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Contributions of attention and elaboration to associative encoding in young and older adults

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ABSTRACT

Episodic memory declines during healthy aging, with a particular reduction in the ability to encode associations. We investigated the role of alternating attentional focus between two items of a pair in order to generate associative links, as well as working memory based elaborative processes in this age-related memory deficit. While their eye gaze behavior and ERPs were recorded, 19 young and 22 elderly (64–79 years) participants used interactive imagery to encode pairs of spatially separated objects. In a subsequent recognition test, older adults showed a larger reduction in associative than item memory, relative to young adults. For both age groups the number of eye gaze transitions between objects at encoding was correlated with associative recognition performance, suggesting that alternating attentional focus between items aids the generation of relational links necessary to encode associative memories. However, the relative time course of eye gaze transitions over the encoding interval for trials that were subsequently retrieved vs. forgotten differed between age groups. Furthermore, the ERPs of older adults exhibited strongly reduced frontal slow wave "subsequent memory effects", suggesting that they engaged to a lesser extent in working memory-based elaboration of the associative link. Based on these results, we propose that older adults exhibit a reduced tendency to generate and elaborate on internal representations of inter-item associative links. Rather, they use a less effective encoding strategy that disproportionally relies on the external stimulus display, resulting in lower associative memory performance.

1. Introduction

Compared to young adults, the elderly have difficulties remembering associations between items while memory for the items themselves remains relatively intact (for a review, see Old and Naveh-Benjamin, 2008). Different factors may contribute to this deficit, such as structural changes of the brain throughout the life span (e.g., West, 1996), or changes in strategic encoding or retrieval processes (e.g., Cohn et al., 2008; Naveh-Benjamin et al., 2007). In particular, older adults appear to exhibit a difficulty in generating associative links between pieces of information during encoding (Addis et al., 2014). The present study utilized eye-tracking and event-related potentials (ERPs) to investigate the nature of this encoding deficit. Thus, we examined the idea that while encoding item pairs, older adults allocate their attention, and engage elaborative processes, in a way that is less effective for creating and encoding durable associative links than for young adults.

Our conceptual basis is the type-token model (Zimmer and Ecker, 2010), which proposes that during episodic encoding, "object tokens" as well as (higher-order) "episodic tokens" are formed. Object tokens store item features. Episodic tokens represent links to other items and contextual information and are therefore the entities from which inter-item associations are typically retrieved. However, depending on bottom-up and top-down processes, information from multiple items can be bound within the same object token, a process known as unitization (Graf and Schacter, 1989). In that case, retrieval of the inter-item association requires reinstatement of the object token only, and should therefore be less error-prone.

We hypothesized that associative encoding of item pairs is supported by (1) alternations of the attentional focus between items in the process of generating associative links and (2) elaboration of the resulting internal associative representation in working memory. We predicted that young adults more successfully engage these processes than older adults, contributing to the

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age difference in associative memory performance. In the next two sections we will derive each of these hypotheses and discuss how eye tracking and ERP measures can provide a means to "observe" the two processes, respectively. We then provide a brief overview of ERP "old/new effects", which can index whether retrieval of associations occurs through reinstatement of an object- or episodic token.

1.1. Attention, eye gaze behavior and associative memory

A study by Reinitz and Hannigan (2001) illustrates the importance of attentional focus in relational encoding. In a recognition memory task, participants discriminated between faces that were previously studied and those that consisted of a recombination of features of two different previously studied faces. "Conjunction errors" (i.e., false alarms to recombined features) were taken as an index that features from different faces had been relationally encoded. The results showed that when pairs of faces were presented simultaneously or in an alternating sequence, but not when faces were encoded individually, participants frequently made conjunction errors. It appears that only when participants alternated their attentional focus between two items, features from both items were bound relationally, perhaps even leading to unitization of representations of two faces into a single object token. More generally, this result suggests that alternating attention between features or items serves a crucial role to bind the information into a durable relational trace.

Eye fixation patterns reveal which parts of a visual scene are in the focus of attention in which order (for a review, see Hannula et al., 2010). Therefore, if alternations of attention allocation directly serve binding, or they are a consequence of processing relational information, fixation patterns may correlate with the number of encoded features or relations. Indeed, for young adults the number of fixations during the study of scenes (Loftus, 1972) or objects (Kafkas and Montaldi, 2011), and the number of eye gaze transitions between the features of a to-be-encoded face (Chan et al., 2011; Sekiguchi, 2011), predict retrieval on a subsequent recognition test. According to the same logic, we hypothesized that during associative encoding of discrete items, eye gaze transitions between the two items are indicative of the generation of relational links between them. Some evidence for this idea comes from a study where participants memorized the relative spatial locations of three sequentially presented objects (Ryan and Villate, 2009). During presentation of the second and third object, participants frequently transitioned their fixation to the – now empty – location of the previous object. This suggests that eye gaze transitions reflect the generation of relational links between objects, but it leaves open the extent to which the patterns index successful vs. unsuccessful formation of associative memories. The present study therefore tested the idea that alternation of attentional focus during relational encoding of item pairs, as indexed by transitions in fixations between the objects, is predictive of the extent to which the association can subsequently be successfully retrieved.

We further hypothesized that during encoding of item pairs older adults do not allocate attention in a manner that is equally effective for the generation of an associative link, leading to a selective reduction in associative memory. This should be reflected in changes in the total number and/or the temporal dynamics of eye gaze transitions between items. To our knowledge, no prior study has examined this question in an inter-item associative memory task.

1.2. Elaboration, ERP slow waves and associative memory

After a relational link has been generated, associative encoding requires binding objects into a relational memory trace, which is strengthened by active elaboration of the representation in working memory. ERP slow waves vary in their amplitudes depending on working memory load (e.g., Bosch et al., 2001; Lehnert and Zimmer, 2008; Ruchkin et al., 1990) and are enhanced under "deep" encoding conditions (Guo et al., 2004; Schott et al., 2002), presumably encouraging semantic elaboration. The contribution of elaborative processes to episodic encoding is reflected in larger amplitudes elicited by subsequently retrieved than not retrieved stimuli ("subsequent memory effects", for reviews see Paller and Wagner, 2002; Werkle-Bergner et al., 2006). Slow waves exhibit subsequent memory effects for information maintained in working memory (Khader et al., 2007), and when lists of words (Fabiani et al., 1990; Karis et al., 1984), or item pairs (Jäger et al., 2006; Kim et al., 2009; Mangels et al., 2001; Weyerts et al., 1997), are encoded associatively. In one study (Kounios et al., 2001), frontal slow wave subsequent memory effects occurred only for word pairs that were successfully fused, suggesting that the effects may be particularly pronounced when items are unitized into a single object token. Frontal slow wave subsequent memory effects can therefore be used to index the contribution of working memory based elaboration to episodic encoding.

We hypothesized that in addition to a change in the patterns of attentional focus in the process of generating the associative link, another contribution to the associative memory deficit in aging is that older adults engage to a lesser extent in elaboration of the associative link than younger adults. This should be reflected by an attenuated frontal slow wave subsequent memory effect in older adults. While this question has not been addressed directly, two subsequent memory studies tested recognition using "remember/know"- (Friedman and Trott, 2000) or confidence judgments (Gutchess et al., 2007). "Remember" and high confidence responses are likely based on recollection, which in turn relies on associative memory (Yonelinas, 2002). In both studies for young, but not for older adults, ERP subsequent memory effects differed between stimuli that were, and those that were not, associated with subsequent recollection. Furthermore, Cansino et al. (2010) reported of age differences in onset and scalp distribution of slow wave subsequent memory effects in a source encoding task. Although the experimental parameters and subsequent memory effects of these studies are rather heterogeneous, together they suggest that the ERP indices of associative encoding differ in older adults, which may in part reflect differences in the extent to which elaborative processes are engaged during episodic encoding. The present study directly tested the idea that frontal slow wave subsequent memory effects in an inter-item associative encoding task are reduced in older adults.

1.3. ERP old/new effects in associative memory tasks

Episodic retrieval can be based on recollection of contextual details or item familiarity without recollection (for a review, see Yonelinas, 2002). ERP "old/new effects" during a recognition test dissociate the two types of retrieval: An early effect (300–500 ms after stimulus onset) indexes familiarity-based retrieval, while a parietal positivity (500–700 ms) indexes recollection (for a review, see Rugg and Curran, 2007). In the type-token model, retrieval of object tokens is based on familiarity and is therefore accompanied by the early effect, while reinstating episodic tokens requires recollection, thus eliciting a parietal effect (Zimmer and Ecker, 2010). However, when inter-item associations have been unitized into an object token, a familiarity signal, indexed by an early old/new effect, is sufficient to retrieve associations (see also Bader et al., 2010; Jäger et al., 2006). This knowledge on the eliciting conditions of old/new effects permits their use as indices of the processes by which associations are retrieved from episodic memory.