguously labelled as belonging to the cortex. In sLORETA it is assumed that the current density variance consists of possible noise in the EEG measurements stemming predominantly from variance in the actual electric neuronal activity. The sLORETA algorithm addresses the inverse problem by assuming related orientations and strengths of neighboring neuronal sources (i.e., adjacent voxels) and by computing the smoothest of all possible activity distributions without a priori assumptions on the number and locations of sources. Several studies validated the previous LORETA version. They combined LORETA with other localization methods such as functional magnetic resonance imaging (MRI, Corrigan et al., 2009; Mulert et al., 2004), structural MRI (Pizzagalli et al., 2004; Worrell et al., 2000), and positron emission

tomography (Pastor, Valencia, Artieda, Alegre, & Masdeu, 2007; Pizzagalli et al., 2004). SLORETA is an improved version of LORETA (Pascual-Marqui, 2002). For example, using sLORETA deeper structures such as the ACC can be more correctly localized (De Ridder, Vanneste, Kovacs, Sunaert, & Dom, 2011).

Mean amplitudes of the two time intervals (FN: 230–300 ms and P300: 350–600 ms) were converted for each participant and experimental condition into a three-dimensional distribution of cortical activations. Then, the 64 electrode positions from the EEG 64-channel electrode cap were transformed to corrected Talairach electrode coordinates (Talairach & Tournoux, 1988). SLORETA estimated the brain regions (i.e., the voxels) that were responsible for the significant differences in the scalp ERPs in the specified time intervals based on estimated standardized current density (i.e., standardized electric neuronal activity) for each voxel. Using the sLORETA-KEY software package, the statistical tests were conducted on the average of all time frames of each of the two time intervals of interest. Non-parametric paired-group tests (for details, see Nichols & Holmes, 2002) were performed using the log-transformed sLORETA values which compared the two levels of an appraisal criterion (i.e., goal conduciveness: loss vs. win, control: low vs. high, and power: low vs. high). The tests estimated, via 5000 permutations, the empirical probability distribution for the maximum of an F statistic under the null hypothesis. This method corrects for multiple testing (i.e., for all tests including all electrodes, voxels, and time intervals). Since the tests are non-parametric, their validity does not rely on any assumption of normality of the data.

7. Results

7.1. Behavioral data

In the gambling task, the smallest amount of bonus money won was 14.25CHF for one participant. All other participants made between 14.50 and 15.75CHF. This result indicates that the participants had well learned the meaning of each feedback stimulus and that they were motivated to maximize the amount of bonus money.

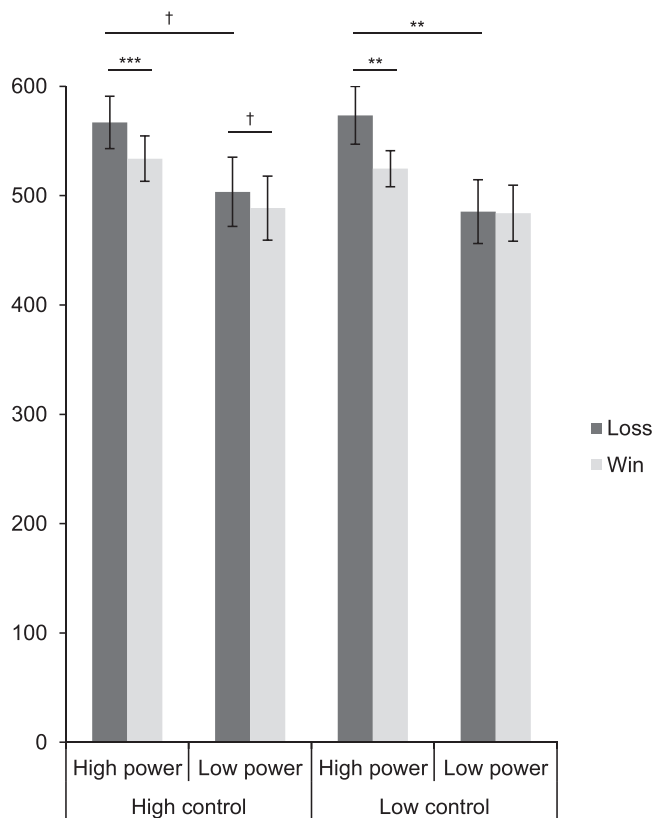


Fig. 2. Mean reaction times depicting the three-way interaction effect of goal conduciveness, control, and power when participants decided on the outcome (see Fig. 1, Choice about outcome). The error bars present the standard error of the mean. † $p < .10$, ** $p < .01$, *** $p < .001$.

The repeated measures ANOVA on the RTs revealed significant main effects of goal conduciveness, $F(1, 23) = 15.94$, $p = .001$, $\eta^2 = .41$, and power, $F(1, 23) = 8.63$, $p = .007$, $\eta^2 = .27$. These main effects were qualified by a significant interaction effect of these two factors, $F(1, 23) = 17.68$, $p < .001$, $\eta^2 = .44$, and a significant three-way interaction effect of all factors, $F(1, 23) = 5.01$, $p = .035$, $\eta^2 = .18$. The three-way interaction effect suggests that participants responded to wins and losses with differing speed depending on the degree of perceived control and power (Fig. 2).

Post hoc analyses revealed that in high and low control blocks, participants responded with differential speed to wins and losses as a function of power (Goal conduciveness $\times$ Power, $F(1, 23) = 6.04$, $p = .022$, $\eta^2 = .21$ and $F(1, 23) = 14.88$, $p = .001$, $\eta^2 = .39$, respectively). Specifically, when participants perceived high control and had free choice (high power), they took significantly more time to decide about losses than wins, $t(23) = 5.19$, $p_{\text{adj}} < .001$. When they perceived high control but had no choice (low power) to decide about the outcome, RTs to wins were marginally faster than to losses, $t(23) = 2.50$, $p_{\text{adj}} = .099$. Moreover, RTs were marginally faster in response to losses when participants had no choice compared to when they had free choice, $t(23) = 2.91$, $p_{\text{adj}} = .056$. When participants perceived low control and had free choice (high power), they decided significantly faster about wins than about losses, $t(23) = 3.61$, $p_{\text{adj}} = .006$. However, when they perceived low control and had no choice, participants responded equally fast to losses and wins, $t(23) = 0.21$. Additionally, participants responded faster to losses when they had low power than when they had high power, $t(23) = 4.06$, $p_{\text{adj}} = .001$. Taken together, when low control and low power were appraised, participants decided equally fast about wins and losses. In this condition, the valence of the outcome seems to have been unimportant for the response. Overall, irrespective of the

degree of control, participants were most hesitant in free choice trials to decide about (potential) losses than about wins, presumably to avoid an (incorrect) acceptance of a loss.

In addition, participants' ratings after each gambling block indicated that the manipulation of perceived control had been successful, $F(1, 23) = 33.29$, $p < .001$, $\eta^2 = .59$. Consistent with the intended manipulation, participants perceived greater control in high control blocks ($M = 13$, $SD = 26$) compared with low control blocks ($M = -33$, $SD = 31$). Moreover, participants rated feedback-stimuli occurrence as less predictable in low control blocks ($M = -32$, $SD = 29$) compared with high control blocks ($M = -7$, $SD = 28$), $F(1, 23) = 15.48$, $p = .001$, $\eta^2 = .40$. Furthermore, high control blocks ($M = 28$, $SD = 28$) were rated as being more positive than low control blocks ($M = 5$, $SD = 27$), $F(1, 23) = 15.81$, $p = .001$, $\eta^2 = .41$. Arousal ratings were similar for high and low control blocks ($M = -11$, $SD = 39$; $M = -7$, $SD = 38$, respectively), $F(1, 23) = 0.70$.

7.2. ERP mean amplitudes

Table 1 presents the results of the repeated measures ANOVA on the mean amplitudes of the FN and P300. Table 2 lists the mean amplitude values of the main and interaction effects.

7.2.1. Goal conduciveness effects

On FN mean amplitudes, there was a significant goal conduciveness main effect consisting of more negative amplitudes following losses than following wins (Fig. 3). On P300 mean amplitudes, wins had more positive mean amplitudes than losses (Fig. 3). The topographical maps (Fig. 4) suggest a differential activity distribution of the goal conduciveness effects over time (medial-frontal activity 230–300 ms and parieto-occipital activity 350–600 ms).

7.2.2. Control effects

On FN mean amplitudes, no control main effect was found, whereas on P300 mean amplitudes it was marginally significant (Fig. 5). Moreover, on P300 mean amplitudes, the interaction between Control $\times$ Channel was significant (Fig. 5). Post hoc analyses of this interaction effect revealed that mean amplitudes were similar in high and low control blocks at Pz ($p_{\text{adj}} = .342$), but at POz, they were marginally more positive in low control than in high control blocks ($p_{\text{adj}} = .088$). The topographical map (Fig. 4) shows a distinct distribution of control effects over parieto-occipital electrode sites (350–600 ms).

7.2.3. Power effects

On FN mean amplitudes, a significant power main effect showed more negative mean amplitudes in low power than high power trials (Fig. 6). On P300 mean amplitudes, the power main effect was significant. Mean amplitudes were more positive in high power than in low power trials (Fig. 6). Moreover, the interaction of Power $\times$ Channel was significant. Post hoc analyses of this interaction effect revealed at both electrode sites (Pz and POz) that mean amplitudes were significantly more positive in high than in low power trials (p_{adj} -values $< .001$). However, the effect was more pronounced at Pz. The topographical maps (Fig. 4) show a distinct distribution of power effects over time (medial-frontal activity 230–300 ms and parieto-occipital activity 350–600 ms).

7.2.4. Interaction effects

On FN mean amplitudes, no significant interaction effects emerged. On P300 mean amplitudes, significant two-way interaction effects were found, which were Control $\times$ Power (Fig. 7) and Goal conduciveness $\times$ Power (Fig. 8). The topographical maps (Fig. 9) show differential effects of these interactions with respect to centro-parietal and parieto-occipital voltage distributions.

Table 1

Results of the two repeated measures ANOVAs on mean voltage amplitudes in the time interval of the feedback-negativity (FN) and the P300.

	FN (230–300 ms)		P300 (350–600 ms)	
	<i>F</i>	η^2	<i>F</i>	η^2
GC	8.72**	.28	10.89**	.32
Control	1.56	.06	3.00†	.12
Power	5.15*	.18	25.63***	.53
GC × Channel	0.43	.02	0.43	.02
Control × Channel	0.79	.03	5.25*	.19
Power × Channel	0.14	.01	6.77*	.23
GC × Control	0.26	.01	2.28	.09
GC × Power	5.91	.21	5.45*	.19
Control × Power	2.06	.16	7.16*	.24
GC × Control × Channel	0.08	.01	0.05	.01
GC × Power × Channel	0.19	.01	1.15	.05
Control × Power × Channel	2.27	.09	0.67	.03
GC × Control × Power	2.85	.11	0.01	.01
GC × Control × Power × Channel	0.55	.02	0.11	.01

Note: *N* = 24. For the FN and P300 a repeated measures ANOVA with the within-subject factors of GC (goal conduciveness: win vs. losses), Control (high vs. low), Power (high vs. low), and Channel (FN: Fz and FCz; P300: Pz, and POz) was calculated.

* *p* < .05.** *p* < .01.*** *p* < .001.† *p* < .10.

Post hoc tests on the Control × Power interaction effect revealed that in high control as well as in low control blocks, P300 mean amplitudes were more positive in high power than in low power trials, $p_{\text{adj}} = .010$ and $p_{\text{adj}} < .001$, respectively. Moreover, *low control, high power* trials had more positive P300 amplitudes than *high control, high power* trials, $p_{\text{adj}} = .018$. P300 mean amplitudes in low

power trials were independent of the degree of perceived control, $p_{\text{adj}} = .984$.

Post hoc tests on the Goal conduciveness × Power interaction effect showed that P300 mean amplitudes were more positive following wins than following losses in high power trials, $p_{\text{adj}} = .001$, but they were similar in low power trials, $p_{\text{adj}} = .271$. Additionally, mean amplitudes in *loss, high power* trials were significantly more

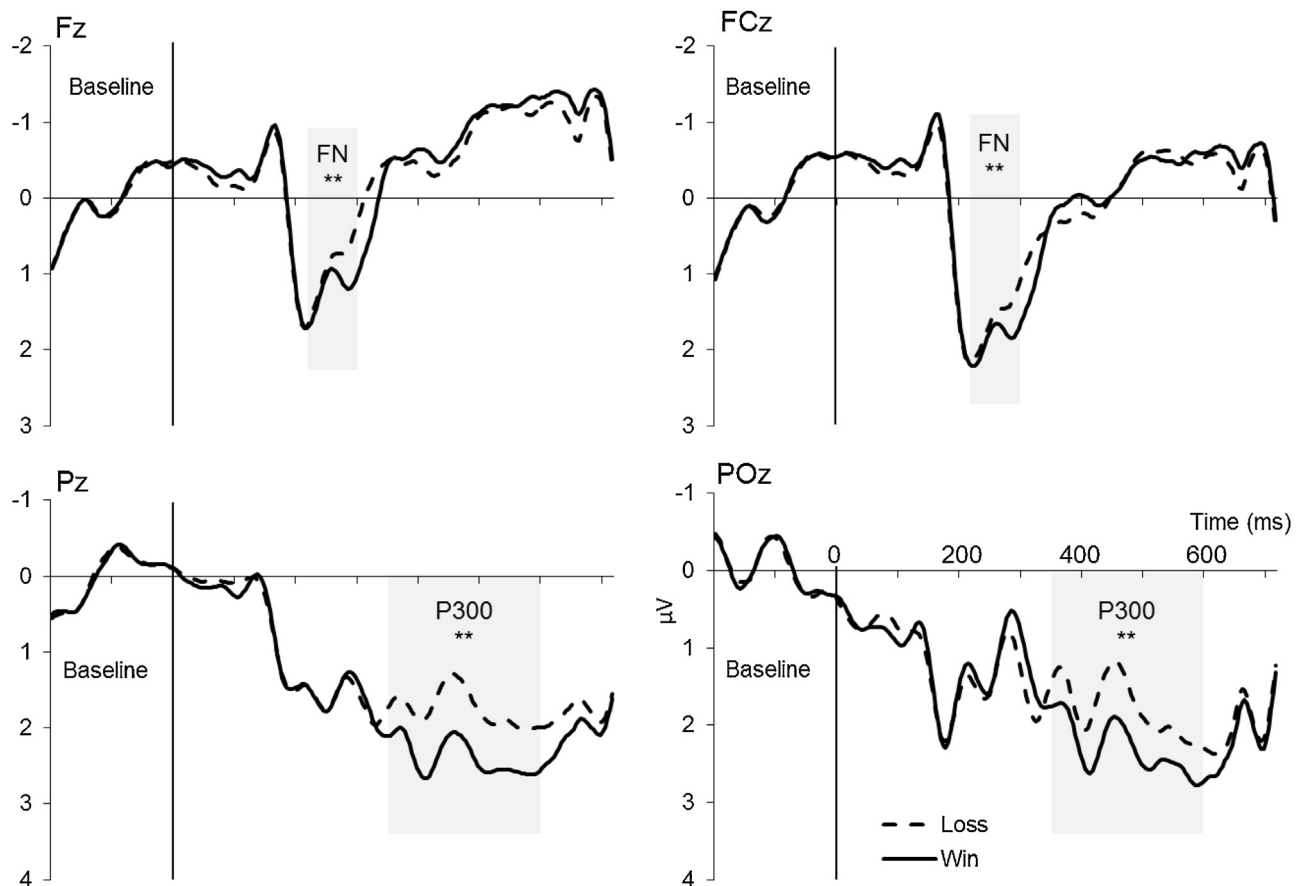


Fig. 3. Grand averaged feedback-locked ERPs related to goal conduciveness at channels FCz, Fz, Pz, and POz. Baseline is presented (–200 ms). Feedback onset is at 0 ms (vertical black line). ***p* < .01.

Table 2
Mean Voltage amplitude values (*M*) and standard deviations (*SD*) of the FN (at Fz, FCz) and the P300 (at Pz, POz).

Feedback conditions		FN				P300			
		Fz		FCz		Pz		POz	
		M	SD	M	SD	M	SD	M	SD
GC	Loss	0.66	1.89	1.39	2.17	1.76	1.33	1.85	1.40
	Win	1.05	1.98	1.73	2.25	2.42	1.21	2.37	1.22
Control	High	0.77	1.93	1.45	2.2	2.01	1.30	1.88	1.15
	Low	0.93	1.98	1.67	2.23	2.16	1.26	2.33	1.38
Power	High	0.99	2.09	1.68	2.43	2.51	1.39	2.81	1.69
	Low	0.71	1.77	1.44	1.96	1.67	1.17	1.40	1.01
GC × Control	Loss, high control	0.59	1.96	1.3	2.22	1.78	1.50	1.73	1.54
	Win, high control	0.96	1.99	1.59	2.28	2.25	1.25	2.03	1.22
	Loss, low control	0.72	1.94	1.48	2.22	1.74	1.31	1.97	1.47
	Win, low control	1.14	2.04	1.86	2.29	2.59	1.36	2.70	1.61
GC × Power	Loss, high power	0.69	2.07	1.42	2.41	2.05	1.47	2.36	1.83
	Win, high power	1.29	2.15	1.94	2.50	2.96	1.45	3.27	1.81
	Loss, low power	0.62	1.74	1.36	1.97	1.47	1.34	1.33	1.36
	Win, low power	0.81	1.88	1.52	2.04	1.87	1.19	1.46	1.22
Control × Power	High control, high power	0.88	2.03	1.48	2.39	2.30	1.37	2.41	1.47
	High control, low power	0.67	1.87	1.41	2.04	1.72	1.41	1.35	1.33
	Low control, high power	1.11	2.24	1.88	2.51	2.71	1.55	3.22	2.11
	Low control, low power	0.76	1.78	1.46	2.02	1.62	1.13	1.45	0.93
GC × Control × Power	Loss, high control, high power	0.54	2.05	1.18	2.37	1.94	1.45	2.08	1.56
	Win, high control, high power	1.21	2.07	1.79	2.51	2.67	1.43	2.75	1.68
	Loss, high control, low power	0.64	1.93	1.42	2.16	1.62	1.73	1.38	1.84
	Win, high control, low power	0.70	2.00	1.40	2.11	1.83	1.56	1.32	1.79
	Loss, low control, high power	0.84	2.22	1.67	2.54	2.17	1.72	2.65	2.30
	Win, low control, high power	1.37	2.32	2.09	2.55	3.25	1.62	3.79	2.31
	Loss, low control, low power	0.60	1.74	1.29	1.98	1.32	1.16	1.28	1.06
	Win, low control, low power	0.91	1.88	1.63	2.13	1.92	1.27	1.61	1.19

Note. *N* = 24. FN = feedback negativity; GC = goal conduciveness.

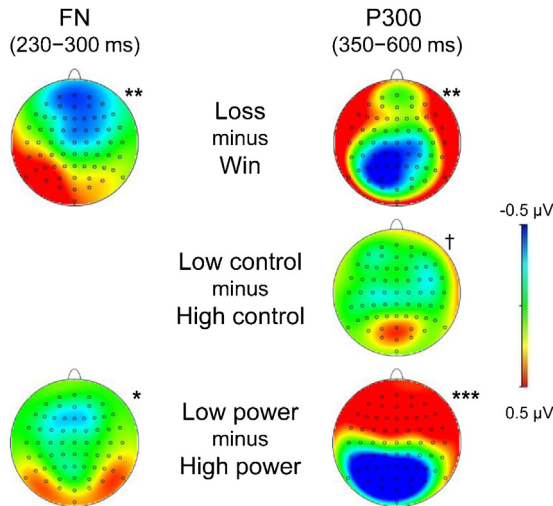


Fig. 4. Scalp topographies of the difference waves of the averaged ERPs for the FN and P300. Significant mean voltage differences are shown for main effects related to the feedback information of goal conduciveness, control, and power. The timing is relative to the onset of the feedback stimuli. $\dagger p < .10$, $*p < .05$, $**p < .01$, $***p < .001$.

positive than in *loss*, *low power* trials, $p_{\text{adj}} = .005$. Likewise, mean amplitudes were more positive in *win*, *high power* trials than in *win*, *low power* trials, $p_{\text{adj}} < .001$.

7.3. Source localization

Table 3 presents the brain regions, the relative Talairach coordinates, and Brodmann areas (BA) for which the log-*F*-ratio reached statistical significance in the time range of the FN and P300. For

the sake of readability, if there were more than three sources under the same anatomical label, only the top three sources are reported in Table 3; Table S1 in the supplementary material section lists all source localization results. Source activity related to the processing of goal conduciveness (*loss* vs. *win*) between 230 and 300 ms was notably located in the right insula, whereas between 350 and 600 ms it was found in the cingulate gyrus (Fig. 10). Source activity for the processing of control (*low* vs. *high*) between 350 and 600 ms was located in a network involving the cingulate gyrus, cuneus, fusiform gyrus, lingual gyrus, middle occipital gyrus, parahippocampal gyrus, posterior cingulate, precuneus, and superior parietal lobule. Source activity linked with the processing of power (*low* vs. *high*) did not reveal a significant source activity localization result (*F*-values < 5.24, *p*-values > .352).

8. Discussion

In the present study, we investigated whether adding a control appraisal manipulation to the previous operationalization of goal conduciveness and power appraisals in a gambling task (Gentsch et al., 2013) will result in the predicted sequence of goal conduciveness, control, and power appraisals in ERPs. We also examined whether these appraisal criteria can be tied to specific neural sources.

On the behavioral level, control and power appraisals differentially affected participants' decision speed about the outcome (wins and losses) when they finalized a trial. Participants took more time to decide about losses relative to wins whenever they had free choice (high power) independent of the perceived degree of control. The prolonged RTs for losses may reflect cautious responding because the consequence of a wrong decision about a loss (loss of money) was worse than a wrong decision about a win (zero money). Interestingly, decision speeds about losses and wins were similar

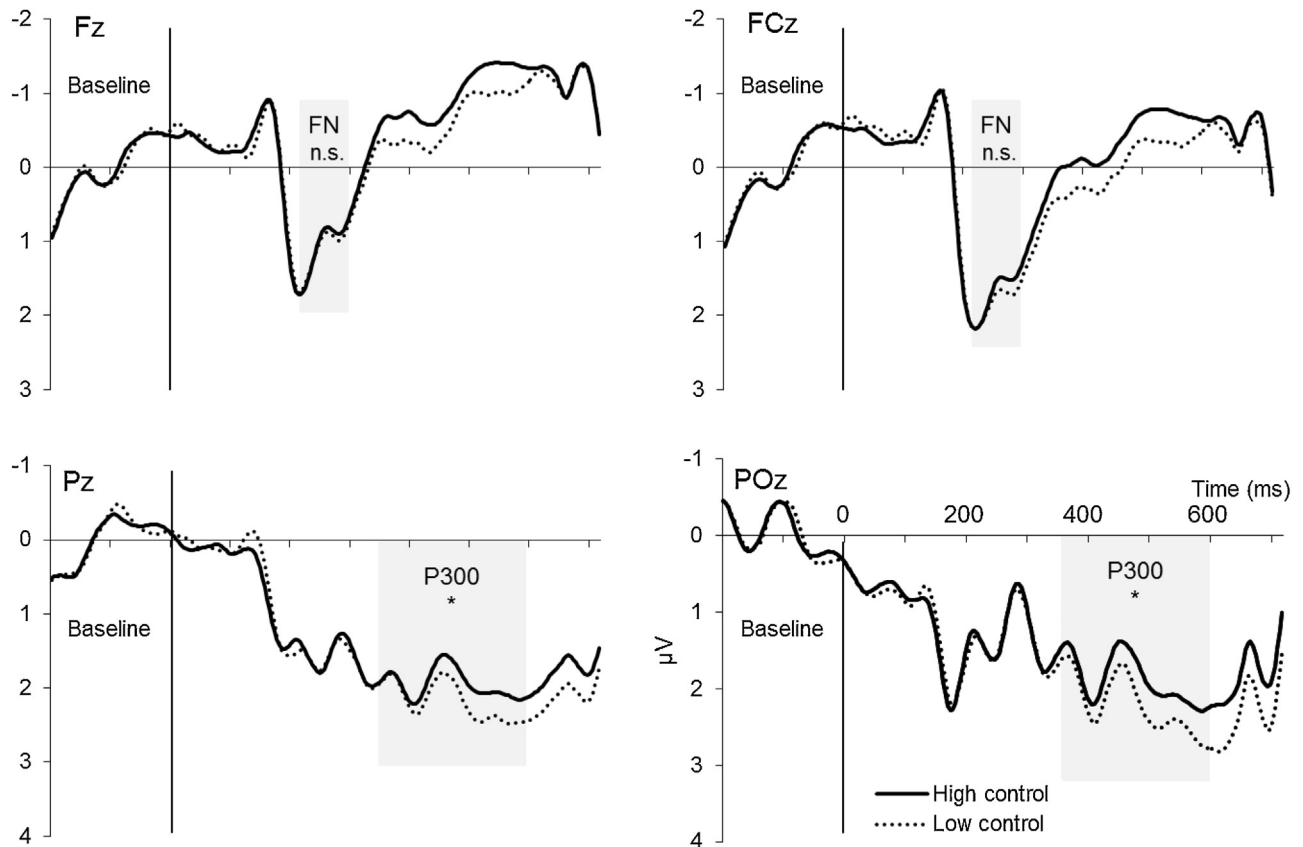


Fig. 5. Grand averaged feedback-locked ERPs related to control at channels FCz, Fz, Pz, and POz. Baseline is presented (–200 ms). Feedback onset is at 0 ms (vertical black line). n.s. not significant, $p < .05$.

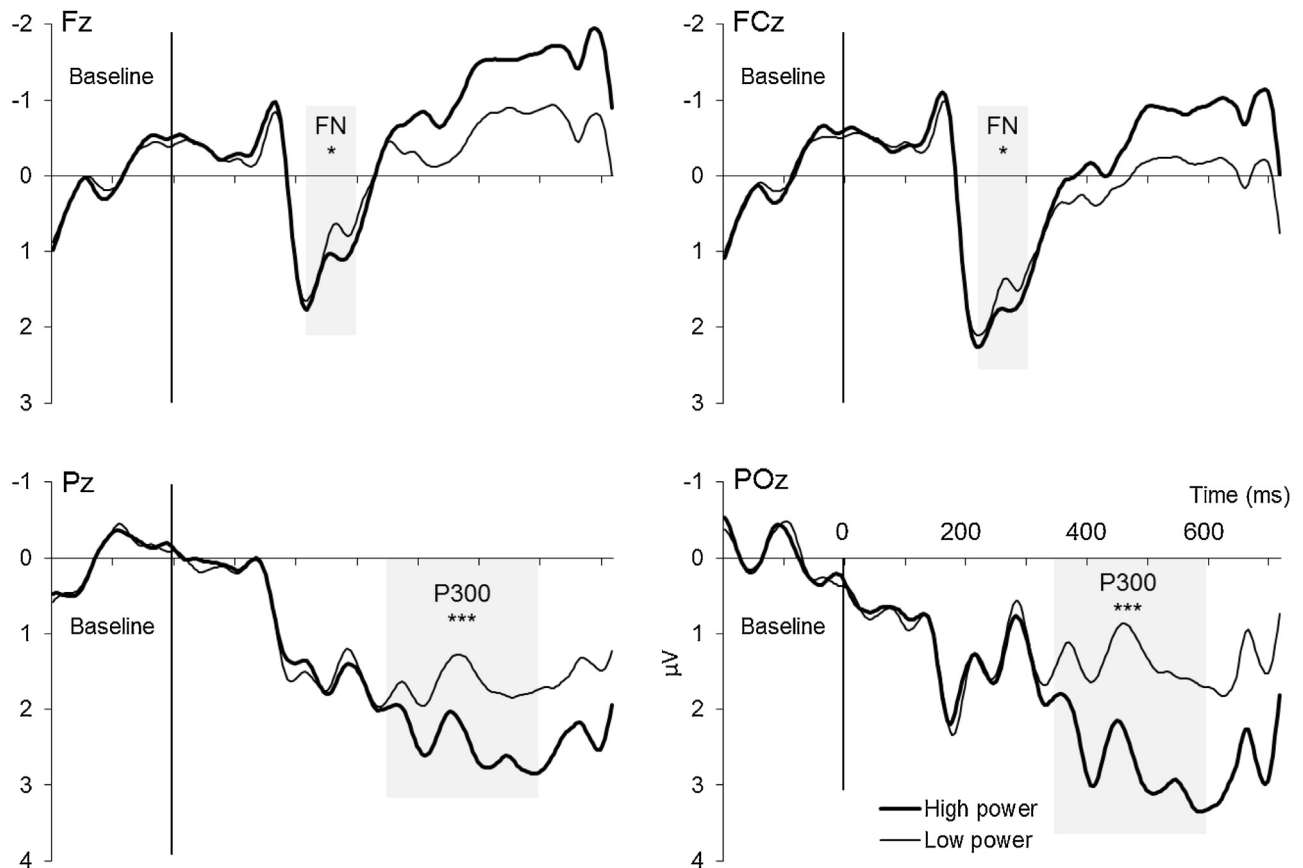


Fig. 6. Grand averaged feedback-locked ERPs related to power at channels FCz, Fz, Pz, and POz. Baseline is presented (–200 ms). Feedback onset is at 0 ms (vertical black line). $*p < .05$, $***p < .001$.

Table 3

Local Maxima of Standardized Current Density for the Contrasts of the Two Levels of Each Appraisal Criterion in Two Time Intervals.

Time interval (ms)	Appraisal								Power: low vs. high $F_{\max}$
	Goal conduciveness: loss vs. win				Control: low vs. high				
	Brain region	Right/left BA	TAL (x, y, z)	$F_{\max}$	Brain region	Right/left BA	TAL (x, y, z)	$F_{\max}$	
230–300	<i>Sub-lobar</i>								
	Insula	R 13	40, 3, 14	5.14 [†]					n.s.
	<i>Limbic lobe</i>				<i>Limbic lobe</i>				
350–600	Cingulate gyrus	R 23	5, –15, 28	5.87 [*]	Cingulate gyrus	23	0, –33, 25	4.95 [*]	n.s.
	Cingulate gyrus	R 23	5, –18, 29	5.58 [*]	Cingulate gyrus	31	0, –38, 25	4.91 [*]	
	Cingulate gyrus	23	0, –18, 29	5.37 [*]	Cingulate gyrus	R 31	20, –42, 25	4.89 [*]	
					Parahippocampal gyrus	R 30	10, –48, 2	5.66 ^{**}	
					Parahippocampal gyrus	L 19	–30, –49, –2	5.51 ^{**}	
					Parahippocampal gyrus	R 30	10, –44, 2	5.45 ^{**}	
					Posterior cingulate	R 30	5, –53, 7	5.71 ^{**}	
					Posterior cingulate	R 29	5, –48, 7	5.69 ^{**}	
					Posterior cingulate	R 30	5, –58, 8	5.65 ^{**}	
	<i>Occipital lobe</i>				<i>Occipital lobe</i>				
	Cuneus	R 30	10, –58, 8	5.82 ^{**}	Cuneus	R 30	10, –63, 8	5.69 ^{**}	
	Cuneus	R 30	5, –63, 8	5.48 ^{**}	Cuneus	R 30	5, –63, 8	5.48 ^{**}	
	Lingual gyrus	R 19	10, –63, –1	6.11 ^{**}	Lingual gyrus	R 19	10, –63, –1	6.11 ^{**}	
	Lingual gyrus	R 18	10, –68, –1	6.04 ^{**}	Lingual gyrus	R 18	10, –68, –1	6.04 ^{**}	
	Lingual gyrus	R 18	10, –63, 3	5.99 ^{**}	Lingual gyrus	R 18	10, –63, 3	5.99 ^{**}	
	Middle occipital gyrus	R 19	30, –87, 18	4.88 [*]	Middle occipital gyrus	R 19	30, –87, 18	4.88 [*]	
	<i>Temporo-occipital lobe</i>				<i>Temporo-occipital lobe</i>				
	Fusiform gyrus	L 37	–35, –54, –10	5.87 ^{**}	Fusiform gyrus	L 37	–35, –54, –10	5.87 ^{**}	
	Fusiform gyrus	L 37	–40, –49, –14	5.83 ^{**}	Fusiform gyrus	L 37	–40, –49, –14	5.83 ^{**}	
	Fusiform gyrus	L 37	–40, –54, –14	5.72 ^{**}	Fusiform gyrus	L 37	–40, –54, –14	5.72 ^{**}	
	<i>Parietal lobe</i>				<i>Parietal lobe</i>				
	Precuneus	L 7	–5, –60, 58	4.97 [*]	Precuneus	L 7	–5, –60, 58	4.97 [*]	
	Superior parietal lobule	L 7	–5, –65, 54	5.20 [*]	Superior parietal lobule	L 7	–5, –65, 54	5.20 [*]	

Note. BA = Brodmann area, TAL (x, y, z) = Talairach space coordinates (Talairach & Tournoux, 1988). Source localization was estimated by computing non-parametric log F-ratio test based on the mean amplitudes of each appraisal check in the time interval of an ERP component. The three highest values are presented. All source localization results are available in Table S1 of Supplementary material.

* $p < .05$.

** $p < .01$.

† $p < .10$.

in the *low control*, *low power* condition and they were also relatively fastest in this condition compared to the others. This effect suggests that in the presence of low control and low power, participants decided about the outcome seemingly independently of its valence. Moreover, participants' ratings of their perceived control in the end of each block suggest a successful manipulation of control. They perceived more control in high control blocks and less control in low control blocks.

8.1. Goal conduciveness effects

Consistent with our prediction, effects of goal conduciveness were found on FN amplitudes (230–300 ms after feedback-stimulus onset). FN amplitudes were more negative following losses than following wins. Furthermore, the topographical map of the difference waves (loss minus win) shows the typical medial-frontal voltage scalp distribution. The results are in line with a motivational valence effect related to the processing of the goal obstructiveness (or non-reward) information of feedback. The source localization analysis revealed a marginal significant source of the goal conduciveness effect in the right insula. Although, the anterior or posterior cingulate gyrus are more frequently discussed as neural source of the FN, some studies have found that the insula was also involved in the non-reward processing of feedback (Donamayor, Marco-Pallares, Heldmann, Schoenfeld, & Munte, 2011; Kobza & Bellebaum, 2015; Tucker, Luu, Frishkoff, Quiring, & Poulsen, 2003). Based on the findings of fMRI studies and a meta-analysis (Nieuwenhuys, 2012; Phan, Wager, Taylor, & Liberzon, 2002; Reiman et al., 1997), the insula has been associated with many different functions. For example, it is involved in cognitively demanding emotional tasks and in the evaluation, experience,

or expression of internally generated emotions, especially in the integration of the emotional interoceptive responses. The insula projects to the ACC and both structures are part of a network that is implicated in processing the non-reward information of stimuli (Liu, Hairston, Schrier, & Fan, 2011; Nieuwenhuys, 2012).

In the subsequent time interval (350–600 ms after feedback-stimulus onset), goal conduciveness effects were found, as predicted, in the form of more positive P300 amplitudes following wins than following losses. This effect was maximal over parietal electrode sites and it is in line with a motivational valence effect of previous gambling task studies (e.g., Hajcak et al., 2005; Hajcak et al., 2007; Pfabigan et al., 2011; Sato et al., 2005). Nevertheless, this effect contrasts with results of gambling task studies that could not find motivational valence effects on P300 amplitudes (Experiment 1, Hajcak et al., 2005; Yeung & Sanfey, 2004). The source localization pointed to the posterior cingulate gyrus as probable source of the P300 deflections of the goal conduciveness appraisal effects which replicates the finding of a previous study on feedback processing (West, Bailey, Anderson, & Kieffaber, 2014). The source is also consistent with the locus-coeruleus-P3 (LC-P3) theory that conceptualizes a network concerned with the processing of the motivational significance of events (Nieuwenhuis, 2011). In this theory, the posterior cingulate cortex is thought to be an important structure.

The differential pattern and the probable neural sources of the goal conduciveness effects in the time interval of the FN and P300 might suggest that first the *goal obstructiveness* of an event (i.e., whether it has negative implications) is processed and second, with a brief delay, its *goal conduciveness* (i.e., whether it has positive implications). The localization results point to two different neural sources of goal conduciveness appraisal depending on the

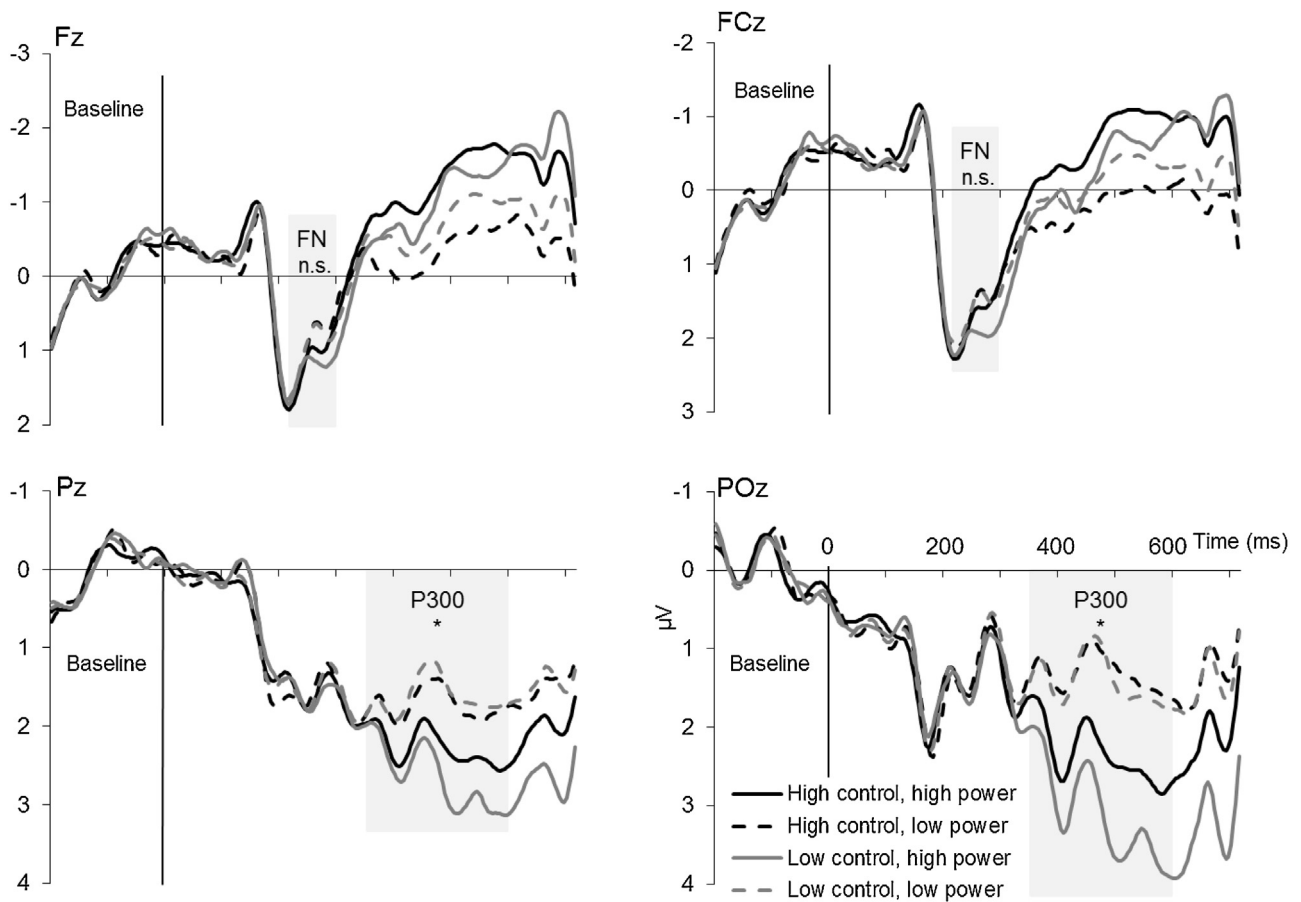


Fig. 7. Grand averaged feedback-locked ERPs showing the interaction of control and power at channels FCz, Fz, Pz, and POz. Baseline is presented (–200 ms). Feedback onset is at 0 ms (vertical black line). n.s. not significant, * $p < .05$.

time interval and ERP component. This finding is interesting and deserves further empirical investigation. It needs to be clarified whether the goal conduciveness effects on both ERP components reflect recursive processing of the same appraisal criterion (i.e., initial processing of goal obstructiveness results in FN deflections and then recursive processing of goal conduciveness leads to P300 deflections), or whether two appraisal criteria operate in separate neural circuits which affect differentially FN and P300 amplitudes. Therefore, future studies should investigate whether goal conduciveness appraisal can be related to specific neural sources or networks depending on the time interval, independent of the task.

8.2. Control effects

Consistent with our prediction, P300 amplitudes but not FN amplitudes were sensitive to control appraisal. P300 amplitudes were more positive in low control than in high control blocks. Potentially, it indicates that more mental resources were implicated in low than in high control blocks. This finding is difficult to interpret and more research is needed to explain and replicate this effect. It might reflect an active coping response in the form of more mental resource allocation when low control is perceived although habitually the increase of mental resource would occur in the context of high control (cf. D. D. P. Johnson & Fowler, 2011).

Furthermore, a possible reason for not having found control main effects on FN amplitudes might be related to the nature of appraisal operationalization in the gambling task. Control appraisal was manipulated across trials. Participants evaluated the degree of control based on a series of events (i.e., action–outcome contingencies). In contrast, goal conduciveness and power appraisals were

manipulated (via geometric shapes) in each trial. Therefore, FN amplitude deflections might be different depending on the nature of assessment (i.e., appraisal of distinct event vs. of experienced action–outcome contingencies). Different types of appraisal assessments could explain the differential effects of control appraisal relative to goal conduciveness and power appraisals. A future study that further investigates the processing of control appraisal should consider an operationalization similar to that of the other appraisal criteria in the task.

The pattern of the control by power interaction effect does not entirely correspond to our prediction. In particular, the finding that power appraisal effects were amplified in low control blocks compared to high control blocks goes against our prediction. Moreover, high power appraisal had increased positive P300 amplitudes in low control blocks compared to high control blocks, whereas low power appraisal effects were similar in high and low control blocks. This finding suggests that there may have been greater investment of mental resources in the case of high power as compared to low power appraisal, and that high power appraisal effects were boosted when perceived control was low. Participants seem to have been more engaged when they had high power in the context of low control, possibly reflecting active coping.

The potential neural source of the P300 amplitudes related to control appraisal (low vs. high control) were estimated to be located in limbic (middle and right cingulate gyrus, left and right parahippocampal gyrus, middle and right posterior cingulate gyrus), occipital (left and right lingual gyrus, right middle occipital gyrus, and right cuneus), occipito-temporal (left and right fusiform gyrus), and parietal structures (i.e. left precuneus and left superior parietal lobule). Limbic structures, especially the parahippocampal

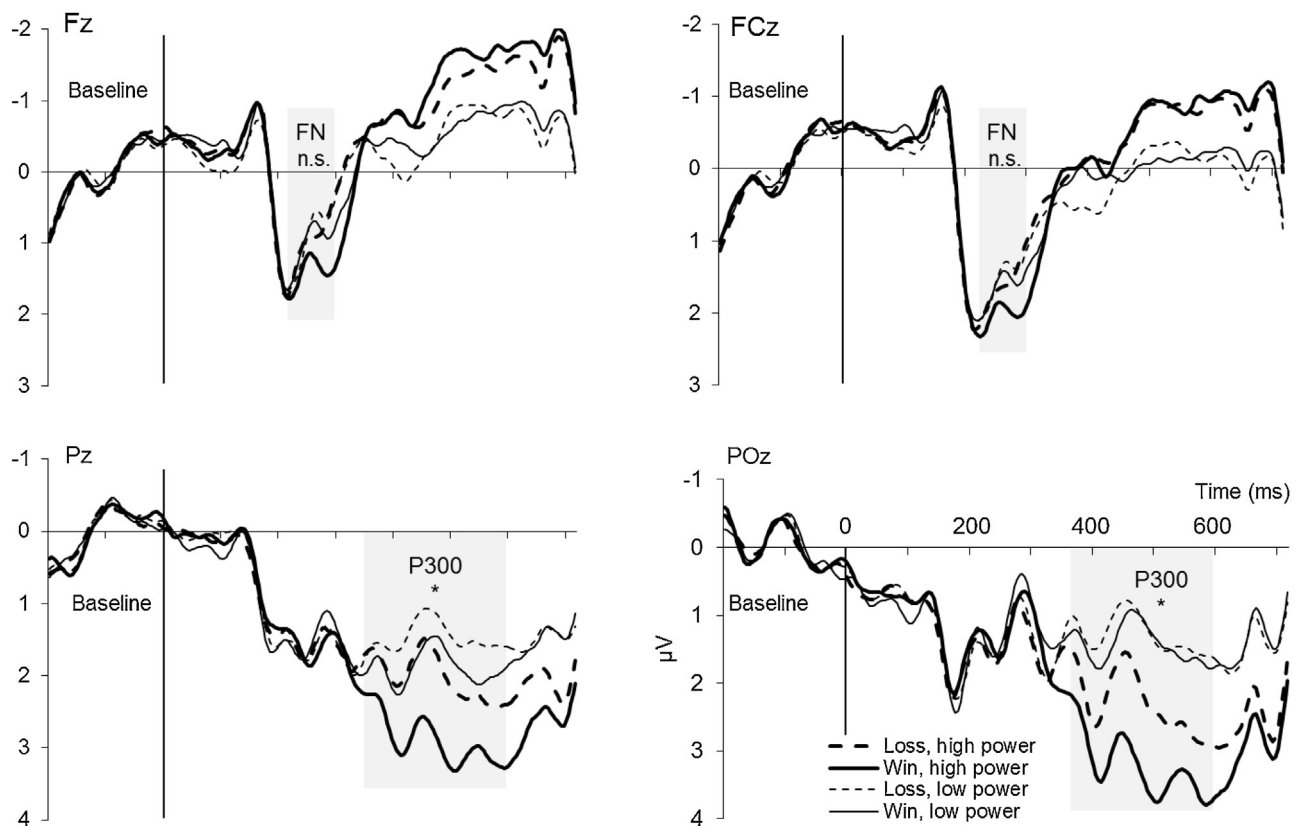


Fig. 8. Grand averaged feedback-locked ERPs showing the interaction of goal conduciveness and power at channels FCz, Fz, Pz, and POz. Baseline is presented (–200 ms). Feedback onset is at 0 ms (vertical black line). n.s. not significant, * $p < .05$.

gyrus, have been associated with encoding and retrieving of contextual information (Diana, Yonelinas, & Ranganath, 2007; Volpe, Mucci, Bucci, Merlotti, Galderisi, & Maj, 2007). The fusiform gyrus is a well-known key structure for visual object identification (face or words), and its left part is related to the variability of P300 amplitudes (e.g., Campanella et al., 2013; Kanwisher, McDermott, & Chun, 1997). The occipital structures have been linked to visual memory, visual processing, and the recollection of visual stimuli (Fink et al., 1996; Henson, Rugg, Shallice, Josephs, & Dolan, 1999; Mechelli, Humphreys, Mayall, Olson, & Price, 2000). The present findings are in line with previous research on the cortical generators of the P300 (cf. Volpe et al., 2007), and appear consistent with the manipulation of perceived control in the present task. Here, control was assessed through the discrimination, retrieval, and memorization of the contextual information within a series of trials in a block. Therefore, the findings suggest that attentive, stimulus categorization, and integrative processes were involved in the assessment of high and low control conditions. Future studies need to investigate to what extent our finding is modality specific and which stimulus information is used to assess control.

8.3. Power effects

On FN amplitudes, a main effect of power was unexpectedly found with a more negative deflection in low power than in high power trials. This effect had a fronto-central scalp distribution. Since having low power was potentially goal obstructive in the gambling task, the early effect could reflect a valenced evaluation of goal incompatibility. As suggested by Gu et al. (2011), the FN might respond to the contextually most salient or relevant information. Since having free choice or no choice was task relevant, it appears plausible that at an early processing stage this information has been

evaluated. It is possible that the added control appraisal manipulation made the information about available choice options (power appraisal) more salient. In our previous study, control appraisal was not manipulated and FN amplitudes were solely sensitive to effects of goal conduciveness appraisal (Gentsch et al., 2013). The source localization analysis (low vs. high power) could not identify a significant potential neural source.

The power appraisal effect on P300 amplitudes replicated the finding of our previous study. High power appraisal was related to more positive deflections than low power appraisal, which fits well with the notion of more task engagement and more mental resource allocation in high than in low power trials. The scalp topography of the difference waves also revealed a parieto-occipital distribution. Likewise, the source localization did not identify a particular neural substrate.

8.4. Goal conduciveness by power interaction effect

Interaction effects of appraisals were solely observed on P300 amplitudes. This result is in agreement with the CPM (e.g., Scherer, 2009). The model holds that the processing of each consecutive appraisal cumulatively modifies the effects of preceding appraisal results through a recursive integrative appraisal process. Those cumulative effects should occur in later processing stages once preceding appraisal processes have reached preliminary closure. The interaction of goal conduciveness and power appraisal is in line with the assumption of cumulative effects. On P300 amplitudes (later component), wins and losses were no longer differentiated when power was low in contrast to when power was high. This finding may suggest that feedback valence became either less relevant when participants had no choice or that having a no choice option induced a negative affective state (disappointment, anger, or frus-

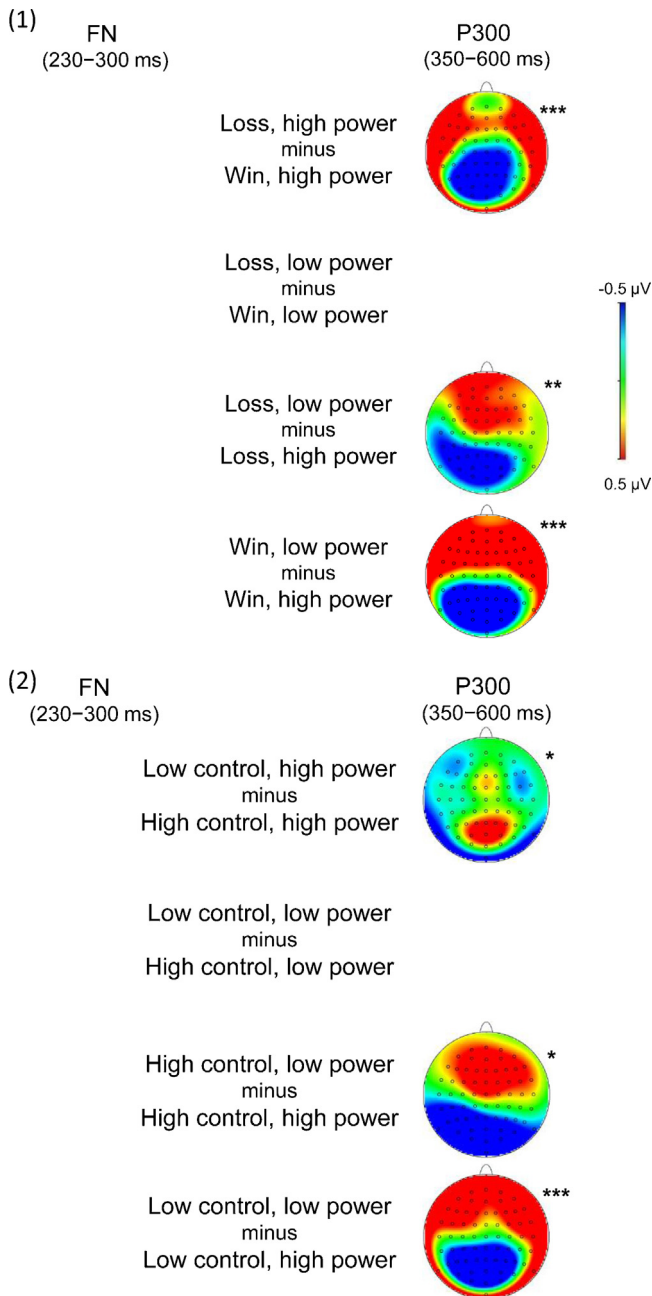


Fig. 9. Scalp topographies of the difference waves of the averaged ERPs for the FN and the P300. Significant mean voltage differences are shown for the two interaction effects of (1) Control $\times$ Power, and of (2) Goal conduciveness $\times$ Power. The timing is relative to the onset of the feedback stimuli. * $p < .05$, ** $p < .01$, *** $p < .001$.

tration) which diminished the differentiation between wins and losses. Furthermore, when participants had free choice to decide about the outcome, differentiating between wins and losses was important to produce a correct decision about the final outcome (i.e., accepting wins and rejecting losses) at the end of the trial. The interaction effect fits well with the RT pattern. Future studies need to specify which mechanism had driven the effect of diminished valence processing, whether it was a task-related relevance effect or whether an affective process induced by the appraisal of low power was activated.

To summarize, appraisal processes related to goal conduciveness, control, and power appraisals were clearly related with distinct mean amplitude deflections and topographical maps, as well as specific neural sources in two time intervals. The simul-

taneous main effects of goal conduciveness and power appraisals on FN amplitudes, and of goal conduciveness, control, and power appraisals on P300 amplitudes indicate sequential and parallel processing deriving from distinct neural sources. The findings on P300 amplitudes are in line with the notion of multiple P300 amplitudes (the triarchic model of P3 amplitudes, Johnson, 1986, 1993). The model holds that activity from different neural generators results in multiple P3s, each related to the processing of a different type of information. Our findings indicate that one process was probably involved in the processing of whether the feedback was goal conducive, since wins elicited more positive P3 amplitudes than losses. Another process seems to have been implicated in the assessment of the degree of power. High power appraisal elicited more positive P3 amplitudes than low power appraisal. Other processes were involved in the assessment of control and in information integration evident in the interaction effects.

8.5. Limitations

Operationalizing only a part of the appraisal sequence and not the entire sequence limits the generalizability of the present findings. Temporal dynamics of all processed appraisal criteria, in particular, cumulative effects of (subsequent) appraisal criteria, might look different depending on the number of processed appraisals and the context-dependent saliency of multi-information of events. Moreover, ERP measures face the problem that one can never be certain that a specific component has been identified without cumulative effects on the electrical modulation.

Furthermore, component overlap is possible and it is difficult to solve this problem. A temporal principal component analysis of the present data extracted temporal factors, which closely match with the time interval of the FN and the P300. Nonetheless, the mean amplitude effects in these two time intervals showed robust effects, indicating that the overall magnitude of the brain responses could be related to the appraisal manipulation.

Source localization analysis faces the inverse solution problem and in sLORETA source localization is limited to the cortical gray matter and both hippocampi. The inverse solution problem can only be solved by conducting brain imaging or invasive intracranial studies during systematic appraisal manipulation. Future studies should investigate emotion-antecedent appraisal processes using such techniques or ideally apply simultaneous recordings of electrical and hemodynamic brain responses.

Linking appraisal theory to cognitive processes measured with EEG-ERP is at its beginning. To solve some of the present limitations, future experimental efforts should focus on the specification of ERP signatures for each appraisal criterion, as well as ERP signatures of integrated (cumulated) effects. This would lead to comprehensive knowledge about the onset and time course of different emotion-antecedent appraisal processes.

A confounding overall effect of differential reward expectancy in high and low control blocks can be considered small in the present study. Wins and losses occurred equally often in high and low control blocks. However, the final monetary gain in high control blocks was indeed almost three times bigger than in low control blocks because of the varying number of free and no choice options at the end of a trial in high and low control blocks. It is difficult to say whether different reward expectancies have significantly influenced the results. Participants did not report to have had a particular reward expectation for each block when we asked them in the end of the experiment. Moreover, in order to equalize participants' expectancies for each experimental block, they were told about the upcoming degree of control and at the same time reminded to find all wins prior to each block. Thus, with respect to the task design, reward expectancy was not made explicitly salient. Furthermore, participants were not instructed to find a strategy

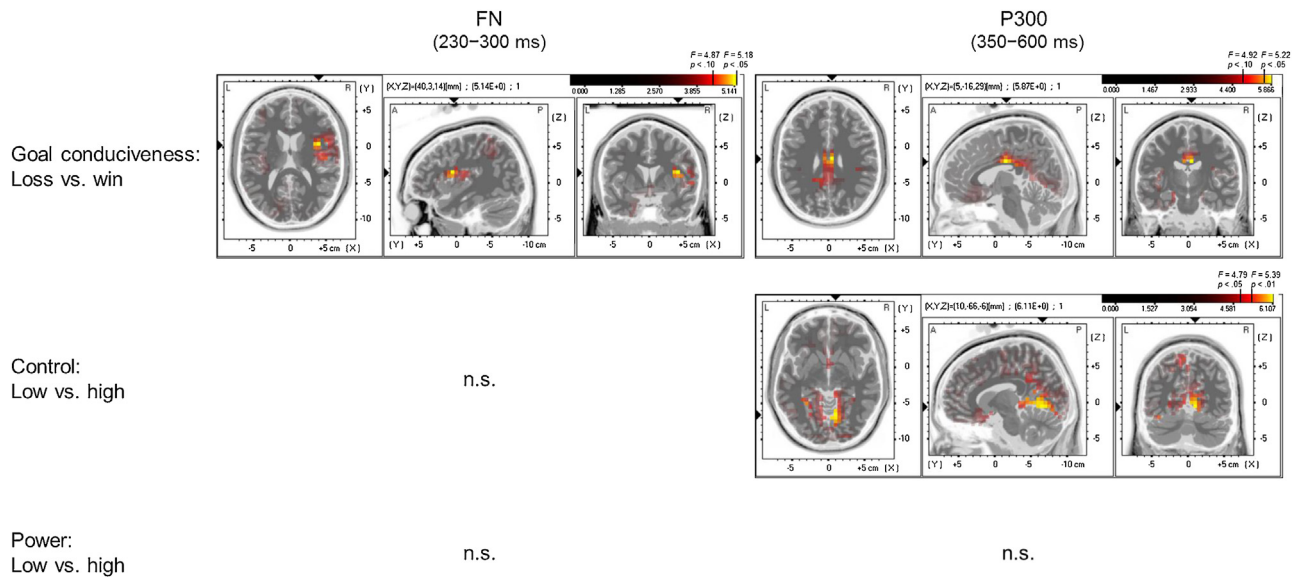


Fig. 10. Source estimation of the effects of each appraisal criteria in the time intervals of FN and P300. Only significant effects are shown. n.s. not significant.

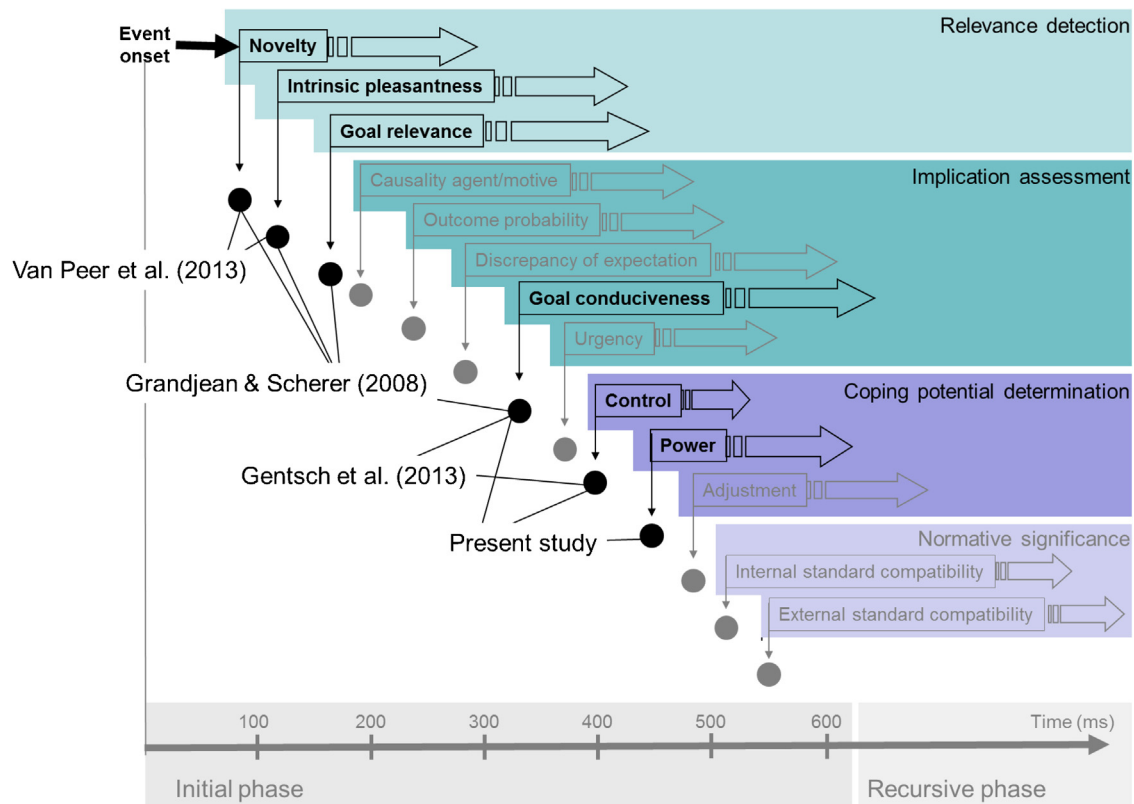


Fig. 11. Appraisal check sequence as predicted by the Component Process Model. The appraisal checks are grouped into four major assessments of an event as indicated by the different background colors: relevance detection, implication assessment, coping potential determination, and normative significance. The appraisal checks that were investigated in EEG–ERP recordings are highlighted in black ink and the respective studies are indicated (next to the circles). The appraisal checks in gray ink have not been studied yet in EEG–ERP recordings. The vertical arrows are pointing to circles, which represent the hypothesized sequential effects of preliminary closure of each appraisal outcome on the response systems (e.g., autonomic nervous system or facial muscle regions). The horizontal arrows symbolize the continued recursive processing of the appraisal checks after they have reached preliminary closure during the initial phase. At the bottom of the figure, the relative timing of appraisal processing (aligned with event onset) is presented. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

that would help them maximize the monetary bonus. When asked participants at the end of the experiment, none of reported to have had a strategy in mind when playing the gambling task.

8.6. Conclusions

The present experiment is, to our knowledge, the first to investigate the sequence hypothesis of the CPM for control appraisal.

Using multi-information feedback stimuli, we manipulated the appraisal criteria of goal conduciveness, control, and power simultaneously. The ERP findings suggest sequential and potentially also parallel effects of these appraisal criteria. Challenging the sequence hypothesis are the simultaneous main effects of goal conduciveness and power appraisal on FN amplitudes. This finding can be resolved by the possibility that early appraisal processes (~230–300 ms) evaluate (trial-wise) multi-information stimuli in terms of goal incompatibility and subsequently (~350–600 ms), appraisal criteria process and integrate the multi-information of stimuli (trial- and block-wise) individually in order to assess the overall implication of the event (cf. [Gu et al., 2011](#)).

In the present task, control was low (or high) but not impossible. The findings add to the theoretical claim ([Scherer, 2009](#)) that power appraisal is assessed only under the condition that control is possible. Low control appraisal, in contrast to high control appraisal, had an impact on high power appraisal. When low control was appraised, more cognitive resources were involved in the presence of high power appraisal in comparison to low power appraisal. This effect could reflect an adaptive mechanism. People may become more engaged when they have appraised that they can act in a particular moment despite a context of low control. It seems that different degrees of control appraisal (e.g., no, low, and high) have curvilinear effects on power appraisal. It is important to investigate this assumption further and to examine whether the results can be replicated in different task designs. If this is the case, the conceptual link in the CPM of the impact of control appraisal on the processing of power appraisal needs to be eventually reconsidered based on accumulated empirical evidence.

Compatible with earlier ERP-EEG studies on the temporal organization of appraisal criteria, the findings confirm the utility of the CPM as a framework to link the conceptualization of emotion-antecedent appraisal to cognitive processes, as investigated in cognitive neuroscience. The use of experimental designs and assessment methods that have been established in cognitive neuroscience provides promising means for future studies on appraisal processes. These studies are necessary to advance emotion research and to clarify diverging theoretical conceptualizations about the mechanisms that elicit and differentiate emotion episodes. The present ERP study contributes to existing knowledge about the organization of appraisal processes. They seem to be sequentially organized. Early appraisal processes concern the assessment of goal incompatibility which may essentially depend on the context that influences the salience of event characteristics, whereas later appraisal stages seem to be influenced by the effects of earlier appraisals (i.e., interaction effects), and then relate to more integrative and more complex evaluation processes.

In conclusion, the present results add a significant contribution to a converging pattern of results which has emerged from the EEG-ERP studies of the last few years ([Gentsch et al., 2013](#); [Grandjean & Scherer, 2008](#); [van Peer et al., 2014](#)). This pattern is comprehensively documented in [Fig. 11](#). It is hoped that this accumulated evidence now makes it possible to pursue work on the processes underlying the elicitation and differentiation of emotion in a hypothesis-guided fashion.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.biopsycho.2015.10.001>.

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