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Dissociating the effects of semantic grouping and rehearsal strategies on event-related brain potentials

T.M.J. Schleepen [a,*], C.R. Markus [b], L.M. Jonkman [a]

[a] Department of Cognitive Neuroscience, Faculty of Psychology and Neuroscience, Maastricht University, The Netherlands
[b] Department of Neuropsychology and Psychopharmacology, Faculty of Psychology and Neuroscience, Maastricht University, The Netherlands

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ABSTRACT

The application of elaborative encoding strategies during learning, such as grouping items on similar semantic categories, increases the likelihood of later recall. Previous studies have suggested that stimuli that encourage semantic grouping strategies had modulating effects on specific ERP components. However, these studies did not differentiate between ERP activation patterns evoked by elaborative working memory strategies like semantic grouping and more simple strategies like rote rehearsal. Identification of neurocognitive correlates underlying successful use of elaborative strategies is important to understand better why certain populations, like children or elderly people, have problems applying such strategies. To compare ERP activation during the application of elaborative versus more simple strategies subjects had to encode either four semantically related or unrelated pictures by respectively applying a semantic category grouping or a simple rehearsal strategy. Another goal was to investigate if maintenance of semantically grouped vs. ungrouped pictures modulated ERP-slow waves differently. At the behavioral level there was only a semantic grouping benefit in terms of faster responding on correct rejections (i.e. when the memory probe stimulus was not part of the memory set). At the neural level, during encoding semantic grouping only had a modest specific modulatory effect on a fronto-central Late Positive Component (LPC), emerging around 650 ms. Other ERP components (i.e. P200, N400 and a second Late Positive Component) that had been earlier related to semantic grouping encoding processes now showed stronger modulation by rehearsal than by semantic grouping. During maintenance semantic grouping had specific modulatory effects on left and right frontal slow wave activity. These results stress the importance of careful control of strategy use when investigating the neural correlates of elaborative encoding.

1. Introduction

Learning enables us to acquire the skills and knowledge to be successful in school and in life more generally. Memory strategies are tools that help us to structure information in such a way that it can be learned (and retrieved from memory) more easily, e.g. learning the sequence u-s-a-f-b-i as meaningful chunks (i.e. USA and FBI). Especially when the material we need to study exceeds our memory span memory strategies can reduce memory load by leading to storage of information in a more organized way. Craik and Lockhart (1972) stressed that especially elaborative encoding (as opposed to shallow encoding as for example on perceptual features) led to improved memory due to the forming of more robust memory traces. Elaboration is the process of making information more meaningful by forming relations between its different parts (by for instance making images, chunks, semantic groups), often based on information/knowledge stored in long-term memory (LTM).

Whereas elaborative encoding strategies like semantic grouping have been shown to aid memory and learning more than simple strategies like rote rehearsal, their spontaneous use has been shown to be limited in certain populations like younger children and the elderly or those with attention disorders (Bjorklund and de Marchena, 1984; Wegesin et al., 2000; Egeland et al., 2010). Since such reduced elaborative strategy application has been linked to impaired memory performance it is important to identify the cognitive and neurobiological factors underlying (or limiting) its use. Behavioral studies suggest that one possible reason for the later (i.e. at a later age) application of elaborative strategies (e.g. semantic grouping) in childhood might be a limit in working memory capacity (Schneider et al., 2004; Schleepen and Jonkman, 2012). Functional MRI work in the elderly corroborates this by showing that learning to successfully use elaborative encoding strategies depends on working memory capacity and requires activation of different areas in the prefrontal cortex (PFC), including the dorsolateral PFC. In an fMRI study with young and older adults, Kirchhoff et al. (2012) for instance showed that older adults were only able to spontaneously initiate semantic encoding strategies after strategy

* Corresponding author at: Department of Cognitive Neuroscience, Faculty of Psychology and Neuroscience, Maastricht University, P.O. Box 616, 6200 MD Maastricht, The Netherlands. Tel.: +31 433881522.
E-mail address: Tamara.schleepen@maastrichtuniversity.nl (T.M.J. Schleepen).

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training thereby increasing their memory recognition performance to the level of that of younger adults. Increased strategy use during during/after training went along with increased brain activity in prefrontal and left lateral temporal regions. Another study showed that also in young adults training by the use of a semantic grouping strategy during encoding led to increased recall and semantic clustering scores and co-occurred with increased activation in bilateral dorsolateral PFC and orbitofrontal cortex (Miotto et al, 2006). Moreover, several studies reported that prefrontal cortex activity was enhanced during the use of elaborative encoding strategies (vs. no strategy) even though such strategies facilitate memory performance and decrease WM-load (Bor et al., 2004; Bor et al., 2003; Bor and Owen, 2007; Kirchhoff and Buckner, 2006). Thus, these studies show that especially prefrontal cortex supports the acquisition and spontaneous use of elaborative encoding strategies.

Although the above imaging studies do provide us with important information about the brain areas involved in elaborative strategy application and learning, they do not inform us about the temporal course and duration of cognitive processes underlying such strategy use. Given the speed of neural processing during memory encoding, ERPs are needed to investigate this. Accordingly, the first aim of the present study is to dissociate spatio-temporal ERP correlates of elaborative (semantic grouping) versus simple (rehearsal) encoding strategies. Semantic grouping is an elaborative strategy that is used to improve verbal learning by reordering items into similar semantic categories (Mandler, 1967). It was chosen as the elaborative strategy in the present study since it was the focus of most prior developmental and ERP-working memory strategy work. Functional imaging studies have linked semantic grouping to left inferior and left dorsolateral PFC in adults, activity being larger during deliberate strategy application (Savage et al., 2001; Fletcher et al., 1998).

Although limited in number, several ERP studies also give some information about the ERP components reflecting different stages of cognitive processing involved in semantic grouping. In a study by Blanchet et al. (2007) EEG was recorded while subjects were presented with sequentially presented words in three encoding conditions that differed in the degree of required semantic grouping. While in the unrelated condition none of the words belonged to a similar semantic category, in both the spontaneous and guided conditions the words belonged to four different semantic categories. The two latter conditions differed from each other in that in the spontaneous condition participants were not informed about the semantic structure of the list and received no strategy instructions, while in the guided condition participants were given the names of the corresponding categories and were explicitly instructed to group the words on semantic category to aid later recall. Blanchet et al. reported several ERP components that were modulated by differences in semantic grouping demands. First, an increased P200 over predominantly fronto-central regions was observed that was the largest for guided vs. spontaneous vs. unrelated conditions. The P200 has been related to early stimulus encoding or detection processes (Picton and Hillyard, 1974) and more recently, to attentional processing during deep encoding (Mangels et al., 2001). The latter led Blanchet et al. to conclude that the largest P200 in the guided condition is caused by larger and faster attention allocation to the semantic features of the words in those conditions, since grouping categories were known beforehand. Second, a Late Positive Component (LPC) was found between 400 and 800 ms over centro-parietal regions. This component was the largest in both the guided and spontaneous conditions compared to the unrelated condition. The LPC was suggested to index voluntary associative processes involved in attempting to link words together that belong to similar semantic categories (e.g. semantic grouping). In general, the LPC has been elicited to stimuli across various modalities and has been related to processes as memory, attention and orienting (e.g. Courchesne et al., 1975; Hillyard and Picton, 1978). Finally, right-frontal sustained slow wave activity was found that was increased in the spontaneous condition compared to both unrelated and guided conditions (600–1200 ms) and in the spontaneous condition vs. the unrelated condition (1200–1800 ms). Because the sustained right frontal slow wave was increased only in the spontaneous condition, Blanchet et al. associated this component with the degree of self-initiation involved in the application of the strategy. Besides the study of Blanchet et al. that directly studied ERP activity during the application of semantic grouping, other studies relevant for the present study are those that investigated which ERP components were modulated by retrieval of category-specific information from long-term memory (LTM). These studies reported modulations of a negative component around 400 ms above fronto-central, parietal and occipital electrodes and an occipital–temporal/parietal positivity (LPC) around 550 ms when specific information about object categories had to be retrieved from semantic LTM (Kiefer, 2001, 2005). A similar negative component around 400 ms (called the N400) has been reported in the language processing-ERP literature, its amplitude being typically increased in response to semantic violations, e.g. "I like my coffee with sugar and shoes" (Kutas and Hillyard, 1980). Based on findings from semantic categorization studies that the N400 indexes activation of the semantic network (Kiefer, 2001, 2005), in this study we focus on the N400 as a measure most likely reflecting the retrieval of (category) information from semantic long-term memory during application of the semantic grouping strategy.

Although the above imaging and ERP studies give some insight in the neural correlates underlying semantic grouping during encoding, they did not directly compare neural correlates of semantic grouping with those evoked by (rote) rehearsal by giving explicit instructions for the application of both. In the above studies neural activity during semantic grouping was often contrasted with activity during trials in which unrelated material was presented and had to be encoded for later recall but in which no explicit strategy instructions were given. In such "no-instruction" trials (e.g. unrelated or related-spontaneous trials) it is not clear whether and which strategies subjects might have used. Because of the requirement of later recall it is however likely that subjects used simple rehearsal strategies (especially with sequential presentation of stimuli and low memory load), that might have also affected encoding ERPs. Thus it cannot be excluded that processes related to rehearsal may (partly) account for the increased activity reflected by the P2, LPC and late sustained potential in the ERP studies and prefrontal cortex in the fMRI studies in structured trials. This is an important issue since rehearsal has been shown to recruit partially overlapping brain networks (including left prefrontal cortex) as those underlying elaborative strategies (e.g. Smith and Jonides, 1999).

In the present study EEG was recorded while subjects encoded four simultaneously presented pictures of objects (S1) in two different strategy instruction conditions. In the semantic grouping condition these four pictures belonged to two semantic categories, and subjects were on each trial explicitly instructed to group these pictures on their corresponding semantic categories during encoding (they were not informed about the exact category names). In the rehearsal condition, the four pictures in S1 belonged to four different semantic categories (to prevent grouping on category), and here subjects received the explicit instruction to rehearse these pictures. In contrast to previous studies, this latter explicit rehearse instruction was given to investigate whether the ERP-components previously associated with semantic grouping are indeed relevant to semantic grouping or might also reflect involved rehearsal processes.

Besides comparing neural activation between different strategy instruction conditions during encoding, we also investigated potential differences in neural activations during maintenance of related (semantic grouping condition) or unrelated (rehearsal condition) pictures (i.e. when stimulus material was no longer visible). Therefore, following encoding, we asked subjects to maintain the four pictures in memory during a delay period until a probe occurred (S2). The processes of briefly retaining and updating/manipulating information in memory are referred to as working memory (WM) processes (Baddeley, 2000), typically giving rise to slow wave brain activity that can last up to several