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Category-specific features and valence in action-effect prediction: An EEG study

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ABSTRACT

Despite extensive research on action-effect anticipation, little attention has been paid to the anticipation of different attributes of an event. An action-effect is not only a sensory event; it is often also an event of emotional value which can be pleasant or aversive. This latter attribute of action-effect prediction is similar to anticipation of reward versus punishment. To date the neural systems controlling sensory and reward anticipation have not been systematically compared. To this end, we designed an experiment to manipulate the sensory content and the emotional valence of the stimuli in an orthogonal fashion. We recorded and compared event-related potentials (ERPs) to the presentation of stimuli instantiating expected or unexpected features. Our results suggest (1) that both features are processed altogether and (2) that the prediction error resulting from the manipulation is reflected in an enhanced N400 component.

1. Introduction

Acting upon our environment in a goal-directed fashion requires us to learn from the sensory-motor contingencies occurring while we interact with the world. The ideomotor theory (Harleß, 1861; James, 1890; Lotze, 1852) suggests that the internal anticipation of a given sensory effect reactivates the motor codes previously associated with this effect resulting in the facilitation of the action necessary to achieve the effect (Elsner & Hommel, 2001; Greenwald, 1970; Prinz, 1997; see Shin, Proctor, & Capaldi, 2010). In other words, an agent acts upon the environment by internally anticipating the desired sensory effect, also designated as action-effect.

To study this action-effect anticipation, researchers have relied mostly on the manipulation of the effect's physical properties, such as shape (Hommel, 1998), spatial location (Kunde, 2001), and onset time (Elsner & Hommel, 2004; Kunde, 2003). However, action-effects are not only sensory events; they are often also events of emotional value which are more or less pleasant. For example, when you drink a glass of sweet juice or a bitter medicine, you not only anticipate perceiving sweetness or bitterness as a perceptual event but also anticipate this event to be pleasant or aversive. In line with this idea, it has been shown that action-effect binding is reinforced by the emotional value of the action's consequence (Colzato, van Wouwe, & Hommel, 2007; Waszak & Pholulamdeth, 2009) and by monetary rewards (Muhle-Karbe & Krebs, 2012).

To study anticipation in a straightforward fashion, one could rely on the observation of brain response to unexpected events using electroencephalography (EEG) recording techniques (Holroyd & Coles, 2002). When an action is followed by an unexpected event, the resulting signal (or prediction error signal) can be considered as the index for participant's surprise. So far, the prediction errors generated by unexpected sensory events (Haggard & Whitford, 2004) and unexpected rewards (Knutson Taylor, Kaufman, Peterson, & Glover, 2005) have never been systematically compared. The current research is meant to fill this gap in the literature. We conceived a protocol that allowed us to assess prediction error signals during a simple action-effect task while orthogonally varying the sensory content and the emotional valence of the predicted action-effect to show whether predictive processes represent these attributes independently or interdependently.

We decided to use pictures of people as action-effects as they offer the advantage of representing category-specific features (age, gender, etc.) as well as valence (positive or negative), which allowed us to design a task where the two factors were orthogonally manipulated (see Fig. 1). Since it has been demonstrated

Abbreviations: EEG, electroencephalogram; ERP, event-related potential.

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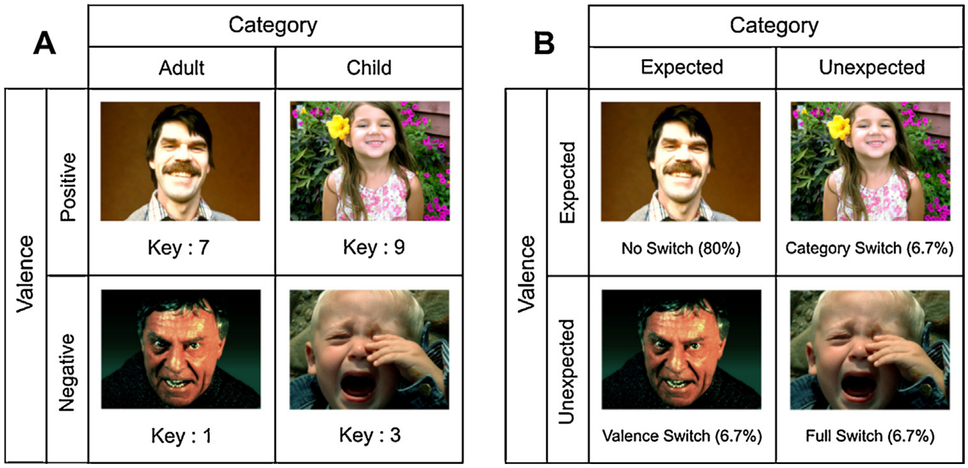

Fig. 1. (A) Illustration of the key – stimulus mapping. Each key press is associated with the presentation of a picture varying in its category-specific properties (adult or children) and its valence (positive or negative). (B) The orthogonal manipulation illustrated by the possible outcomes of a key "7" stroke (see panel A). It can result in either a "no switch" where both dimensions are expected (a positive adult picture), a "category switch" where the category is unexpected (a positive child picture), a "valence switch" where the valence is unexpected (a negative adult picture), or a "full switch" where both dimensions are unexpected (a negative child picture).

on several occasions (Ashby, Isen, & Turken, 1999) that emotional pictures carry a motivational value, we considered them as suitable stimuli for the purpose of this experiment. Moreover, previous results suggest that action-effect prediction modulates event-related potential (ERP) components (Baëss, Jacobsen, & Schröger, 2008; Waszak & Herwig, 2007; Waszak, Cardoso-Leite, & Hughes, 2012). As a consequence, we hypothesized that the presentation of action-effects comprising unexpected category-specific features (category switch), unexpected valence (valence switch), or both (full switch) would result in a prediction error signal representing the inconsistency with the previously learned action-effect mapping. We focused on two candidate ERP components which might reflect inconsistencies regarding action-effect mapping. Firstly, the results of a previous attempt to link action-effect anticipation to the associative learning literature (Band, van Steenbergen, Ridderinkhof, Falkenstein, & Hommel, 2009) suggested a suppression of the centro-parietal N200 component (labelled as "action-effect negativity") for unexpected action-effect. This effect is very similar in amplitude and location to the classical feedback negativity (Holroyd, Nieuwenhuis, Yeung, & Cohen, 2003; Yeung, Botvinick, & Cohen, 2004). If category-specific and valence prediction errors can be compared, we are likely to find a similar variation of the ERP signal in this time range. Secondly, the literature on semantic matching for faces (Barrett & Rugg, 1989; Olivares, Iglesias, & Antonieta Bobes, 1999) and pictures (Barrett & Rugg, 1990; Holcomb & McPherson, 1994) suggested that unexpected visual stimuli containing higher order information enhance the N400 response, similarly to the presence of an odd word into a meaningful sentence (see Kutas & Federmeier, 2011; Lau, Phillips, & Poeppel, 2008; for a review). Contrarily to previous action-effect ERP studies using simple tones (Hughes, Desantis, & Waszak, 2012) or vowels (Band et al., 2009) as stimuli, our experimental design relies on semantically rich items which might require later cortical processing. For this reason, we also anticipated an alteration of later ERP components in the N400 range.

2. Material & methods

2.1. Participants

This study included 19 volunteers. All participants had normal or corrected-to-normal vision, and had no history of any neurological disease as indicated by self-reports. Two participants were excluded from the analysis described below because of extremely noisy EEG data, leaving 13 female and 4 male participants (mean age: 27 years and 2 months). This study was performed in accordance with the declaration of Helsinki. Ethical approval was granted by the CPP (Comité de Protection des Personnes) Ile de France II. All participants gave informed consent and received 20 euros for their participation.

2.2. Stimuli

We selected 44 pictures from the International Affective Picture Set (IAPS; Lang, Bradley, & Cuthbert, 2008), including eleven pictures from each of the following four subsets: positive pictures of adults, negative pictures of adults, positive pictures of children, and negative pictures of children. Pictures were selected on the basis of their IAPS normative ratings in order to maximize valence scores for positive pictures, minimize valence scores for negative pictures, and keep the arousal score constant across subsets. Pictures of violent content were excluded. Pictures were also matched for gender, age, and ethnicity. Table 1 provides mean IAPS normative ratings for valence and arousal for the selected pictures. Fig. 1 shows example pictures.

2.3. Task

We recorded EEG while participants were presented with pictures of expected or unexpected category (adult or children) and/or valence (positive or negative) triggered by a specific key press. Participants were required to choose among four possible keys on a numeric key pad ("1", "3", "7" and "9"). Each key was associated with the presentation of a picture belonging to one of the following four subsets: positive pictures of adults, negative pictures of adults, positive pictures of children, and negative pictures of children. The key-picture category mapping was consistent throughout the whole experiment and counterbalanced across participants. In 80% of the case, the picture presented on the screen corresponded to the mapping (expected trial), whereas in 20% of the trials the picture belonged to one of the three remaining subsets (unexpected trial). Within these 20% of trials, an equal proportion of trials (6.7%) was unexpected with respect to the category-specific feature only (category switch), with respect to the valence only (valence switch), or with respect to both (full switch). For example, if a key triggered the presentation of a positive picture of children in 80% of the trials,