BRAIN RESEARCH 1626 (2015) 31–44

Available online at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/brainres

Research Report

Automatic prediction regarding the next state of a visual object: Electrophysiological indicators of prediction match and mismatch

*Motohiro Kimura**, *Yuji Takeda*

National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan

ARTICLE INFO

Article history:
Accepted 9 January 2015
Available online 15 January 2015

Keywords:
Automatic visual prediction
Sequential rule
Match
Mismatch
Event-related brain potential (ERP)

ABSTRACT

Behavioral phenomena such as representational momentum suggest that the brain can automatically predict the next state of a visual object, based on sequential rules embedded in its preceding spatiotemporal context. To identify electrophysiological indicators of automatic visual prediction in terms of prediction match and mismatch, we recorded event-related brain potentials (ERPs) while participants passively viewed three types of task-irrelevant sequences of a bar stimulus: (1) an oddball sequence, which contained a sequential rule defined by stimulus repetition, providing repetition-rule-conforming (standard) and -violating (deviant) stimuli; (2) a rotating-oddball sequence, which contained a sequential rule defined by stimulus change (i.e., rotation), providing change-rule-conforming (regular) and -violating (irregular) stimuli; and (3) a random sequence, which did not contain a sequential rule, providing a neutral (control) stimulus. This protocol allowed us to expect that (1) an ERP effect that reflects a prediction-mismatch process should be exclusively observed in both the deviant-minus-control and irregular-minus-control comparisons and (2) an ERP effect that reflects a prediction-match process should be exclusively observed in both the standard-minus-control and regular-minus-control comparisons. The results showed that the ERP effect that met the criterion for prediction mismatch was an occipito-temporal negative deflection at around 170–300 ms (visual mismatch negativity), while the ERP effect that met the criterion for prediction match was a frontal/central negative deflection at around 150–270 ms (probably, the reduction of P2). These two contrasting ERP effects support a hypothetical view that automatic visual prediction would involve both an increase in the neural response to prediction-incongruent (i.e., novel) events and a decrease in the neural response to prediction-congruent (i.e., redundant) events.

This article is part of a Special Issue entitled SI: Prediction and Attention.

*Correspondence to: Cognition and Action Research Group, Human Technology Research Institute, National Institute of Advanced Industrial Science and Technology (AIST), Central 6, 1-1-1 Higashi, Tsukuba, Ibaraki 305-8566, Japan. Fax: +81 29 861 6636.

E-mail address: m.kimura@aist.go.jp (M. Kimura).

http://dx.doi.org/10.1016/j.brainres.2015.01.013
0006-8993/© 2015 Elsevier B.V. All rights reserved.

1. Introduction

1.1. *Predicting the next state of a visual object*

A visual environment contains many objects, and the spatial locations and features of these objects can change dynamically over time (e.g., moving machines, flying birds, and walking people). As a result of these changes, an essential task of the brain is to deal with the neural delay involved in processing visual information. When the image of an object hits the eyes, the observer does not perceive it instantaneously. Rather, it takes about a tenth of a second for the brain to process an image before the observer can actually perceive it. In the case of a changing object, its state changes dramatically during this delay period. To compensate for the delay and maintain real-time interaction with an actual object, the brain is thought to constantly form a temporally-aligned prediction about what happens next to the object (Hubbard, 1995, 2005; Nijhawan, 1994, 2008; Schutz-Bosbach and Prinz, 2007; Wilson and Knoblich, 2005).

Empirical support for this idea mainly comes from studies on representational momentum (RM; Freyd and Finke, 1984, 1985; Hubbard and Bharucha, 1988). RM denotes a forward displacement of the remembered final state of a changing object. For example, Freyd and Finke (1984) reported that, when the participant is required to compare the final orientation of a regularly changing bar stimulus (e.g., 10°/30°/**50°**/) to the orientation of a following probe bar stimulus, the participant is more likely to report that they are the "same" when the probe bar is shifted forward along the direction of orientation change (e.g., 55°) than when it is exactly the same (50°) or shifted backward (e.g., 45°). RM can be observed not only for a change in orientation but also for changes in several visual attributes such as spatial location, shape, and size (Kelly and Freyd, 1987). Importantly, the magnitude of RM can be greater when less attention is allocated to the visual stimulus (Hayes and Freyd, 2002), which suggests that this phenomenon is largely automatic and obligatory. Based on a range of findings on RM, it has been proposed that the brain can predict the next state of a visual object in an automatic manner, on the basis of sequential rules embedded in its preceding spatiotemporal context (Hubbard, 1995, 2005). This type of visual prediction can also be suggested by the flash-lag effect (MacKay, 1958; Nijhawan, 1994, 2008) and perceptual-based sequence learning (Coomans et al., 2011; Mayr, 1996; Remillard, 2003).

1.2. *An electrophysiological indicator of prediction mismatch*

Consistent with the existence of such automatic prediction, electrophysiological studies have shown that, even when the participant passively views a task-irrelevant sequence of a visual stimulus, event-related brain potentials (ERPs) in response to rule-conforming and -violating events embedded in the stimulus sequence can differ. The most robust difference is an occipito-temporal negative deflection in response to rule-violating compared to rule-conforming events at around 100–400 ms after stimulus onset, which has been interpreted as an ERP component, visual mismatch negativity (MMN) (for reviews, see Czigler, 2007; Kimura, 2012; Kimura et al., 2011; Pazo-Alvarez et al., 2003; Stefanics et al., 2014; Winkler and Czigler, 2012). Visual MMN has typically been observed in response to repetition-rule-violating (deviant) stimuli that are occasionally inserted in a sequence of repetition-rule-conforming (standard) stimuli (i.e., an oddball sequence; e.g., Czigler et al., 2002; Kimura et al., 2009; Kimura and Takeda, 2013; Winkler et al., 2005). Importantly, visual MMN can also be observed in response to change-rule-violating (irregular) stimuli that are occasionally inserted in a more complex sequence of change-rule-conforming (regular) stimuli (Czigler et al., 2006; Kimura et al., 2012; Kimura and Takeda, 2014; Stefanics et al., 2011). This confirms that visual MMN is sensitive to violations of sequential rules rather than physical stimulus deviations.

Based on these findings, recent theories have proposed that visual MMN is an ERP effect that reflects a prediction-mismatch process, which specifically occurs when the current event and the event that has been automatically predicted on the basis of a sequential rule are incongruent (Kimura, 2012; Kimura et al., 2011; Stefanics et al., 2014; Winkler and Czigler, 2012); this is an updated version of the original memory-trace-mismatch account of MMN (Näätänen, 1992). To be more precise, (1) sequential rules embedded in the stimulus sequence are extracted, (2) a memory representation in the form of a predictive model that encodes the extracted sequential rules is established, (3) predictions about the forthcoming event are formed based on the predictive model, and (4) the current and predicted events are compared. When incongruence between them has been detected via the comparison, visual MMN is elicited (for more details, see Kimura, 2012; see also Schröger, 2007).

1.3. *Present study: an electrophysiological indicator of prediction match*

Although visual MMN is thought to be a reliable electrophysiological indicator of automatic prediction, this ERP effect may not be the only indicator of automatic prediction. Rather, automatic prediction may also be reflected by a prediction-match ERP effect (i.e., the counterpart of visual MMN), which would specifically emerge when the current and predicted events are congruent (for this perspective, see Bendixen et al., 2012; see also Baldeweg, 2006; Haenschel et al., 2005). However, no previous study has directly addressed this issue. In the present study, to identify a prediction-match ERP effect, we recorded ERPs while participants passively viewed three types of task-irrelevant sequences of a bar stimulus (Fig. 1): (1) an oddball sequence, which contained a sequential rule defined by stimulus repetition, providing repetition-rule-conforming (standard) and -violating (deviant) stimuli (Fig. 1B, first row), (2) a rotating-oddball sequence, which contained a sequential rule defined by stimulus change (i.e., rotation), providing change-rule-conforming (regular) and -violating (irregular) stimuli (Fig. 1B, second row), and (3) a random sequence, which did not contain a sequential rule, providing a neutral (control) stimulus (Fig. 1B, third row).

Then, we systematically made four types of ERP comparisons (Table 1): (1) deviant-minus-control, (2) irregular-minus-