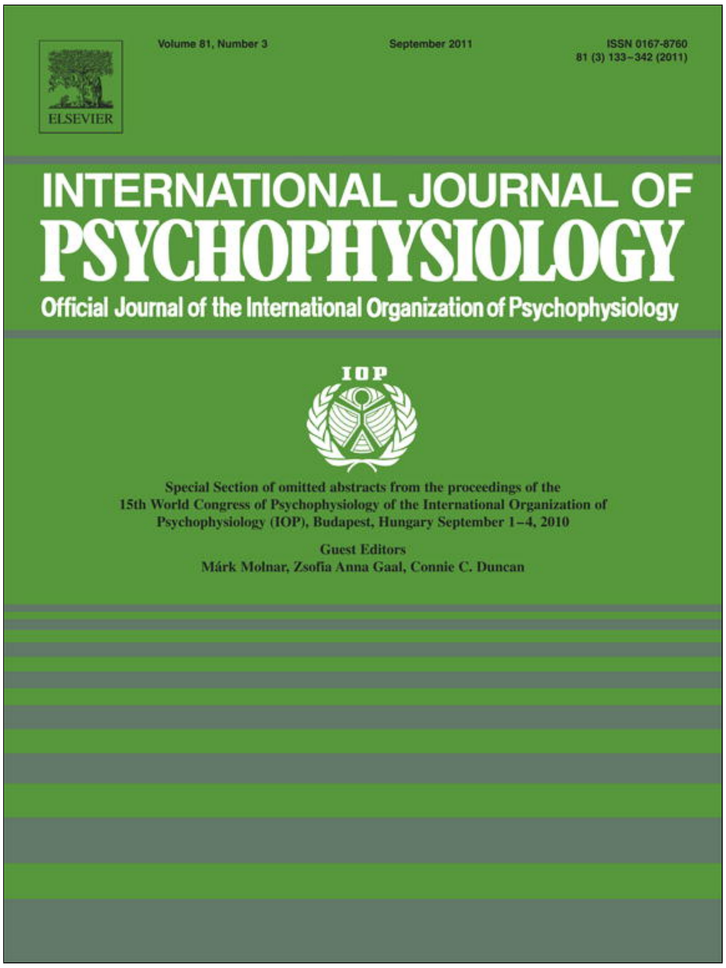
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Effects of performance feedback on cardiovascular reactivity and frontal EEG asymmetry

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ABSTRACT

The process of goal-setting may be captured by psychophysiological variables, such as cardiovascular reactivity (representative of effort mobilisation) and frontal EEG asymmetry (motivational disposition). The current study exposed 32 participants to false performance feedback in order to manipulate goal-setting and mental effort investment. Participants performed five consecutive blocks of the n-back task and received false performance feedback. One group received repeated positive feedback (i.e. performance steadily improved over the five blocks) whilst a second group were exposed to repeated negative feedback (i.e. performance deterioration over five blocks). Blood pressure, power in the mid-frequency and high-frequency component of Heart Rate Variability (HRV), heart rate, frontal EEG asymmetry and subjective self-assessment data were collected. Sustained and repeated positive feedback led to increased systolic blood pressure reactivity and a suppression of the 0.1 Hz component of HRV. Increased relative left hemisphere activation was observed at F3/F4 and FC1/FC2 over successive task blocks in the presence of feedback regardless of positive or negative direction. It is argued that upward goal adjustment accounted for the psychophysiological changes observed in the positive feedback condition.

1. Introduction

The regulation of goals is a regular cycle of psychological activity for most people. When faced with the prospect of failure, we must decide to strengthen our resolve or disengage from the task, effectively abandoning the active goal. When our efforts meet with success, another kind of decision must be made—to relax and rest on our laurels or aspire to even higher levels of achievement. This agentic perspective emphasises the roles of volition and individual agency (Karoly et al., 2005) during the process of goal regulation.

If the investment of mental effort is described as energy mobilisation in the service of cognitive goals (Fairclough and Houston, 2004; Hockey, 1997; Kahneman, 1973; Mulder, 1986; Veltman and Gaillard, 1997), then it is logical that the process of goal regulation is manifested by mental effort investment at a psychophysiological level (Locke and Latham, 1990). Studies of cardiovascular reactivity have characterised effort investment in terms of active coping (Bongard, 1995; Gendolla and Krusken, 2001a; Obrist, 1981), challenge (Blascovich and Tomaka, 1996) and task engagement (Fairclough and Venables, 2006). In terms of physiological pathways, mental effort investment has been associated with beta-adrenergic influences on cardiovascular reactivity (e.g. systolic blood pressure, preejection period) (Richter and Gendolla, 2006, 2009). A related strand of research has quantified mental effort investment as suppression of the mid-frequency component of heart rate variability (HRV) (Capa et al., 2008; Fairclough and Venables, 2006; Mulder, 1986; Mulder et al., 1992).

The relationship between goal-setting and effort investment may be described in terms of self-regulation based on discrepancy reduction and enlargement. When a person wishes to achieve a goal, a negative feedback loop may be activated wherein the individual wishes to reduce any discrepancy between performance and a desired goal standard; alternatively the individual may seek to avoid failure by increasing the discrepancy between themselves and an undesirable state of inadequate performance (Carver and Scheier, 2000). Therefore, the person who desires to 'do well' on a task would compensate for increased task difficulty by investing mental effort in order to achieve the goal. This strategy is both discrepancy-reducing in the sense that increased effort should keep the individual on course to attain the goal; it is also a strategy for discrepancy enlargement as the person invests effort in order to avoid undesirable consequences such as performance failure. However, the capability of the individual to compensate for increased task difficulty is finite and this limitation is clearly articulated in the motivational intensity theory (MIT) (Brehm and Self, 1989; Wright, 2008; Wright and Kirby, 2001). MIT emphasises a compensatory dynamic where effort is increased in response to rising levels of perceived difficulty. However, this relationship is nonmonotonic and includes a 'tipping point' where effort may be abruptly withdrawn due to an appraisal of impossible

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task demand, a perception of insufficient ability or a judgment that the benefits of goal attainment do not justify the required investment of effort (Brehm and Self, 1989; Wright and Kirby, 2001). Finally, changes in goal regulation that are initiated by the individual may influence effort investment directly; in this example the interaction between goal regulation and effort investment reflects a proactive dynamic where goals are adjusted upwards by an individual in order to aspire towards a higher level of performance (Carver and Scheier, 1998; Locke and Latham, 1990), resulting in a higher level of mental effort investment.

The exploration of a compensatory dynamic between goals and effort investment has been explored in the psychophysiological literature via cardiovascular reactivity. Both systolic blood pressure and pre-ejection period have been used to operationalise mental effort in response to a range of independent variables, e.g. ability appraisal (Wright and Dill, 1993; Wright and Dismukes, 1995), self-esteem (Gendolla, 1999), mood (Gendolla and Krusken, 2001b), and incentives (Richter and Gendolla, 2006, 2009). The strategic decision to invest or withdraw mental effort has a parallel with the motivational disposition to approach or avoid (see Elliot (2008) for recent collection); in this context, effort withdrawal may correspond with a decline in approach motivation (down-regulation of goal) or an active strategy of avoidance/effort withdrawal (abandonment of goal). Asymmetrical EEG activation in the frontal cortex has been used to capture motivation disposition; greater left activity being representative of enhanced approach motivation whereas avoidance or withdrawal is linked to greater activity from the right frontal area (Davidson, 1995, 2004; Harmon-Jones and Allen, 1998). Evidence to support the motivational model of frontal EEG asymmetry has been generated from several studies where incentives for performance were manipulated. For instance, Sobotka et al. (1992) reported greater left activation at midfrontal sites in response to reward (i.e. opportunity to win money) as opposed to punishment (i.e. opportunity to lose money). This effect was replicated by Miller and Tomarken (2001) and Pizzagalli et al. (2005); the latter used a source localization analysis of EEG data to associate the left dorsolateral prefrontal area with a bias towards reward-related cues. This link between motivational disposition and mental effort is purely intuitive as no previous studies (to our knowledge) linked motivational disposition to mental effort investment, or investigated both frontal EEG asymmetry and cardiovascular reactivity within a goal-setting context.

The purpose of the current study was to explore how the perception of success and failure influenced motivational disposition (frontal EEG asymmetry) and effort investment (cardiovascular reactivity). It was decided to manipulate the perception of success or failure by exposing participants to false feedback of performance quality. Performance feedback exerts a profound effect on goal-setting and mental effort investment (Kluger and DeNisi, 1996). Previous studies have used false performance feedback to investigate the connection between self-efficacy, i.e. expectations of successful task outcome (Bandura, 1997) and cardiovascular reactivity (Wright and Dill, 1993; Wright and Dismukes, 1995). Whilst Wright and colleagues used feedback to alter self-efficacy prior to task exposure, Bandura and Jourden (1991) exposed their participants to bogus performance feedback on repeated occasions within the same task to study the progressive influence of success and failure on performance and self-efficacy. This dynamic adjustment of goals in response to repeated episodes of performance feedback has also been demonstrated by Ilies and Judge (2005) and Donovan and Williams (2003), both of whom reported evidence of upward goal adjustment in response to positive feedback and downward goal revision following negative feedback.

An initial attempt to combine the repeated bogus feedback methodology of Bandura and Jourden (1991) with psychophysiological measures was reported by Venables and Fairclough (2009). This study found some evidence of changes in autonomic activation, i.e. greater activation of both sympathetic and parasympathetic responses in response to negative performance feedback in conjunction with increased negative effect, but it was difficult to interpret findings with a sufficient degree of confidence. This was mostly due to limitations in the experimental design as the study did not include a control (no feedback) condition, hence patterns of psychophysiological reactivity evoked by positive and negative feedback could only be assessed in relation to one another. In addition, the number of sites used for EEG asymmetry analysis was inadequate in terms of coverage and a linked-ears montage was not achieved, which is essential for this type of data collection (Allen et al., 2004).

The aim of the current study is to investigate how repeated exposure to bogus positive and negative performance feedback influences psychophysiological variables related to mental effort investment (blood pressure, heart rate, HRV) and motivational disposition (frontal EEG asymmetry). We hypothesised that initial exposure to negative feedback would increase effort investment (e.g. greater systolic reactivity, greater suppression of 0.1 Hz component of HRV, greater heart rate) and approach motivation (i.e. increased left hemisphere activation at F3/F4) in order to facilitate subsequent recovery. However, consistent and repeated exposure to negative feedback would reduce both effort investment and approach motivation in combination with increased negative affect—as participants feel there is no possibility of reversing the decline of performance. In the case of positive feedback, we anticipated little effect on psychophysiology during initial exposure. However, consistent positive feedback was hypothesised to produce an upward adjustment of task goal with subsequent increase of mental effort investment and approach motivation as well as a decline of negative effect.

2. Method

2.1. Participants

34 participants (17 males and 17 females) were recruited and all received financial remuneration for taking part. All participants were healthy, right-handed and free from permanent medication other than the contraceptive pill. Participants were divided into two groups: (a) a positive feedback group who received false performance feedback indicative of gradual improvement over time, and (b) a negative feedback group who were presented with false feedback of a progressive decline in performance. Data from two participants were omitted from the analysis as both reported serious doubts about the integrity of performance feedback during the debriefing session. Therefore, the positive feedback group contained sixteen participants (age range 18–29, M = 22.8 yrs., S.D. = 3.6) and a negative group of sixteen participants (age range 19–32, M = 23.5 yrs., S.D. = 4.5); both groups contained an equal number of males and females.

2.2. Spatial working memory task

A spatial memory task was created using E-Prime software (Psychology Software Tools Inc.). This task was developed from the 'n-back task' described by Gevins and Smith (2003), specifically the two-back version of the task. During the task, participants were presented with a 3 × 3 grid on the screen. On each trial, a green square appeared at one of the nine grid locations for 1.75 s. Participants were required to respond to each appearance of the green square by pressing one of two keyboard buttons to indicate that the location of the current square was either in the same location as the square seen two trials previously (a match) or in a different location (a mismatch). The task was divided into five blocks, each of which contained 90 trials and lasted approx. 2.5 min. Matches occurred on approx. 35% of trials.

2.3. Performance feedback

In the experimental condition, participants were provided with artificial performance feedback as a percentage of accuracy achieved during each task block (there were five task blocks in total). Performance feedback was presented via a second computer placed adjacent to the computer running the spatial working memory task (i.e. feedback was presented after performance of each task block, hence participants did not have to attend to both screens simultaneously). Participants were misled to believe that performance data was calculated in real-time on this second computer following each block of task activity. This illusion was achieved via a macro written using Microsoft Excel. The macro simulated a process of calculation and analysis and produced a bar chart to display performance accuracy. Each bar chart also included performance levels from previous block/s which provided a visual representation of gradual decline or improvement.

Both groups received performance feedback of 60% accuracy after the first task block and were exposed to a cumulative decline or increase of 11% in total from block two to block five. For the negative feedback group, performance accuracy scores fell from 60% to 56% (block two), 53% (block three), 52% (block four) and finally reached 49% after the fifth and final block. The positive feedback group received performance accuracy scores that mirrored these intervals albeit in the opposite direction over the five task blocks, e.g. from 60% to 71% accuracy. The irregular intervals of performance accuracy change between task blocks were selected to improve the credibility of the feedback.

2.4. Experimental design

The study was designed as a mixed design containing both within- and between-participants factors. Participants were divided into two independent groups (positive and negative feedback). Each group performed five blocks of task activity under two conditions, with and without performance feedback, thus yielding two within-participant factors (task block, condition). However, data from only three of the five blocks were selected for analysis; these were block_2 (following presentation of 60% accuracy feedback for all participants), block_3 (following initial exposure to positive or negative performance feedback) and block_5 (following three exposures to positive or negative feedback). The order of presentation for experimental condition was counterbalanced across all participants. In order to reduce transfer effects (particularly for those participants who received feedback as the first condition), each task session was separated by a period of at least nine days. The experimental protocol was approved by the University Ethics Committee prior to commencement of the study.

2.5. Dependent variables

2.5.1. Self-reported states

A selection of scales from the Dundee State Stress Questionnaire (DSSQ) (Matthews et al., 2002) was administered prior to the task and following each task block in both experimental conditions. Changes in mood were assessed via a mood adjective checklist (Matthews et al., 1990) which delivered three scores: energetical arousal (EA: alert vs. tired), tense arousal (TA: tense vs. relaxed) and hedonic tone (HT: happy vs. sad). Motivation was assessed via an eight-item scale from the DSSQ.

2.5.2. Cardiovascular activity

Heart rate activity was measured using a standard Lead I configuration with electrodes positioned on the right and left side of the body using a MP150 data collection system (BIOPAC Inc.). A common ground electrode was placed on the hip on the right side of the body. The ECG was sampled at 1000 Hz. R peaks of the ECG were detected offline, and both beats per min (bpm) and interbeat interval (IBI) between successive R waves were calculated using AcKnowledge software (BIOPAC Inc.). The IBI data for each task block were subsequently subjected to Fast Fourier Transform (FFT) analysis utilising the dedicated Heart Rate Variability analysis module available in AcqKnowledge 3.9 (BIOPAC Systems), this software included testing the IBI data for artefacts, which were dealt with via interpolation. The FFT yielded total power values for the mid-frequency 0.09–0.13 Hz bandwidth (the 0.1 Hz component, also referred to as sinus arrhythmia), which was subjected to a natural log transformation prior to analysis.

2.5.3. Blood pressure

Blood pressure was recorded using a Dinamap V100 system with the pressure cuff placed over the brachial region of the participant's left arm. Initial screening (for hypertension) and baseline readings were taken from each participant prior to performance (the baseline period lasted for 10 min during which BP was recorded every 2 min and subsequently averaged prior to analysis). Two blood pressure readings were collected after approximately 20 s and 120 s of each task block, from which averages were calculated for both systolic and diastolic values.

2.5.4. Electroencephalogram (EEG)

EEG was collected using an ActiveTwo system (BioSemi Inc.) incorporating active electrode recordings from 32 sites [Fp1, Fp2, AF3, AF4, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T6, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, PO3, PO4, O1, Oz, O2] sampled at 512 Hz. Additional recordings were made from both earlobes and four points around the eyes for the purposes of generating a montage and correcting for eye movement. Data collection was achieved via Actiview software (BioSemi Inc.). EEG signals were amplified at source via AC differential amplifiers with continuous digitization at 16,384 Hz and online down sampling to 512 Hz. No filters were applied online to allow visual inspection of noise, offline filtering was performed using high and low pass filters of 0.05 Hz and 60 Hz respectively and a notch filter of 50 Hz. Analysis was performed using BESA software (MEGIS software GmbH, Gräfelfing, Germany). Data was visually inspected for artefacts from external electromagnetic sources. Automatic correction of blink artefacts and horizontal and vertical saccades was performed using detection through predefined topographies. Muscle activity over 100 μV was also excluded. Fast Fourier transforms were computed over 50% overlapped windows of 2 s (1024points). Average power spectra were then computed for each experimental condition by averaging mean FFT results of both blocks for each level. Power spectra in μV^2 were log transformed (using the natural log) to normalise distribution. Mean power in the alpha (8–12 Hz) bandwidth was calculated via Fast Fourier Transform analysis using a 2048 data points in each step (i.e. 2 s) with a Hanning window.

2.6. Procedure

Upon arrival at the laboratory, participants signed a consent form and resting blood pressure was taken in order to screen for participants with hypertension. The participants were subsequently fitted with electrodes for monitoring EEG, ECG and fEMG. The participants completed a training session on the task. The training included full instructions and a visual example of the task. The training session lasted for approximately 30 min, which was felt to be a sufficient to stabilise performance (based on pilot testing). Participants were provided with an opportunity to ask questions prior to commencing the practise session. During the training and the test sessions, the participant was alone in the experimental booth and the experimenter was located in an adjacent room. Psychophysiological data was recorded during the practise session so that participants would be familiar with the experience of wearing the equipment as well as the actual memory task. Following training, participants were allowed to rest for 10 min and were asked to complete a pre-test version of the DSSQ that referred to their feelings about the forthcoming task.

Five task blocks were presented following completion of the pre-test DSSQ. After each block, participants had 8 min to take a break from the task in order to reduce fatigue and complete a computerised copy of the DSSQ. Most participants were able to complete the DSSQ within the first 3–4 min of the break period prior to the presentation of performance feedback. In total, the five experimental task blocks, including breaks lasted up to 50 min. Participants were however lead to believe there would be six task blocks via onscreen instructions in order to prevent end spurts. After the fifth block, the experimenter commented that the data collected so far was sufficient and ended the experiment.

In the feedback condition, the following statement was included in the task instructions prior to the session: "Pilot tests have shown that performance tends to gradually improve over the course of the task providing that you stay focused. However, it is rare for people to score above 65% even by the 5th block. Similarly, most people do not score below 55% by the 5th block. This should give you an idea of what to aim for." This statement was intended to provide a context for the feedback scores received by both groups of participants. Following completion of each task block, the experimenter entered the room to initiate presentation of performance feedback score. The experimenter also made a point of recording this false information on a score sheet to increase credibility. The control condition followed the same procedure with the exception that participants did not receive any feedback between the task blocks.

At the end of the second session, participants completed a 10 item Likert scale that appeared to investigate their experience of taking part in the experiment. The real purpose of this questionnaire was to assess perceived credibility of the feedback scores. One question embedded within other general questions was used for this purpose. At the end of the experiment, participants were debriefed and further probed for suspicions regarding the false nature of the feedback.

2.7. Statistical analysis

Data from performance, subjective measures, and psychophysiology were collected from three task blocks (block_2, block_3, block_5). These three blocks were selected to examine: (1) the effect of feedback per se (i.e. all participants received the same performance feedback (60%) prior to block_2), (2) the effect of initial feedback (i.e. participants had one exposure to either positive (64%) or negative feedback (56%) prior to block_3) and (3) the effect of repeated and consistent feedback (i.e. participants had received three instances of positive (64–67–68%) or negative feedback (56–53–52%) prior to block_5).

Baseline data for the three blocks in each Condition (Feedback vs. No Feedback) were created by subtracting these data from a pre-test baseline period of 10 min duration where participants were asked to sit quietly, i.e. block data minus baseline data. These data were used to create 2 (Feedback Valence: positive vs. negative) × 2 (Condition: feedback vs. no feedback) × 3 (Block: 2 vs. 3 vs. 5) repeated measures ANOVA models in SPSS v.17 (SPSS Inc.). As a first step in this process, variance in the cells were checked in order to identify any outliers where the baselined score fell above or below 3 standard deviations of the cell mean.

Performance was scored as the number of correct match/no-match responses and mean reaction time in milliseconds (RT) for each task block. Four subjective self-report variables were derived from the DSSQ (energetical arousal, tense arousal, hedonic tone, motivation). Each variable was baselined by subtracting post-test values from the previous scores and the resulting change scores were analysed via 2 × 2 × 3 ANOVA models.

The level of alpha activity was quantified from seven pairs of electrode sites on the left and right hemisphere: Fp1/2, AF3/4, F3/4, F7/8, FC1/2, C1/2, P3/P4 and T7/8. All data were converted into a ratio measure of frontal asymmetry, i.e. Ln (power at right hemisphere site) minus Ln (power at left hemisphere site) (Allen et al., 2004), i.e. higher ratio = greater activation of left hemisphere site. The resulting ratio scores were baselined, i.e. higher score = greater relative activation of left hemisphere, and entered into a series of 2 × 2 × 3 ANOVA models.

Mean values for systolic and diastolic blood pressure (SBP and DBP respectively) were calculated (based on two readings captured in each task block), transformed into baselined scores and analysed via separate 2 × 2 × 3 ANOVA models. The same ANOVA model was used to analyse heart rate (beats per min), the 0.1 Hz (mid-frequency) component of HRV and the upper-frequency component of HRV.

For all ANOVA models, the degrees of freedom were adjusted using the Greenhouse–Geisser epsilon if sphericity had been violated. Post-hoc interaction effects related to the hypotheses were explored using *T* tests with p value for statistical significance adjusted via the Bonferroni method.

3. Results

3.1. Performance

Performance accuracy and the mean reaction time associated with correct responses were each analysed by 2 × 2 × 3 ANOVA (Feedback Valence × Condition × Block). Missing data led to the exclusion of three participants from the Negative Feedback group for both measures of performance. The ANOVA on performance accuracy revealed no significant differences. The analysis of mean reaction time (RT) revealed a significant main effect for Block, $F(2,26) = 6.52$, $p < .01$, $\eta^2 = 0.33$; a post-hoc test revealed that mean RT was significantly reduced during the final block of activity (M = 617 ms, s.d. = 22.18) compared to the two earlier blocks (M = 668 ms, s.d. = 24.39 and 666 ms, s.d. = 20.46). There was also a significant interaction between condition and block, $F(2,26) = 4.01$, $p = .03$, $\eta^2 = 0.24$. A series of 3 post-hoc t-tests revealed only one significant difference—that mean RT was significantly reduced during the final block during the Feedback condition (M = 571 ms, s.d. = 21.55), $t(27) = 3.1$, $p < 0.01$, compared to the Control condition (M = 663 ms, s.d. = 24.62).

3.2. Subjective measures

A number of 2 (positive, negative) × 2 (feedback, no feedback) × 3 (task block) ANOVA models were conducted on the subjective self-report data. The analysis of Energetical Arousal (EA) revealed a significant interaction between Feedback and Condition, $F(1,29) = 4.03$, $p = .05$, $\eta^2 = 0.12$ (one participant from the Negative Feedback group was excluded as an outlier). Post-hoc testing in the form of 2 post-hoc t-tests revealed that EA was higher during the Feedback (M = 1.9, s.d. = 3.40) compared to the No Feedback condition (M = −0.41, s.d. = 4.68) but this effect was only statistically significant for the Positive Feedback group, $t(15) = 3.61$, $p < .01$.

A significant interaction between Condition × Task Block was found during the analysis of Tense Arousal (TA), $F(2,29) = 4.25$, $p = .02$, $\eta^2 = 0.23$. Three post-hoc t-tests were conducted in order to locate this effect. The level of subjective tension/anxiety was higher during block_3 with Feedback condition (M = 1.5, s.d. = 3.89) compared to No Feedback (M = −0.9, s.d. = 3.87), $t(31) = 1.95$, $p = .05$.

The analysis of Hedonic Tone (HT) revealed a significant main effect for Feedback Valence, $F(1,30) = 20.07$, $p < .01$, $\eta^2 = 0.41$; participants in the Negative Feedback condition experienced a higher level of negative affect (M = −3.22, s.d. = 2.37) compared to the Positive Feedback Group (M = 2.0, s.d. = 2.12). There was also a significant interaction between Feedback Valence and Condition, $F(1,30)=13.41$, $p<.01$, $\eta^2=0.31$. A single post-hoc *t*-test revealed that HT was higher in the Feedback condition (M = 1.89, s.d. = 2.27) compared to No Feedback (M = 0.42, s.d. = 2.85) for the Positive Feedback Group only, $t(15)=3.6$, $p<.01$. There was also a significant interaction between Feedback Valence and Block, $F(2,39)=6.52$, $p<.01$, $\eta^2=0.31$, i.e. HT was higher during block_5 for the Positive Feedback group (M = 1.53, s.d. = 2.3) compared to those in the Negative Feedback group (M = −2.0, s.d. = 2.19), $t(30)=4.65$, $p<.01$.

The 2×2×3 ANOVA model was also applied to the subjective motivation scale. This analysis revealed a significant effect of Task Block, $F(2,29)=7.01$, $p<.01$, $\eta^2=0.37$; post-hoc tests (Bonferroni) revealed that motivation declined after block_5 (M = −2.19, s.d. = 1.86) compared to block_2 (M = −0.64, s.d. = 2.10).

3.3. Psychophysiological measures

Blood Pressure: A 2×2×3 ANOVA was conducted to examine differences in systolic reactivity (SBP). This analysis revealed a significant main effect for Condition, $F(1,30)=3.95$, $p=.05$, $\eta^2=0.12$; systolic reactivity was higher in the Feedback condition (M = 4.01) compared to the No Feedback condition (M = 1.52). There was also a significant interaction between Feedback × Task Block, $F(2,29)=6.91$, $p<.01$, $\eta^2=0.32$. Post-hoc tests revealed that SBP was significantly higher during Block_5 in the Feedback condition (M = 5.22) compared to the No Feedback condition (M = 1.27); $t(31)=2.34$, $p<.05$. There was also a significant 3-way interaction between all main effects, $F(2,29)=5.82$, $p<.01$, $\eta^2=0.29$. Descriptive statistics are presented in Fig. 1. Post-hoc testing (5 t-tests) revealed that SBP was significantly higher in block_5 compared to block_3 during the Feedback condition for the Positive Feedback group only, $t(15)=-4.1$, $p<.01$. We also found that SBP was significantly higher during the final task block for the Positive Feedback group in the Feedback condition compared to the No Feedback condition, $t(15)=3.39$, $p<.01$. It was also apparent that SBP was higher at block_5 for participants in the Positive Feedback group during the Feedback condition compared to those in the Negative Feedback group, $t(30)=2.40$, $p=.02$.

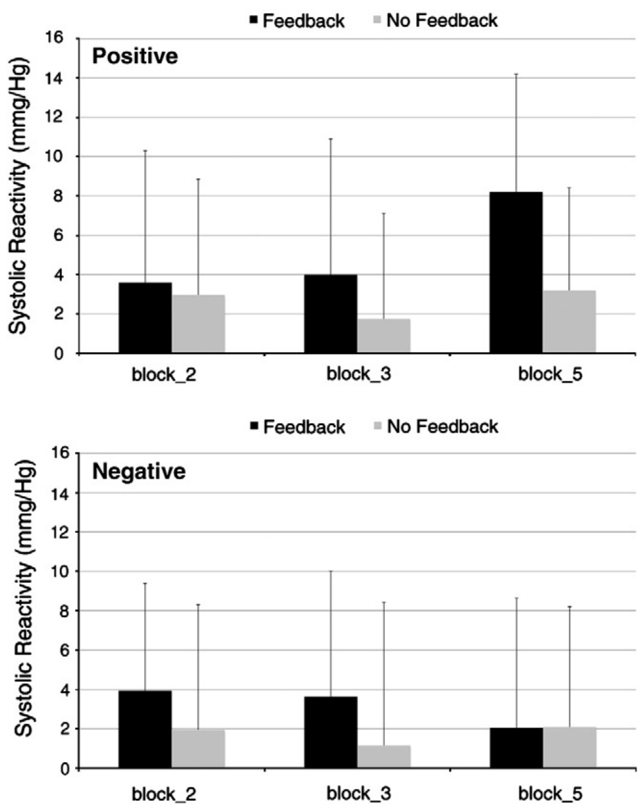


Fig. 1. Means and standard errors for systolic reactivity for both positive and negative feedback valence groups (N = 32).

The same ANOVA model was used to analyse changes in diastolic blood pressure (DBP) from baseline. There was a significant main effect for Task Block, $F(2,28)=6.05$, $p=.01$, $\eta^2=0.29$; a Bonferroni post-hoc comparison indicated that DBP was significantly higher at block_5 (M = 5.84) compared to block_2 (M = 3.42, s.d. = 4.34) and block_3 (M = 3.52, s.d. = 6.14).

Heart Rate (HR): Heart rate was captured as beats per min (bpm), baselined and subjected to analysis via ANOVA. There was a main effect for Condition, $F(1,30)=4.24$, $p=.05$, $\eta^2=0.12$, indicating that heart rate was higher (M = 0.84 bpm) in the Feedback condition compared to the No Feedback condition (M = −0.54 bpm). There was also a significant effect for Task Block, $F(2,29)=7.38$, $p<.01$, $\eta^2=0.34$; heart rate was significantly lower at block_5 (M = −1.01 bpm) compared to either block_2 (M = 1.26 bpm) or block_3 (M = 0.30 bpm). There was a significant interaction between Feedback Valence × Condition, $F(1,30)=6.41$, $p=.02$, $\eta^2=0.18$. Post-hoc analysis based upon four t-tests revealed that heart rate was significantly higher in the Feedback condition (M = 2.54 bpm) compared to the No Feedback condition (M = −0.54 bpm), but only for the Positive Feedback Group, $t(15)=3.22$, $p<.01$ (Table 1).

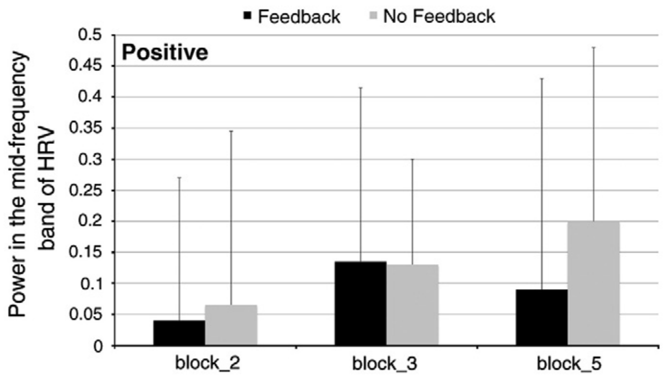
Heart Rate Variability (HRV): Two measures of HRV were calculated, the mid-frequency component (.09–.13 Hz) associated with sinus arrhythmia and the upper band (.14–.40 Hz) associated with respiratory sinus arrhythmia. Two participants were excluded as outliers from the analysis of the mid-frequency component (one from each Feedback Group). This ANOVA revealed a significant three-way interaction, $F(2,27)=2.94$, $p=.05$, $\eta^2=0.18$. A series of three post-hoc t-tests were conducted and revealed that this effect was localised to the Positive Feedback group who exhibited a reduction of the mid-frequency component at block_5 during the Feedback condition (M = 0.10) compared to the No Feedback condition (M = 0.20), $t(14)=3.04$, $p=.05$ (See Fig. 2). The same ANOVA model was applied to upper band of respiratory sinus arrhythmia but no significant differences were found.

Frontal EEG asymmetry: Baselined EEG asymmetry data from eight pairs of sites (Fp1/2, AF3/4, F3/4, F7/8, FC1/2, C1/2, P3/P4, T7/8) were subjected to 2×2×3 ANOVA models (Feedback Valence × Condition × Task Block). The analysis of F3/F4 revealed a significant effect due to Task Block, $F(2,29)=3.78$, $p<.01$, $\eta^2=0.21$. Post-hoc tests revealed that relative activation of the left hemisphere was lower at block_2 (M = 0.04, s.d. = 0.07) compared to block_5 (M = 0.08, s.d. = 0.05). There was also a significant interaction between Condition and Task Block, $F(2,29)=2.93$, $p=.05$, $\eta^2=0.09$; post-hoc analysis confirmed that relative activation of the left hemisphere was higher at block_5 (M = 0.11, s.d. = 0.06) compared to block_2 (M = 0.05, s.d. = 0.05) but this effect was confined to the Feedback condition, $t(30)=1.99$, $p=.05$.

The analysis of frontal asymmetry at FC1/FC2 also revealed a significant main effect for Task Block, $F(2,28)=5.19$, $p<.01$, $\eta^2=0.27$, and an interaction between Condition × Task Block, $F(2,28)=4.56$, $p=.02$, $\eta^2=0.25$ (one participant omitted as an outlier). As with F3/4, the main effect indicated that left side activation was relatively higher

Table 1
Means and standard deviations for mean heart rate (beats per min) represented as a baseline score (N = 32).

	Positive feedback		Negative feedback	
	Feedback	No feedback	Feedback	No feedback
Task Block_1	3.60 [4.37]	1.16 [4.42]	1.23 [2.96]	1.05 [3.25]
Task Block_2	2.81 [4.08]	−0.36 [4.64]	−1.11 [2.65]	−0.16 [4.21]
Task Block_5	1.20 [4.19]	−2.41 [4.88]	−1.68 [2.74]	−1.50 [4.13]



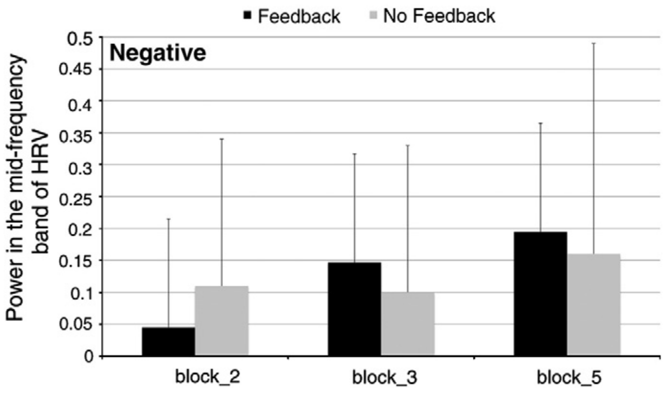


Fig. 2. Means and standard errors for power in the mid-frequency band of heart rate variability for both positive and negative feedback valence groups (N = 30).

at block_5 (M = 0.03, s.d. = 0.05) compared to block_2 (M = 0.00, s.d. = 0.05). A series of two post-hoc t-tests revealed greater relative left activation at block_3 in the Feedback condition (M = 0.05, s.d. = 0.07) compared to the No Feedback condition (M = 0.01, s.d. = 0.06), $t(30) = 2.24$, $p = .05$.

4. Discussion

It was predicted that positive performance feedback would generally increase motivation and positive affect. The subjective self-report data provided mixed support for this hypothesis, i.e. alertness (EA) was enhanced for positive feedback whereas tension (TA) increased in the presence of feedback per se. The hypothesis that positive feedback would promote positive affect was supported, i.e. HT was higher for this group and was enhanced during feedback condition for the positive feedback group. Surprisingly, there was no evidence for any influence on subjective motivation due to the direction of performance feedback.

Positive feedback was predicted to significantly increase mental effort at block_5 due to upward goal adjustment as demonstrated by Ilies and Judge (2005) and Donovan and Williams (2003). Data from SBP reactivity (Fig. 1) and the 0.1 Hz component (Fig. 2) supported this hypothesis. The positive feedback group exhibited increased systolic reactivity from block_3 to block_5 and SBP was significantly higher at block_5 compared to the negative feedback group. In addition, an interaction effect revealed that the 0.1 Hz component was significantly suppressed during block_5 for the positive feedback group in the presence of feedback. It is proposed that systolic reactivity peaked during the final block of activity due to an upward adjustment of performance standards in response to sustained and repeated feedback of task success, i.e. enhanced self-efficacy. The suppression of the 0.1 Hz component of HRV supports this interpretation, being indicative of increased effort investment during the final block of activity in the presence of sustained positive feedback. The analysis of heart rate data provided some circumstantial support for an interpretation of increased beta-adrenergic activation during positive feedback, i.e. heart rate was significantly higher in the presence of positive feedback only.

Frontal EEG asymmetry was measured to capture relative change in approach/avoidance motivational disposition. It was proposed that approach motivation would reach a maximum level at block_5 for the positive feedback group in correspondence with the cardiovascular markers of energy mobilisation. There was no strong evidence to support this hypothesis, relative left activation at F3/F4 and FC1/FC2 increased from block_2 to block_5 regardless of the direction of performance feedback; it is difficult to interpret this trend as left activation has been associated with approach motivation (i.e. effort mobilisation) and the experience of anger (Harmon-Jones et al., 2003)—and both interpretations are plausible in the context of the current study, i.e. sustained negative feedback may have irritated our participants. We also found some evidence of increased relative left activation at FC1/FC2 in the presence of performance feedback at block_3. This trend may be interpreted as enhanced approach motivation but it is difficult to explain how a single presentation of positive or negative performance feedback prompted the same response. It could be argued that positive and negative feedback are both capable of eliciting approach motivation, as a single exposure to positive or negative feedback could both prompt the individual to 'try harder', but this interpretation remains high speculative. The localisation of effect at FC1/FC2 was unexpected, previous studies (Miller and Tomarken, 2001) would have suggested frontal asymmetry effects at F3/F4 and AF3/AF4; however, the pattern of results observed at FC1/FC2 was broadly in line with a predicted association between approach/positive feedback and avoidance/negative feedback. Alternatively, the pattern of frontal EEG asymmetry data may indicate an interaction effect between presentation of performance feedback and between-groups traits that resulted in differential impact at block_2. In hindsight, it may be appropriate for further studies to examine the influence of trait data known to influence frontal EEG asymmetry within this context, e.g. Behavioural Activation/Behavioural Inhibition (Coan and Allen, 2003), regulatory focus (Shah and Higgins, 2001), Achievement Motivation (Capa et al., 2008).

The presentation of negative feedback was associated with two specific hypotheses; the first was that initial exposure to negative feedback would prompt an increase of mental effort and approach motivation, whereas sustained and repeated negative feedback would lead to goal abandonment with a consequent reduction of mental effort and approach motivation. There was no evidence to support either prediction. A perusal of the descriptive statistics for this group (e.g. Fig. 1)suggests that negative feedback had very little impact on any psychophysiological indicators. The lack of evidence for any downward goal revision or progressive increase of avoidance motivation was puzzling. This begs some questions about both the methodology and the operationalisation of key variables in the current study. With respect to the former, the minimum level of false performance feedback was an accuracy level of 49%, which may have been a little high, despite the instructions received by participant prior to the task. Unfortunately the apparatus used in the current study did not permit a higher fidelity of data collection, which may been particularly problematic in the case of blood pressure. Our apparatus only permitted two samples of blood pressure within each block of activity, which have inflated variability to compromise the sensitivity of these data. However, the same apparatus was obviously sufficient to detect change in SBP in response to positive feedback. In hindsight, cardiovascular impedance variables, such as the pre-ejection period, may have provided a clearer indication of beta-adrenergic activation of the sympathetic nervous system compared to SBP (Richter and Gendolla, 2009). Our analysis of HRV focused on a narrow bandwidth that has been associated with the baroreflex and mental effort regulation (Mulder et al., 2009; Mulder et al., 2002), however a broader bandwidth may have improved the sensitivity of our analysis (Berntson et al., 1997; ESC and Naspe, 1996); in addition, the 2.5 minute duration of each block may have been rather short for assessment of HRV.

The failure of negative feedback to consistently support the experimental hypotheses may have been influenced by the type of experimental task used. The n-back task was selected because it satisfied essential criteria of being both cognitively challenging and opaque with respect to the self-assessment of performance. However, it was also a rather boring experience for our participants that provided little impetus in terms of intrinsic motivation. By contrast, the upward adjustment of goals observed for the positive feedback group may have reflected a self-activated strategy to increase the level of engagement with the n-back task by demonstrating a degree of mastery. The current study also set out a rationale for the selection of three blocks of data for our analysis but we must acknowledge that if our reasoning was incorrect, then we could have missed an important trend or blunted the sensitivity of our design to existing effect, such as the impact of negative feedback. However, this does seem unlikely as three of the four task blocks used after feedback presentation were included in our analysis.

The study provided evidence for upward goal adjustment in response to sustained positive feedback that provoked increased mental effort investment. This finding supports an self-initiated agentic perspective (Bandura and Locke, 2003) on mental effort regulation that is consistent with previous research (Donovan and Williams, 2003; Ilies and Judge, 2005) and positive goal change (Locke and Latham, 1990; Philips et al., 1996), to our knowledge, this type of self-initiated increase of mental effort has not been demonstrated with respect to psychophysiological indicators. Existing psychophysiological research on this topic has emphasised the compensatory role of mental effort in response to increased task difficulty (Hockey, 1997).

The methodology used in the current study, which was adapted from previous studies (Bandura and Jourden, 1991; Venables and Fairclough, 2009), demonstrated how task goals may be adjusted dynamically via performance feedback and provided some evidence for a psychophysiological manifestation of this process. Our earlier study (Venables and Fairclough, 2009) emphasised the impact of negative feedback on psychophysiological responses, however this interpretation may have been incorrect as the influence of positive performance feedback was more pronounced in the current study. This draws attention to the weakness of the earlier study that only considered the impact of positive and negative performance feedback as relative to one another; the inclusion of a control condition in the current study demonstrated a blunted response to negative feedback. A secondary goal of the study was to seek evidence for an association between motivational disposition and autonomic markers of effort mobilisation. Evidence for this connection was weak as frontal asymmetry variables failed to differentiate the effects of positive from negative performance feedback.

Future research could consider the same primary manipulation (performance feedback) and hypotheses within a task context where intrinsic motivation is increased (e.g. a task that is engaging as well as cognitive challenging) or additional variables are included to provide a degree of extrinsic motivation, e.g. financial rewards or punishments associated with performance goals, competition with another group or individual. The current study investigated a linear increase or decline of performance effectiveness as indicated by false feedback. This methodology could be extended by deploying quadratic trends with respect to performance feedback, i.e. positive feedback followed by negative feedback and vice versa, in order to further investigate how psychophysiological measures of mental effort respond to changing beliefs about success likelihood.

The study provided psychophysiological evidence of dynamic regulation of mental effort regulation in response to performance feedback. The data provided some support for our hypotheses but further work is required to clarify several key topics, particularly the link between EEG measures of motivational disposition and cardiovascular indices of effort mobilisation.

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