Physiology & Behavior 163 (2016) 43–50

Contents lists available at ScienceDirect

Physiology & Behavior

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

The content of lexical stimuli and self-reported physiological state modulate error-related negativity amplitude

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HIGHLIGHTS

- We used food and non-food related words and pseudo words in a lexical decision task.
- Self-reported state thirst, hunger, and wakefulness were collected
- A robust ERN, CRN, Pe and Pc were generated
- Thirst correlated to improved performance, smaller CRNs, and larger ERNs
- Responses to food-related stimuli were faster and more accurate than non-food stimuli

ARTICLE INFO

Article history:
Received 23 July 2015
Received in revised form 19 March 2016
Accepted 19 April 2016
Available online 26 April 2016

Keywords:
Error monitoring
Thirst
Hunger
Wakefulness
Event-related potentials
Lexical decision task

ABSTRACT

The Error-Related Negativity (ERN) and Correct-Response Negativity (CRN) are brief event-related potential (ERP) components—elicited after the commission of a response—associated with motivation, emotion, and affect. The Error Positivity (Pe) typically appears after the ERN, and corresponds to awareness of having committed an error. Although motivation has long been established as an important factor in the expression and morphology of the ERN, physiological state has rarely been explored as a variable in these investigations. In the present study, we investigated whether self-reported physiological state (SRPS; wakefulness, hunger, or thirst) corresponds with ERN amplitude and type of lexical stimuli. Participants completed a SRPS questionnaire and then completed a speeded Lexical Decision Task with words and pseudowords that were either food-related or neutral. Though similar in frequency and length, food-related stimuli elicited increased accuracy, faster errors, and generated a larger ERN and smaller CRN than neutral words. Self-reported thirst correlated with improved accuracy and smaller ERN and CRN amplitudes. The Pe and Pc (correct positivity) were not impacted by physiological state or by stimulus content. The results indicate that physiological state and manipulations of lexical content may serve as important avenues for future research. Future studies that apply more sensitive measures of physiological and motivational state (e.g., biomarkers for satiety) or direct manipulations of satiety may be a useful technique for future research into response monitoring.

1. Introduction

The Error-Related Negativity (ERN) is an event-related potential (ERP) associated with response monitoring and is linked to a variety of pathological and motivational influences. The ERN is typically defined as the first negative deflection after an error is made, typically peaking within 100 ms [32]. A component with similar morphology and time course, the Correct-Response Negativity (CRN), is often elicited following correct responses, which likely reflects similar processes to the ERN [6,48]. The ERN and CRN are typically followed by the Error Positivity (Pe) and Correct Positivity (Pc). The Pe and Pc have been associated with conscious error detection and reorienting of cognitive resources, while the ERN/CRN is thought to reflect a non-specific response to an error, an affective response to an error, and/or the buildup of information to be processed in what is reflected in the Pe/Pc [6,39,45,48,50]. The Pe and Pc are typically analyzed within the window encompassing a positive peak immediately following a response, around 100–200 ms post-response [38,39,45]. Others argue that error awareness is reflected in a later time window within 200 to 600 ms, and the more traditional early window (i.e., 100–200 ms) reflects similar processes to the ERN [9,39,52]. Individual differences in Pe/Pc expression are rarely reported. The early Pe/Pc appears to be largely insensitive to state-level motivational influences or feedback within a task [35,39,45,58], whereas the later Pe is sensitive to trait perfectionism in both healthy [52] and

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http://dx.doi.org/10.1016/j.physbeh.2016.04.036
0031-9384/

depressed individuals [47]. To our knowledge, the Pc has yet to be associated with individual differences measures or variations in task [31,37,46].

The ERN has chiefly been utilized to explore the neural underpinnings of negative affect (NA), though more recent investigations have explored a variety of psychopathologies [32,34,55,56]. More specifically, the ERN has been instrumental in improving our conceptualization and nosology of anxiety [32]. For example, larger ERN amplitudes are typically seen in individuals exhibiting increased anxiety, even at subclinical levels [12,14,17]. These associations seem specific to particular aspects of anxiety (e.g., worry) but not others such as physiological reactivity [13,31,32]. Increased ERN activity in anxious individuals may reflect heightened vigilance, perseveration, and/or perfectionism that are pathognomonic of anxiety [32,55]; however, perfectionism may be a distinct construct that also influences the Pe [52]. Importantly, the ERN is associated with genuine negative affect, as individuals in a misattribution paradigm designed to elicit sham anxiety did not show increased ERN amplitude despite reporting increased anxiety [23].

The ERN is modulated by state emotional and motivational characteristics in healthy individuals. College students with high levels of state NA had significantly larger ERNs and CRNs than those who did not [16,27]. A similar pattern was seen when NA was induced, though only magnitude of change in mood correlated to ERN amplitude, while group differences were not statistically significant [37]. Some studies show that individuals with prominent negative emotion had larger ERNs early in the task, but did not differ from unaffected controls later in the task [27,57], while others did not find this temporal limitation [16]. In terms of motivational influences of the ERN, asking participants to focus on accuracy over speed increases ERN amplitude [10] as does incentivized performance [41]. Therefore, it is clear that the ERN and CRN are sensitive both to trait and state influences of motivation and affect, though the roles of task and motivation have not yet been fully explored [13,29,31,32,46,55].

An understudied aspect of state-level influence of the ERN is the physiological state of the participant. Studies pertaining to physiological state have primarily focused on fatigue or sleepiness. Compared to a rested state, 20 h of wakefulness was associated with increased subjective feelings of poor performance and reduced Pe amplitude, though actual execution of errors and ERN amplitude were not impacted [33]. Others found that the Pe and ERN were reduced, and behavioral performance was significantly worse (i.e., more errors of omission and commission, slower response time) in total sleep deprivation conditions [20,21,53]. Therefore, it remains unclear to what degree fatigue and sleep deprivation impacts response monitoring and ERN/CRN amplitude.

To our knowledge, no study to date has explored the role of other aspects of physiological state, such as thirst and hunger, in the generation of the ERN/CRN and Pe/Pc. There is evidence that increases in need states influence attentional bias to stimuli relevant to need-states. For example, individuals with increased thirst are faster to identify thirst-related stimuli in a lexical decision task [1,54], individuals with increased hunger identify food-related stimuli faster and more accurately [26,30,44], and sleep deprived individuals show attentional bias to sleep-related stimuli [3,49]. Due to their heightened salience, errors to need-state-relevant stimuli should increase the ERN and Pe.

The goal of the present study is to investigate how need-state and stimuli content can influence error monitoring. If physiological state influences the expression of these components, it is clear that broad aspects of motivation may influence the functioning that underlies the ERN/CRN and Pe/Pc. Further, since studies to date have predominantly utilized nonverbal stimuli to elicit these components, the use of other stimuli for the expression of the ERN will better determine if these components are specific to nonverbal processes, and to what degree the content of the stimuli themselves modulate the error monitoring and awareness. To explore these goals, we analyzed the relation of self-reported physiological state (SRPS)–specifically wakefulness, hunger, and thirst–to ERN/CRN and Pe/Pc amplitudes in a lexical decision task using both food-related and non-food-related stimuli. We had two main hypotheses: first, we hypothesized that, due to increased autonomic activity associated with hunger, hunger would correspond to larger ERN and CRN amplitudes across the whole task; second, we hypothesized that increases in hunger would more strongly correlate with improved behavioral responses (faster RT and increased accuracy), larger (more negative) ERN and CRN amplitude and larger (more positive) Pe amplitude to food-related stimuli.

2. Method

2.1. Participants

Sixty-one undergraduate participants completed this study in exchange for class credit in introductory psychology classes. By self-report, participants had no history of head injury, had normal or corrected vision, were right-handed, and native speakers of English. Participants were only included in final analyses if they had six or more artifact-free correct and error trials for both food-related and not-food related stimuli, as reliable ERNs require at least this number of trials (e.g., [25]). This constraint resulted in the removal of seven subjects. An additional participant's data was lost due to recording failure. Eleven subjects were removed if they made more error responses than correct responses, and/or their median RT for correct responses was <200 ms, similar to previous studies (e.g., [41,46]). These constraints were used to ensure that participants included in the analysis were sufficiently engaged in the task. The final data set included 43 participants (29 women). One participant's behavioral data was lost due to recording failure, so they were removed from analyses pertaining to behavior; all other data for this subject was complete and included in the remaining analyses (removal of this participant did not impact significance on any of the analyses in the study). χ^2 tests confirmed that excluded and included participants did not significantly differ in terms of ethnicity or gender ($ps > 0.2$) and Mann-Whitney U-tests confirmed that SRPS and age did not significantly differ between these two groups ($ps > 0.2$). The University of the Sciences' Institutional Review Board approved the study and each subject completed informed consent procedures prior to study participation.

2.2. Questionnaires

SRPS was collected using questions adapted from Grand [11]). The present study used the items pertaining to perceived thirst, hunger, and wakefulness using the item: "On a scale of 0–7, how [hungry/thirsty/awake] are you?" To our knowledge, this questionnaire has not been formally assessed for validity or reliability, and no other questionnaire has been developed to assess perceived physiological state. Previous studies have used this scale and the results imply validity: fasted individuals reported higher scores on the instrument than non-fasted individuals [26,30]. Further, Leland and Pineda [26]) found that higher hunger ratings were associated with higher electrophysiological response and attentional bias to food-related items.

2.2.1. Task

We selected a lexical decision task (LDT) using judgments of orthography to explore the role of affect in verbal processing as there is sufficient evidence that such a task can elicit an ERN in college students (e.g., [18]). Previous studies have also shown that LDTs can measure attentional bias to need-state-relevant stimuli (e.g., [1,44]), though none to date have extended this to error monitoring.

2.2.1.1. Stimuli. Words were selected that were high frequency based on SUBTLEX norms [5], 4–10 letters (M = 5.86, SD = 1.29), and no more than three syllables. The list contained 360 total letter strings presented in random order in lower case Courier font. Half of the stimuli were