Clinical Neurophysiology 121 (2010) 1502–1510

Contents lists available at ScienceDirect

Clinical Neurophysiology

journal homepage: www.elsevier.com/locate/clinph

Veridical and false feedback sensitivity and punishment-reward system (BIS/BAS): ERP amplitude and theta frequency band analysis

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ARTICLE INFO

Article history:
Accepted 17 March 2010
Available online 8 April 2010

Keywords:
Agency
BIS/BAS
EEG
Feedback
FERN
Theta band

ABSTRACT

Objective: Disruption of the sense of agency and of being causally determinant in action was explored in the present research by inducing an erroneous external spatial feedback in response to the subject's behaviour.

Methods: ERPs and theta frequency band oscillation (ERD) were recorded from 15 subjects when they were receiving mismatching/matching feedback information. In addition, subjective sensitivity to the external cues was monitored by BIS (Behavioral Inibition System) and BAS (Behavioral Activation System) measures.

Results: One negative ERP deflection of higher amplitude was revealed in response to false feedback, peaking at 210 ms post-stimulus, central-posteriorly localized. A specific cortical network, more central-posteriorly distributed, seems to be implicated. Moreover, theta synchronization was observed in response to false feedback within the posterior cortical site.

Conclusions: A direct relationship between ERP/theta band oscillation was supposed, as a marker of salient and unattended cues that produce an alerting response. Moreover, BIS showed an enhanced response to external feedback, and specifically to false feedback, with an increased negative deflection and theta frequency band effect.

Significance: ERP negativity may represent a monitoring system, comparable with erroneous feedback effect. Moreover, specific motivation towards negative context was related to higher BIS, since they were more sensitive to negative, false outcome.

1. Introduction

The presence of a systematic mismatch between subject's action and feedback information related to action produces a significant variation in the feeling of being in control of action. This disruption may be artificially produced by an external device, which induces a mismatch between attended and unattended external feedback (Blakemore et al., 2001; Farrer et al., 2003; de Vignemont and Fourneret, 2004; Ehlis et al., 2005; Miltner et al., 1997). This effect may be produced by manipulating the external response. Indeed visual and auditory (Blakemore et al., 2001; Farrer et al., 2003), somatosensory (Wolpert and Flanagan, 2001) and temporally delayed (Haggard, 2003) feedback were used to induce a sense of disruption in causal action, producing a feeling of causal inefficacy at different degree (David et al., 2008; Gallagher, 2008).

The present study aimed at evaluating whether the awareness of controlling one's action can be correlated with specific brain activity. We manipulated the feedback content (i.e. veridical vs. false feedback), in order to test the subjective response to these different types of feedback and to analyze the neurophysiological mechanisms of action regulation. The discovery of specific neural correlates of behaviour evaluation has inspired recent research, and a neural ERP response to erroneous performance has been founded, i.e. ERN, or Error-Related-Negativity (Falkenstein et al., 1990; Gehring et al., 1990; Holroyd et al., 2005). Whereas initially the ERN was associated only with error detection, more recently it was suggested that the ERN is involved in a more general evaluation of action plans (Luu et al., 2000b) or conflict monitoring (Yeung et al., 2004). Activation of anterior cingulate cortex has been found to be associated with error detection between subject's intention and the outcomes of those intended actions (Gehring and Fencsik, 2001; Holroyd et al., 2009; Taylor et al., 2006).

A number of studies have also recorded ERP responses, time locked to feedback. Recent research has underlined that especially equivocal or unattended feedback requires the evaluation and

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doi:10.1016/j.clinph.2010.03.015

comparison of external and internal information (Müller et al., 2005). A more specific related ERP effect, feedback-ERN, i.e. FERN, was found in response to an external feedback, which amplitude in some cases was found to be monotonically related to the expectedness of the event: it is larger for unexpected than for expected outcomes (Heldmann et al., 2008), and, more generally, it is thought to represent the activity of a generic response monitoring system. This deflection was found to be produced in response to different cognitive tasks: unattended feedback, unexpected and negative feedback, ambiguous feedback, or false feedback. Specifically, it was recorded in case of a feedback indicting incorrect performance in a time-production task, or in case of a distorted and anomalous feedback (Ehlis et al., 2005; Müller et al., 2005; Krigolson and Holroyd, 2006; Katahira et al., 2008; Vocat et al., 2008). Recently Holroyd et al. (2008) underlined the similarity of this deflection with the N200 ERP effect, that was similar in terms of cortical distribution, time courses and functional significance. This critical point is actually under consideration and it is considered an important issue to be elucidated.

Nevertheless only limited research has explicitly compared the effect of veridical vs. false feedback. About the false feedback, random information was provided not related to the real performance (Chwilla and Brunia, 1991; Miltner et al., 1997). It was observed that parietal areas (mainly posterior parietal cortex) represent a very likely candidate for providing reference to the agent of an action as this region seems to monitor the concordance between self-produced actions and their visual consequences, being especially involved in the detection of visual and motor incongruence (Fink et al., 1999; Chaminade and Decety, 2002; Farrer and Frith, 2002; Farrer et al., 2003).

Secondly, in the present research we monitored brain oscillation modulation to gain more information on the nature and the cognitive effect on behaviour of an erroneous and unattended feedback. Recent studies have found a significant correlation between theta frequency band modulation and ERN. Indeed, an increased midline frontal theta EEG activity was found in response to error monitoring (Luu and Tucker, 2001; Makeig et al., 2002; Luu and Tucker, 2003). ERN was accompanied by theta band activity recorded above motor cortex. Başar-Eroğlu et al. (1992) have proposed that ERP components can reflect the summing up of phase-aligned oscillatory EEG activity. Indeed, it was recognized ERP components may result from relative phase consistency, with respect to the stimulus delivery (Luu et al., 2004). Thus, it is possible that theta synchronization effect is intimately related to the appearance of that feedback. Nevertheless, conflicting results were obtained by previous study (Yeung et al., 2007) which underlined the discordance of methods of analysis. Therefore, these varieties of methods cannot provide unambiguous evidence that the ERN is generated by phase resetting of ongoing oscillations. Theta frequency range has been associated with attention and cognitive processes, and brain oscillations around 4 Hz respond to the relevance of the stimulus, internal or external, being processed. More generally, it was observed an "orienting" function of this frequency band, since a synchronization of theta was revealed in case of coordinated response indicating alertness, arousal and readiness to process information (Başar et al., 2000; Aftanas et al., 2001). Moreover, for the first time the direct relationship between an erroneous feedback and specific frequency band changes (theta) was tested in the present research.

Third, we considered whether the subjective sensitivity to external cues of reward vs. punishment, measured by BIS/BAS, may have an effect in processing the external feedback, erroneous and veridical. Feedback perception and error-feedback may be directly related to subject's personal features, that is subjective motivation and affective style, as well as the personal sensitivity to internal/external cues (Dikman and Allen, 2000). A prevalent view suggests the bases of this subjective sensitivity correspond to two general systems (Gray, 1981; Carver and White, 1994). The first system functions to halt ongoing behaviour while processing potential threat cues, referred to as *Behavioral Inhibition System* (BIS) (Gray, 1990; Lang et al., 1990). A second system is believed to govern the engagement of action and has been referred to as the *Behavioral Approach System* (Gray, 1982) or the *Behavioral Activation System* (BAS) (Fowles, 1980). The BAS is conceptualized as a motivational system that is sensitive to signals of reward, nonpunishment, and that is important for engaging behaviour toward a reward. The BIS, conversely, inhibits behaviour in response to stimuli that are novel, innately feared, and conditioned to be aversive (Boksem et al., 2006). Research suggests that BAS is mediated by mostly dopaminergic pathways emanating from the ventral tegmental area to the nucleus accumbens and ventral striatum (Nöthen et al., 1992; Fowles, 1994), whereas BIS controls the important non-dopaminergic pathway finalized to behavior inhibition. Thus, whereas the BAS is conceptualized as a motivational system that is sensitive to signals of reward and, more generally, of reinforce of the adopted behaviour, BIS, conversely, is conceptualized as an attentional system that functions to interrupt ongoing behaviour in order to facilitate the processing of these cues in preparation for a response (Fowles, 2000; Yu and Dayan, 2005). In addition, according to Gray, activation of BIS is guided by a comparator, in response to prediction errors and to aversive stimuli (punishment or non reward) (Gray, 1989).

Only two recent studies examined the relationship between BIS/BAS and ERN. However they did not consider directly the subjective response to external feedback, contrarily to our present goals. Boksem et al. (2006, 2008) found a substantial increased amplitude of ERN for BIS subjects, and, on the contrary, a significant increased positive deflection, i.e. the Pe effect, for BAS (in particular BAS-Drive subscale). They interpreted these results in terms of subjective predisposition to control the conflict monitoring for BIS. Based on these goals, we hypothesized firstly that a specific ERP effect may be found in response to an external feedback, increased in case of false condition (Miltner et al., 1997; Holroyd and Coles, 2002). In addition, a cortical system should exist deputed to process feedback response, it coming from matching or mismatching condition. Secondly, theta modulation should be observed in response to ERP modifications, that is in relationship with false feedback condition. Moreover, about BIS/BAS effect on ERP and theta, we expected a significant sensitivity by higher BIS to feedback, in response to both erroneous and negative feedback. Thus, an increased response to feedback should be found for BIS more than BAS subjects. This trend should be observed in case of false feedback in greater measure. In that condition a higher theta synchronization (ERD decreasing) should be found for higher BIS than BAS.

2. Materials and methods

2.1. Subjects

Fifteen undergraduate students took part in the study (nine women, age range 20–30, mean = 23.47, SD = 2.13). They were all right-handed and with normal or corrected-to-normal visual acuity. Exclusion criteria were history of psychopathology for the subjects or immediate family. They gave informed written consent for participating in the study.

2.2. Procedure

Subjects were seated comfortably in a moderately lighted room with the monitor screen (CRT) positioned approximately 100 cm in