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Out of sight, out of mind: Categorization learning and normal aging

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ABSTRACT

The present combined EEG and eye tracking study examined the process of categorization learning at different age ranges and aimed to investigate to which degree categorization learning is mediated by visual attention and perceptual strategies. Seventeen young subjects and ten elderly subjects had to perform a visual categorization task with two abstract categories. Each category consisted of prototypical stimuli and an exception. The categorization of prototypical stimuli was learned very early during the experiment, while the learning of exceptions was delayed. The categorization of exceptions was accompanied by higher P150, P250 and P300 amplitudes. In contrast to younger subjects, elderly subjects had problems in the categorization of exceptions, but showed an intact categorization performance for prototypical stimuli. Moreover, elderly subjects showed higher fixation rates for important stimulus features and higher P150 amplitudes, which were positively correlated with the categorization performances. These results indicate that elderly subjects compensate for cognitive decline through enhanced perceptual and attentional processing of individual stimulus features. Additionally, a computational approach has been applied and showed a transition away from purely abstraction-based learning to an exemplar-based learning in the middle block for both groups. However, the calculated models provide a better fit for younger subjects than for elderly subjects. The current study demonstrates that human categorization learning is based on early abstraction-based processing followed by an exemplar-memorization stage. This strategy combination facilitates the learning of real world categories with a nuanced category structure. In addition, the present study suggests that categorization learning is affected by normal aging and modulated by perceptual processing and visual attention.

1. Introduction

1.1. Basic models of categorization learning

Categorization learning is a cognitive ability that helps human and non-human animals to detect and avoid malicious objects, for example toxic plants (Ashby and Maddox, 2005; Smith and Minda, 1998; Smith et al., 2008; Sloutsky, 2010; Zentall et al., 2008). The ability to categorize is innate in humans and improves by experience during the lifespan (Quinn et al., 1993).

Both flexibility and generalization form integral components of categorization learning. Ignoring irrelevant information and focusing on specific stimulus features is supported by selective attention. Less coherent categories are more difficult to learn, because they share a lower number of defining characteristics (Kloos and Sloutsky, 2008; Sloutsky, 2010; Wascher et al., 2012). Furthermore, categorization learning is influenced by visual perception (Thompson and Oden, 2000) and is based on a network of neurobiological structures and processes; especially the attention system as well as declarative and procedural memory systems (Ashby and Crossley, 2010; Ashby and Maddox, 2011; Lech et al., 2016; Seger and Cincotta, 2005, 2006; Seger, 2013). Overall, categorization learning is a very complex process and many models suggest that it is based on multiple learning strategies (e.g., Ashby et al., 1998; Lech et al., 2016), which are used at different learning stages (Ashby and Maddox, 2005, 2011). It has been discussed that a psychological transition takes place from an early procedural prototype-based strategy (Minda and Smith, 2001) to a later declarative exemplar-memorization stage (Medin and Schaffer, 1978; Cook and Smith, 2006; Lech et al., 2016). The prototype-based learning is based on abstract prototypes for each category (Smith and Minda, 1998), whereas the exemplar-memorization strategy is mediated by the learning of all category members or all features of a stimulus (Lamberts, 2000; Medin and Schaffer, 1978).

1.2. The influence of attention and exploration capacity

Visual attention mechanisms enable the structural identification of category-typical features (Nosofsky, 1986) and thus modify

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and support perceptual categorization learning. Several studies indicated that visual attention is accompanied by an activity increase in occipital areas (Moran and Desimone, 1985) and is reflected in various event-related potentials (ERP). The parieto-occipital P150 component is associated with an early perceptual analysis of stimulus material, which is modified by selective attention to certain stimulus features (Bigman and Pratt, 2004; Johnson and Olshausen, 2003; Long et al., 2010). The temporo-parietal P250 and P300 components can be identified in visual decision and categorization tasks of different stimuli. They are related to semantic memory and semantic information processing (Chung et al., 2010; García-Larrea et al., 1992; Polich, 2007; Curran, 2004; Donchin and Coles, 1988; Reinvang et al., 2000).

Additionally, eye tracking enables us to measure the relevance of selective attention in categorization learning. Eye movement detection assesses how much attention is directed to specific stimulus features that are used for the categorization of various stimuli (Blair et al., 2009; Sloutsky, 2010; Wascher et al., 2012). This feature-dependent attention is based on a dynamic interplay between bottom-up and top-down processes that results in an optimum of attention allocation, which in turn leads to an improved classification performance (Wascher and Beste, 2010). It is assumed that categorization learning is based on multiple exploration and learning stages. In the beginning of a learning process, participants test one-dimensional rules and therefore focus on all stimulus dimensions. In later stages, participants selectively focus on relevant stimulus dimensions (Rehder and Hoffman, 2005).

1.3. Aging

It is well established that many aspects of cognition decline with normal aging. Previous studies have shown age-related changes and decline in processes involved in maintaining and updating information in declarative memory and attention, especially attention control (Colcombe et al., 2003). Healthy elderly adults show a top-down suppression deficit for task-irrelevant information. This impaired attentional process results in poorer dual-task performance (Gazzaley et al., 2005; Salthouse et al., 1995).

Visual search performance shows age-dependency as well. Elderly participants use more knowledge of task-relevant features than younger subjects (Whiting et al., 2005). They also show better eye movement planning (Rosler et al., 2000), early parallel processing of visual information and a delayed serial processing stage, during in which stimulus features are conjoined to form complex stimuli (Plude and Doussard-Roosevelt, 1989).

Neurocognitive studies showed an increase in parietal activation, which was correlated with the visual search performance of elderly subjects (e.g., Reuter-Lorenz and Cappell, 2008). This age-related over-activation in the parietal lobe seems to be a compensatory mechanism for the decreased bottom-up inputs of sensory processing found in older age (Reuter-Lorenz and Cappell, 2008). Furthermore, it reflects the increased search for important semantic features using top-down driven attention and the knowledge of task-relevant stimulus features during visual tasks (Madden, 2007; Madden et al., 2007; Reuter-Lorenz and Cappell, 2008; Salthouse et al., 1995).

Several authors observed an age-related advantage in implicit categorization learning, e.g. A/Not-A prototype learning (Bozoki et al., 2006; Casale and Ashby, 2008; Heindel et al., 2013; Knowlton and Squire, 1993; Squire and Knowlton, 1995). This age-related advantage is mostly mediated by the perceptual learning system (Zeithamova et al., 2008). Explicit categorization learning, on the other hand, relies on the declarative memory system (Seger et al., 2000) and shows age-related decline (Glass et al., 2012). Additionally, computational models support the notion of broader selective attention in the A/Not-A task (e.g., Glass et al., 2012) in older age.

Taken together, these studies suggest the involvement of an implicit prototype-based and a declarative exemplar-based memory system during categorization learning. The interaction of multiple memory systems facilitates the representation of nuanced categories which consist of prototype-based stimuli and exceptions. It seems that the learning of nuanced categories is negatively affected by aging. In elderly subjects the processes that separate exceptions and prototype-based items appear to be impaired. They showed impaired categorization learning for exceptions but had no problems in categorizing prototype-based stimuli (Davis et al., 2012a, 2012b; Glass et al., 2012). However, up to now, age-related decline of attentional mechanisms which may contribute to categorization learning, is not fully understood. This is e.g. illustrated by the fact that several divergent explanations have been offered for the over-activation of the parietal lobe in elderly subjects (e.g., Madden, 2007, Madden et al., 2007; Reuter-Lorenz and Cappell, 2008; Salthouse et al., 1995).

Furthermore, Rabi and Minda (2016) could show that, although categorization tasks involving a single relevant rule are as easy to learn for elderly as for younger subjects, elderly subjects have more problems with the learning of complex disjunctive rule-based categories and of rule-plus-exception categories (e.g., Davis et al., 2012b). In comparison to younger subjects, the learning of a disjunctive rule-based category (e.g., 5 of the 6 stimulus features are relevant for the disjunctive rule) was more challenging for elderly subjects than the learning of family resemblance based categories. Rabi und Minda (2016) attribute these findings to the fact that complex disjunctive rule-based categories place the highest demands on working memory, which in turn declines with normal aging (Peters, 2006).

The current study used electroencephalography (EEG), eye tracking and computational modelling procedures to examine the process of categorization learning at different age ranges. More specifically, we also aimed to investigate to which degree categorization learning is mediated by visual attention and perceptual strategies. As mentioned before, it is assumed that correct categorizations usually depend on separate learning strategies (abstraction- and exemplar-based strategies), which involve attentional mechanisms to varying degrees. Additionally, the study examined the effects of aging on the usage of different learning strategies during categorization learning. Finally, to investigate whether elderly subjects compensate for cognitive decline through enhanced perceptual and attentional processing, the categorization performance, the allocation of attention to relevant stimulus features and event-related potentials associated with visual attention were assessed and correlated with each other.

2. Material and methods

2.1. Participants

Ten right-handed, neurologically healthy elderly subjects (mean age 58.20 years, SD=7.48 years; 8 female and 2 male subjects) and seventeen right-handed, neurologically healthy young subjects (mean age 22.53 years, SD=4.16 years; 14 female and 3 male subjects) participated in the current study. We originally tested fifteen elderly subjects but five of them performed far below chance level over the whole experiment and therefore had to be excluded. Psychiatric and neurological disorders were general exclusion criteria for study participation. After a detailed explanation of the procedure all subjects gave informed written consent. Besides, all subjects had normal or corrected-to-normal vision. The study was approved by the Ethics Committee of the Faculty of Psychology of the Ruhr University Bochum, Germany.