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Research report

Available processing resources influence encoding-related brain activity before an event

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ABSTRACT

Effective cognitive functioning not only relies on brain activity elicited by an event, but also on activity that precedes it. This has been demonstrated in a number of cognitive domains, including memory. Here, we show that brain activity that precedes the effective encoding of a word into long-term memory depends on the availability of sufficient processing resources. We recorded electrical brain activity from the scalps of healthy adult men and women while they memorized intermixed visual and auditory words for later recall. Each word was preceded by a cue that indicated the modality of the upcoming word. The degree to which processing resources were available before word onset was manipulated by asking participants to make an easy or difficult perceptual discrimination on the cue. Brain activity before word onset predicted later recall of the word, but only in the easy discrimination condition. These findings indicate that anticipatory influences on long-term memory are limited in capacity and sensitive to the degree to which attention is divided between tasks. Prestimulus activity that affects later encoding can only be engaged when the necessary cognitive resources can be allocated to the encoding process.

1. Introduction

The pattern of brain activity that precedes an event can influence the way the event is processed. It has been shown that activity within a few seconds of an imminent event can indicate how that event will be perceived, attended, emotionally processed, decided upon, and acted upon (e.g., Cunnington et al., 2003; Driver and Frith, 2000; Hesselmann et al., 2008; Mackiewicz et al., 2006; Shibata et al., 2008). In the area of long-term memory, prestimulus activity contributes to the likelihood that retrieval will be successful. Activity before event onset may reflect a state that encourages events to be treated as retrieval cues and orient the search through memory toward relevant kinds of information (Rugg and Wilding, 2000).

More recently, prestimulus activity has been shown to also affect the initial encoding of an event into long-term memory. There are now a good number of studies that have demonstrated that brain activity elicited by a cue that gives advance information about an upcoming event can predict whether that event will be remembered or forgotten in a later memory test. This activity is therefore thought to play a role in effective encoding (Paller and Wagner, 2002). Encoding-related activity before an event has been shown using functional magnetic resonance imaging (Adcock et al., 2006; Bollinger et al., 2010; Mackiewicz et al., 2006; Park and Rugg, 2010; Uncapher et al., 2011; Wittmann et al., 2005, 2007), magnetoencephalography (Düzel et al., 2005; Guderian et al., 2009), scalp-recorded electroencephalography (Galli et al., 2011, 2012; Gruber and Otten, 2010; Otten et al., 2006, 2010; Padovani et al., 2011) and

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intracranial recordings (Fell et al., 2011; Rutishauser et al., 2010). Prestimulus activity can affect the encoding of a variety of stimulus events, especially in deep processing tasks, and is dissociable from encoding-related activity after an event (Galli et al., 2011; Otten et al., 2006, 2010). The main brain regions implicated thus far are the medial temporal lobe and midbrain (Adcock et al., 2006; Fell et al., 2011; Guderian et al., 2009; Mackiewicz et al., 2006; Park and Rugg, 2010; Rutishauser et al., 2010; Wittmann et al., 2005, 2007).

The role that prestimulus activity plays in memory encoding is unknown. Generally speaking, such activity may reflect a neural context that is conducive to encoding (Meeter et al., 2004; Yoo et al., 2012), an active preparatory process (Otten et al., 2010) or perhaps an increase in attention or arousal that strengthens later memory-related processes (Park and Rugg, 2010). To help discern its functional role, we used a dual task paradigm in the present experiment to assess how encoding-related activity varies as a function of the amount of processing resources that are available before event onset. The idea behind this paradigm is to tax the system's limited pool of resources and interfere with the encoding process by way of a secondary task. If encoding-related processes before an event are sensitive to the division of attention between tasks, such processes may be limited in capacity and not able to operate independently (Pashler, 1994). This would imply that sufficient processing resources are needed to engage encoding-related activity before event onset. If, in contrast, encoding-related processes proceed relatively automatically without being dependent on resource-availability, prestimulus activity would be expected to be similar in size regardless of the difficulty of a secondary task. Although the concept of 'resources' has received substantial criticism (e.g., Navon, 1984), the dual task paradigm has made a significant contribution to our understanding of the functional and neural architecture in health and disease (e.g., Bonato et al., 2010; Wild-Wall et al., 2011).

The degree to which encoding-related processes rely on processing resources has been investigated extensively for neural activity that follows an event. This work has shown that explicit memory critically depends on the deployment of processing resources. The overall amount of attention paid to an event, and which aspects of the event are attended, determine the size and type of encoding-related neural activity elicited by the event (e.g., Mangels et al., 2001; Uncapher et al., 2011). With respect to memory performance, at least a basic level of resources needs to be allocated to an event when it is first experienced for memory to be successful. Performing a secondary task while encoding an event into memory makes it less likely that the event will later be retrieved, and retrieval success furthermore varies with the emphasis that is placed on the secondary task (Craik and Lockhart, 1972; Hicks and Marsh, 2000). Such performance differences are typically interpreted as being due to encoding-related processes after event onset.

The aim of the present experiment was to assess whether encoding-related processes before event onset also depend on the degree to which processing resources are available. Engaging prestimulus activity that is relevant for encoding may compete with other ongoing processes. Two observations in the literature hint that this might be the case. First, prestimulus activity is sensitive to a match between the input modalities of the to-be-encoded event and preceding cue. Prestimulus activity affects the encoding of visual words when the cue is also visual in nature, but not when it is auditory (Otten et al., 2006, 2010). A mismatch in input modalities may necessitate an initial reorienting of attention toward the other modality, leaving insufficient resources to also set up brain activity that helps encoding. Second, a functional magnetic resonance imaging study has shown that encoding-related brain activity before a visual object differs depending on whether the object occurs in an expected or unexpected location (Uncapher et al., 2011). This has been taken to suggest that prestimulus activity is sensitive to where attention is directed. Following on from these observations, the present experiment evaluated whether encoding-related activity before event onset is affected by the degree to which processing resources are available.

We recorded electrical brain activity from the scalps of healthy adults while they memorized short lists of intermixed visual and auditory words for later free recall. A cue presented just before word onset signaled the upcoming input modality. A visual cue signaled a visual word, and an auditory cue an auditory word. The deployment of processing resources before word onset was manipulated by asking participants to perform a perceptual discrimination task on the cue as well as prepare for the upcoming memorization. The difficulty of the discrimination task was varied across task blocks by making the cues more or less similar to one another. A more difficult discrimination was presumed to require more processing resources, leaving fewer resources to also set up preparatory encoding-related activity. The question of interest was how encoding-related activity before word onset varies as a function of discrimination difficulty. If encoding-related activity primarily occurs in the context of easy cue discriminations, this would lend support to the view that the activity is limited in capacity and sensitive to available processing resources.

2. Method

2.1. Participants

The experimental procedures were approved by the University College London Research Ethics Committee. Twenty-eight volunteers [mean age = 21.5 years, standard deviation (SD) = 2.1, 10 men] were remunerated at a rate of £7.50/h for their participation. All were right-handed, had normal or corrected-to-normal vision, and reported to be native English speakers without psychiatric or neurological illnesses. All participants provided written informed consent before participating.

2.2. Memory task

The experiment involved the intentional memorization of short lists of words, each followed by free recall. Participants were seated in front of a computer monitor and given a pen and clipboard with 24 blank recall sheets. They then memorized 24 lists of 16 words (concrete nouns, 3–12 letters, 0–500 occurrences/million; Kučera and Francis, 1967). Each list

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