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Cognitive aging: is there a dark side to environmental support?

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It has been known for some time that memory deficits among older adults increase when self-initiated processing is required and decrease when the environment provides task-appropriate cues. We propose that this observation is not confined to memory but can be subsumed under a more general developmental trend. In perception, learning or memory, and action management, older adults often rely more on external information than younger adults do, probably both as a direct reflection and indirect adaptation to difficulties in internally triggering and maintaining cognitive representations. This age-graded shift from internal towards environmental control is often associated with compromised performance. Cognitive aging research and the design of aging-friendly environments can benefit from paying closer attention to the developmental dynamics and implications of this shift.

Environmental support in old age

Thirty years ago, Fergus Craik [1] placed findings on adult age differences in memory on a continuum ranging from self-initiated processing to environmental support. According to Craik, memory performance is particularly impaired when retrieval depends on self-generated cues and active control processes. By contrast, when retrieval cues (e.g., hints, reminders, contextual reinstatement) are provided by the environment, age-related deficits decrease or disappear altogether (Box 1).

Craik explicated his claim by noting that self-initiated processing and constructive cue generation require a considerable amount of 'attentional resources', which decline with advancing adult age. From the current perspective, deploying attentional resources refers to maintaining task representations through recurrent connections between prefrontal and more posterior regions of the brain [2]. The ability to hold task representations in mind declines with age [3], as reflected by impairments in a variety of cognitive functions such as attention, working memory (WM), and executive control [4,5]. Task-relevant cues serve as reminders of what to do and when, thereby reducing the need to trigger and maintain task representations internally. Hence, environmental support facilitates performance, especially in old age.

On the basis of these considerations, we may expect a gradual shift away from self-initiated processing towards reliance on environmental support with advancing adult age. This is indeed what we see: across processing stages and modalities, older adults are more likely to be guided by external cues than younger adults are. Here, we argue that this shift also comes at a cost, as the affordances of the environment increasingly dominate the structure and content of thought and behavior. To substantiate this claim, we scrutinize adult age differences in behavior from perception to goal-directed action. We examine developmental mechanisms underlying the tendency of older adults to outsource control to the environment, and discuss implications for environments that support successful aging.

Perception: environmental entrainment

Perceptual processing often requires that individuals detect infrequent events in the context of frequent distractor events. In an electroencephalograpy (EEG) experiment, Müller *et al.* asked younger and older adults to listen to a series of auditory stimuli consisting of a frequent and a rare ('oddball') tone [6]. Measures of phase locking and evoked power were used to quantify the extent to which perceptual processing was entrained by stimulus onset. In younger adults, individual differences in synchronization to attended stimuli were positively correlated with independently assessed measures of perceptual speed (Figure 1A). In older adults, however, individual differences in synchronization were negatively correlated with perceptual speed (Figure 1B). These results indicate that the early representation of auditory sensory events in old age occurs in a highly stimulus-driven manner that is less easily modulated by top-down influences and less easily integrated into ongoing cognitive activity.

Likewise, Passow *et al.* examined adult age differences in the interplay between perceptual saliency and attentional control over auditory processing [7] in a dichotic listening task originally introduced by Hugdahl *et al.* [8] and later refined by Westerhausen *et al.* [9]. Perceptual saliency was manipulated by decreasing the intensity of either the right- or the left-ear input in 5-dB steps until a maximum difference of 20 dB between ears was reached.

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Box 1. Self-initiated processing versus environmental support: Craik's 1983 account

Craik's article [1] marked a departure from the modal model of memory [59], which assumed that memory formation and retrieval are achieved as a series of transfers among separate places, or systems, for information storage, such as a short-term store and a long-term store. In line with the levels-of-processing approach [60], Craik proposed a functionalist approach to memory, or remembering, by taking a closer look at the kinds of cognitive activity people engage in during encoding and retrieval.

After having noted that both encoding and retrieval tasks vary in the degree to which they require self-initiated constructive operations, Craik illustrated the distinction between self-initiated processing and environmental support with the following examples (p. 112 [1]):

> *Some encoding operations are so well practiced, or the stimuli are so compatible with the relevant processing mechanisms that the encoding is carried out 'automatically,' without conscious effort (e.g. perceiving a picture or an expected word in context). Other encoding operations, for example, involving deductions or inference, require much more attention and effort. Retrieval tasks also vary in the degree to which they require self-initiated constructive operations; some, like free recall, involve minimal 'environmental support'.*

At the other end of the continuum, Craik continued, we find 'procedural' tasks such as learning to read mirror-image script or solve jigsaw puzzles. These require relatively little self-initiated processing, because there is no need to go beyond the information provided by the environment to reconstruct details of the event, as in recall, or details of the original context of occurrence, as in recognition.

On the basis of this line of reasoning, Craik arranged experimental paradigms for memory retrieval in an order that is supposed to reflect the degree to which retrieval operations are either driven by the environment or by self-initiated activities (Figure I). On the basis of assumptions that normal aging depletes attentional resources and that resource demands increase monotonically with the amount of self-initiated activity, he hypothesized that the magnitude of age-related performance impairments should increase with the need for self-initiated processing. The results of a meta-analysis by La Voie and Light [61] are in good agreement with this hypothesis (Figure I; cf. [62]): the effect sizes of the performance advantage of younger over older adults are large for free recall, moderate for recognition memory, and small for associative and item priming (i.e., paradigms taxing procedural learning).

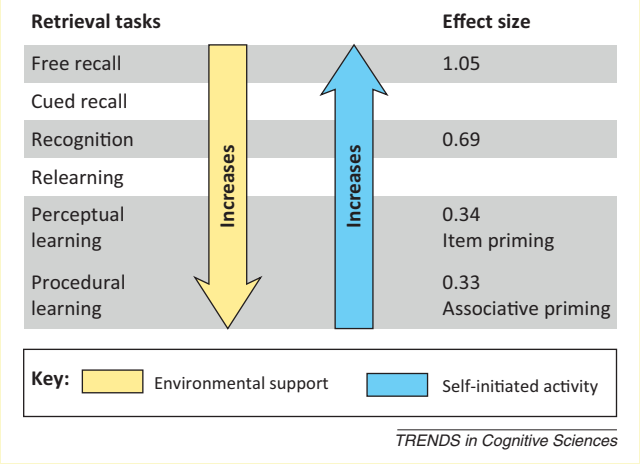

Figure I. A hypothetical rank order of the relative importance of environmental support and self-initiated processing for different experimental paradigms of learning and memory. The numbers to the right of the figure are based on a meta-analysis by La Voie and Light [61]. They show effect size estimates for the performance advantage of younger over older adults. The data follow the hypothesized order [62]. Adapted from Craik [1] with permission.

The 0-dB difference condition served as the baseline intensity and was adapted to each participant's individual hearing threshold. Twelve different dichotic syllable pairs were presented twice for each of the nine interaural intensity conditions. Attentional focus was manipulated by instructing the participants to focus on the right ear, on the left ear, or on both ears (neutral focus). When stimulus of the attended ear is louder, then attention is facilitated by saliency; however, when stimulus of the attended ear is softer, then attention has to overcome the saliency advantage of stimuli presented to the unattended ear. Across all interaural intensity conditions, younger adults were capable of flexibly focusing their attention on auditory inputs from either the right or left ear (Figure 2A). In stark contrast to younger adults, the performance of older adults was driven almost exclusively by perceptual saliency, with attentional focus having little effect on performance (Figure 2B). In a follow-up event-related potential (ERP) study, Passow *et al.* observed a late negativity at fronto-central and parietal electrodes in younger adults that was sensitive to perceptual–attentional conflicts and correlated positively with task performance [10]. In older adults, this component was absent.

The findings reported thus far show that auditory stimuli entrain the cognitive systems of older adults in relatively mandatory ways that are not easily modulated or overcome by attentional control. In the visual domain, the picture is similar. Using a cued change detection task with hemifield presentation introduced by Vogel *et al.* [11], several studies have found that older adults are more likely to encode and process distractors than younger adults are [12,13]. Following up on a paradigm introduced by Vogel and colleagues, Sauseng *et al.* found that the amplitude of alpha oscillations during the retention interval is greater ipsilaterally than contralaterally to the attended hemifield [14]. The authors also noted that the lateralized difference in alpha power increased with load and predicted individual WM capacity, confirming that alpha oscillations play a role in inhibitory processing [15,16]. On the basis of these findings, Sander *et al.* compared inhibitory control over WM contents in children, younger adults, and older adults [17]. To keep task difficulty comparable across age groups, children and older adults worked under easier load conditions than younger adults did. Ipsilateral alpha oscillations were weaker in older adults than in younger adults and children, in line with less efficient inhibitory control among older adults. At the same time, older adult showed greater phase locking of alpha oscillations immediately after stimulus presentation than both younger adults and children did. These results agree with those in the auditory domain, and again suggest that high levels of phase locking among older individuals may reflect mandatory stimulus processing that is not easily modulated by task requirements.

Other studies with visual stimuli have confirmed that older adults have difficulties in resisting indiscriminate entrainment by distractors, disengaging from distracting information, or both [12,18–25] (for general accounts, see [4,5,26]). For instance, Störmer *et al.* found that normal aging compromises early multifocal visual attention