Neuropsychologia 96 (2017) 150–163

Contents lists available at ScienceDirect

Neuropsychologia

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

Disentangling stimulus plausibility and contextual congruency: Electro-physiological evidence for differential cognitive dynamics

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ARTICLE INFO

Keywords:
Event plausibility
Contextual congruency
Cross-modal verification
Stimulus processing
Electro-physiology

ABSTRACT

Expectancy mechanisms are routinely used by the cognitive system in stimulus processing and in anticipation of appropriate responses. Electrophysiology research has documented negative shifts of brain activity when expectancies are violated within a local stimulus context (e.g., reading an implausible word in a sentence) or more globally between consecutive stimuli (e.g., a narrative of images with an incongruent end). In this EEG study, we examine the interaction between expectancies operating at the level of stimulus *plausibility* and at more global level of contextual *congruency* to provide evidence for, or against, a disassociation of the underlying processing mechanisms. We asked participants to verify the congruency of pairs of cross-modal stimuli (a sentence and a scene), which varied in plausibility. ANOVAs on ERP amplitudes in selected windows of interest show that congruency violation has longer-lasting (from 100 to 500 ms) and more widespread effects than plausibility violation (from 200 to 400 ms). We also observed critical interactions between these factors, whereby incongruent and implausible pairs elicited stronger negative shifts than their congruent counterpart, both early on (100–200 ms) and between 400–500 ms. Our results suggest that the integration mechanisms are sensitive to both global and local effects of expectancy in a modality independent manner. Overall, we provide novel insights into the interdependence of expectancy during meaning integration of cross-modal stimuli in a verification task.

1. Introduction

The cognitive system heavily relies on expectations of real-world events to optimize the processing of incoming information and forward appropriate responses (Rao and Ballard, 1999; Bar, 2007; Friston, 2010; Wacongne et al. 2012; Clark, 2013; Pickering and Clark, 2014). Behavioral and neural evidence suggests that expectancy mechanisms are found across a variety of tasks. During reading, for example, the predictability of a word directly mediates the amount of attention allocated and associated patterns of brain activity (e.g., Kutas and Hillyard, 1980; Van Berkum et al., 1999; Halgren et al., 2002; DeLong et al., 2005, and Rayner, 2009; Kutas and Federmeier, 2011 for reviews on the topic). Similar findings are obtained in visual tasks, where the expected target location regulates eye-movement responses, memory recognition, and associated brain activity (e.g, Biederman et al., 1973; Loftus and Mackworth, 19781978; Boyce and Pollatsek, 1992; Henderson et al., 1999; Davenport and Potter, 2004; Võ and Wolfe, 2013; Coco et al., 2014).

Expectation[1] is an important concept in electro-physiology (EEG) research on the dynamics of stimulus processing, and the underlying mechanisms of semantic integration. A key observation in these studies is that negative shifts in the EEG activity may reflect processing costs due to expectation violations of linguistic and non-linguistic stimuli. With linguistic stimuli, for example, a seminal study by Kutas and Hillyard (1980) demonstrated that an unexpected word within a sentence (e.g., *the boy spreads butter with* **socks**) generates negative EEG activity around 400 ms from stimulus onset (i.e., N400 ERP component), when compared to an expected word (e.g., *knife*).

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[1] In this study, we mainly discuss the notion of *expectation*, rather than *predictability*, and refer to processing mechanisms that are mediated by the likelihood of expectancy at a local (within a stimulus) or a more global (across stimuli) scale. We avoid predictability, because it generally refers to incremental processing in psycholinguistic research, such as expecting a particular word, given its prior context, before it is actually presented. This is not the type of experimental manipulation implemented in the current study, so we opted against entering into this debate. We refer the interested reader to Van Petten and Luka (2012) for an insightful discussion about predictability and expectation.

http://dx.doi.org/10.1016/j.neuropsychologia.2016.12.008
Received 23 June 2016; Received in revised form 21 November 2016; Accepted 6 December 2016
Available online 11 December 2016
0028-3932/

Likewise with non-linguistic stimuli (e.g., a visual scene), a N390 is found when participants watch a visual scene (e.g., a soccer field with a player) and an unexpected (vs. expected) object is cued in it (e.g., a toilet-roll vs. a ball, Ganis and Kutas, 2003). Moreover, earlier negative shifts are also observed (between 250–300 ms) when unexpected objects are embedded in the scene (Mudrik et al., 2010; 2014; Võ and Wolfe, 2013).

Ample evidence has been gathered about the N400 component (e.g., Kutas et al., 2006; Hagoort and van Berkum, 2007; Lau et al., 2008 for reviews); but its root causes are still debated (e.g., Kutas and Federmeier, 2011). In fact, even though negative shifts are observed when unexpected stimuli are processed, a wide range of factors is directly implicated in the latency and distribution of such shifts. One of the most important factor is the contextual information that surrounds an unexpected stimulus.

In particular, two types (or levels) of context can be distinguished: (a) *local*, such as a short sentence enclosing an unexpected word (e.g., Marslen-Wilson and Tyler, 1980; Kutas and Hillyard, 1980; DeLong et al., 2005), or an image onto which an additional visual stimulus is superimposed (e.g., Ganis and Kutas, 2003); and (b) *global*, such as a discourse preamble before reading the critical sentence (e.g., Kutas, 1993; Camblin et al., 2007; Menenti et al., 2009; Lau et al., 2013) or a narrative of images with an incongruent ending (e.g., West and Holcomb, 2002; Sitnikova et al., 2008; Cohn et al., 2012). The information conveyed by a global context bears direct consequences on the processing of a local context, as observed with both linguistic and non-linguistic information. Camblin et al. (2007), for example, showed that N400 effects elicited by unassociated word pairs (e.g, arms-nose, versus the associated arms-legs) in a local sentence context, can be reduced when preceded by a supportive global discourse statement. West and Holcomb (2002) similarly found a large negativity (at ≈300 and ≈500 ms after scene onset) when presenting a global narrative of images and an incongruous ending image (local context) than a congruous one. Furthermore, larger negativities are observed for scenes containing ambiguous objects, especially when the context of the scene is neutral with respect to the semantics of the object (Dyck and Brodeur, 2015). Moreover, a global context (e.g., a narrative of images depicting a man cutting a loaf of bread) could generate expectations that might or might not be consistent with a local context (e.g., a final image where the man is ironing rather than cutting the bread). Sitnikova et al. (2008) investigated this particular case showing earlier, and longer-lasting, negative shifts when the congruency between global and local context was violated as compared to when the local context was congruent with the global context.

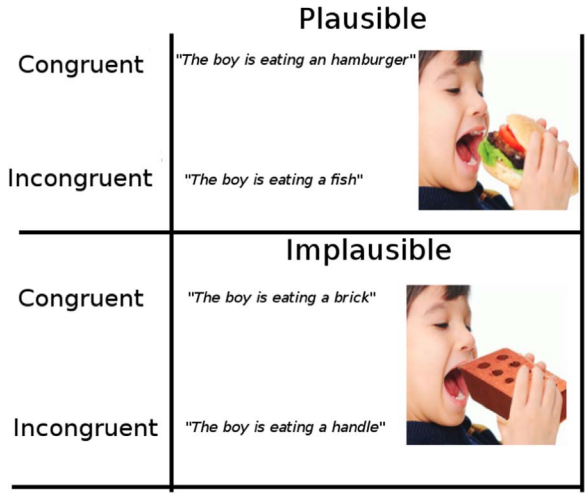

Fig. 1. Experimental design with a full set of crossed pairs of sentence-scene stimulus pairs: Plausibility (Plausible and Implausible) and Congruency (Congruent, Incongruent).

Verification tasks also provide additional insights about the role of congruency on processing costs. Dikker and Pylkkanen (2011), for example, used a word-picture matching task, and demonstrated that when the content of a word does not completely match the content of a subsequently presented picture, a negative shift of brain activity is observed as early as 100 ms after picture onset (cf., Brunellière et al. 2013) for corroborating evidences in spoken word recognition). Similar results are obtained with other cross-modal verification tasks when the congruency is manipulated between: (a) the source of an audio signal and its location in the visual context (i.e., left and right) (Teder-Salejarvi et al., 2005), or (b) the emotional valency of speech and an associated face expression (Pourtois et al., 2000).

To sum up, negative shifts of EEG brain activity result from expectation violations. Expectancy mechanisms seem to operate at two levels: (1) the local plausibility of a specific stimulus, and (2) the congruency between a global and a local context. In the current study, we precisely examine the processing costs arising when both types of expectancy are simultaneously violated. Our main goal is to provide evidences for, or against, a disassociation of expectancy mechanisms driven by stimulus plausibility and message congruency. We do so by designing a cross-modal (sentence-scene) verification paradigm, which naturally affords a crossed 2×2 design of plausibility and congruency[2] (refer Clark and Chase (1972), and Carpenter and Just (1975) for seminal psycholinguistic work on this task).

Participants first read a sentence (plausible or not, e.g., *the boy is eating a* **brick**), building a global context, and then are exposed to a visual scene (local context), which matches it, or not, in content (e.g., a picture depicting a boy eating a brick, refer to Fig. 1 for an example of the material used in this study). By examining EEG responses at the onset of the scene, we can capture how expectations from the global context interact with the plausibility in the downstream local context. This allows us to disentangle the mechanisms of congruency from those driven by plausibility under the same experimental design.[3]

If different processing mechanisms are involved when the congruency between contexts is assessed and the plausibility of the stimuli is evaluated, then we should observe different ERP latencies and distributions when either, or both, are violated. Moreover, if such factors jointly contribute to the processing cost, we should observe an interaction between the two, i.e., the more the violations, the higher the processing cost.

First, we expect to replicate previous literature with respect to the main effects of congruency and plausibility. In line with cross-modal verification studies (e.g., Dikker and Pylkkanen, 2011), we predict an early effect of congruency driven by the congruency/incongruency between the stimuli (i.e., sentence and scene), whereby a larger negative shift is expected with incongruous as compared to congruous trials, between 100–200 ms). Incongruent trials are also expected to display a larger negative shift between 300–400 ms and 400–500 ms (e.g., West and Holcomb, 2002; Sitnikova et al., 2008). Plausibility, instead, is expected to kick in between 200–300 ms and 400–500 ms with implausible scenes triggering a larger negativity than plausible scenes (see Ganis and Kutas, 2003, Mudrik et al. 2010; 2014, Sun et al., 2011; Võ and Wolfe 2013).

Second, and perhaps most importantly, our study makes it possible to establish whether these two sources of expectancy jointly contribute to processing costs. We expect a larger negativity for incongruent stimuli conveying implausible content where both plausibility and congruency are simultaneously violated. We predict this specific interaction to occur as soon as the content of both sentence and scene

[2] Note, our design departs from Sitnikova et al. (2008) by having a cross-modal verification paradigm where plausibility of stimuli can directly interact and compete with expectation processes of congruency.

[3] Differently from Knoeferle et al. (2011), we present the sentence as a global context for the scene, rather than vice-versa; and focus on the electro-physiological response during the processing of visual information.