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Review

Cognitive Control As a Double-Edged Sword

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Cognitive control, the ability to limit attention to goal-relevant information, aids performance on a wide range of laboratory tasks. However, there are many day-to-day functions which require little to no control and others which even benefit from reduced control. We review behavioral and neuroimaging evidence demonstrating that reduced control can enhance the performance of both older and, under some circumstances, younger adults. Using healthy aging as a model, we demonstrate that decreased cognitive control benefits performance on tasks ranging from acquiring and using environmental information to generating creative solutions to problems. Cognitive control is thus a double-edged sword – aiding performance on some tasks when fully engaged, and many others when less engaged.

Trends

The ability to selectively focus attention and inhibit distraction (i.e., cognitive control) contributes to a broad set of cognitive functions aiding performance on explicit, goal-driven tasks.

Recent developments have shown that a broader focus of attention, afforded by reduced control, is more beneficial in some learning, memory, and problem-solving contexts which depend on extracting and utilizing information from a variety of sources.

In older adults, reduced control appears to provide advantages on some tasks, such as using previously acquired environmental information, learning regularities, and creative problem solving.

This processing style allows older and, under some circumstances, younger adults to handle many challenges encountered in everyday life, and possibly contributes to the high functioning of many older adults outside the lab.

Cognitive Control As a Double-Edged Sword

Reduced Cognitive Control with Age: The Upside

The ability to limit attention to goal-relevant information and inhibit, or suppress, irrelevant distraction provides extensive advantages across a range of tasks [1]. This ability, generally referred to as 'cognitive control', is associated with a set of frontoparietal regions that regulate the processing of incoming sensory information and attenuate the disruptive effects of task-irrelevant stimuli. By minimizing distraction, cognitive control enhances performance on selective attention, working memory, and various other intentional tasks that rely on a narrow focus of attention on target information. In contrast to these goal-based explicit tasks, implicit stimulus-driven tasks that depend on processing and extracting knowledge from a wealth of information benefit from a less regulated, broader focus of attention. In fact, on the latter tasks greater cognitive control may actually hinder performance.

In this article we start by briefly discussing the typical benefits of enhanced cognitive control and then review findings from the memory, learning, and creativity literatures which, taken together, suggest that reduced attentional control can actually be beneficial in a range of cognitive tasks. We elaborate on this idea using aging as a model of reduced control, and we propose that the broader scope of attention of older adults is well suited for tasks that rely less on top-down driven goals, and more on intuitive, automatic, and implicit-based learning. These tasks may involve learning statistical patterns and regularities over time, using accrued knowledge and experiences for wise decision-making, and solving problems by generating novel and creative solutions. This is a timely subject given the attention and resources dedicated to brain-training programs that aim to modify the cognitive performance of older adults to mirror that of younger adults [2–5], rather than to the nature of tasks and contexts that can be exploited based on age-specific cognitive profiles.

An Optimal Cognitive Pattern Is Context-Dependent

Cognitive Control Benefits

The advantages of enhanced cognitive control extend across a wide range of attention and memory tasks. For example, evidence indicates that the number of items that can be maintained

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in working memory, or working memory capacity, is associated with the ability to inhibit irrelevant items and prevent them from gaining access to working memory [6]. That is, high-capacity individuals have better cognitive control and are more efficient at storing only relevant items, relative to low-capacity individuals, who additionally encode and maintain access to capacity-consuming irrelevant items (see also [7,8]).

Recent studies also show that cognitive control contributes to memory retrieval by resolving interference from competing memories. In particular, the ability to suppress related memories at retrieval, whether actually seen [9] or simply thought about [10] in the context of an experiment, contributes to memory performance, and the failure to suppress competitors accounts for age-related memory deficits ([10,11], see also [12]). This suppression mechanism has also been implicated in the motivated forgetting of unwanted or unpleasant memories, suggesting that it plays a crucial role in limiting the experiences we easily access from the past [13,14].

The benefits of cognitive control can also be seen in domains outside memory. For example, the ability to ignore distractors while reading is associated with enhanced reading speed and comprehension [15,16]. In addition, ignoring distractors has been associated with performance on measures of audiovisual speech perception [17] and processing speed [18], the latter of which correlates with fluid intelligence. Thus, taken together, evidence based on those tasks suggests that cognitive control is a domain-general mechanism that positively contributes to a broad set of cognitive functions, including working-memory capacity, fluid intelligence, and long-term memory (see [19]).

Cognitive Control Costs

In contrast to the intentional, goal-based tasks listed above are tasks that can actually be disrupted by heightened cognitive control. This is most often seen in tasks that are aided by the use of previously irrelevant information, or on tasks that generally benefit from drawing on diverse bits of information from various sources. For example, in the retrieval-induced forgetting paradigm, increased cognitive control in young adults is associated with the suppression of competing information for better retrieval of target information. However, when the suppressed non-target information becomes relevant in a future task, young adults show poor memory for that information [20]. The effect of poor memory for suppressed information is diminished, however, when reduced cognitive control (and presumably less suppression of that information) is simulated by simultaneous engagement of a secondary task [21]. A similar effect in the same paradigm is also observed when cognitive control is reduced through the disruption of a key control region (the right dorsolateral PFC) via transcranial direct current stimulation, providing more direct evidence for the role of cognitive control in impairing memory in particular situations [22]. That is, although suppression typically enhances memory by reducing interference at retrieval [9–12], there are some contexts that require knowledge of the suppressed information in which low cognitive control would provide a benefit. In settings that are more implicit, there is evidence that low cognitive control through dorsolateral PFC disruption also enhances implicit recognition memory for visual stimuli that are optimally encoded in a holistic manner (i.e., without explicit, relational strategies) [23].

Reduced cognitive control has also been shown to enhance some forms of learning and problem solving. With respect to learning, less control improves the detection of statistical patterns when encoded information exceeds working-memory capacity. This ability is seen in infants who can extract structure from complex visual and auditory stimuli [24], and it is also known to contribute to language learning in children [25,26] – populations with an immature prefrontal cortex (PFC) and a developing control system [27]. In young adults, there is evidence that effortful, control-mediated processing interferes with the learning of complex grammatical structure – which relies heavily on the automatic detection of statistical regularities [28].

Moreover, reduction of these processes through dual task engagement [29] and hypnosis [30] enhances the learning of such regularities. Finally, neural evidence indicates that effortful and automatic (implicit) sequence-learning processes, which respectively depend on the presence or absence of explicit instructions to find and learn sequences, are mediated by distinct brain activity and connectivity patterns, with engagement of the former suppressing the latter and, consequently, resulting in a failure of implicit learning [31].

With respect to problem solving, reduced cognitive control has been found to promote the application of creative solutions and facilitate the use of simple strategies when complex ones are less optimal. For example, one study [32] showed that individuals with reduced control, as measured by working-memory capacity [6,7], outperform individuals with greater control on mathematical problems that can be solved with simple and computationally undemanding strategies. That is, low-control individuals in the study were more able to access and apply the simple strategy and fixated less on solving the problem using more-complex algorithms. In addition, successful performance on creativity tasks, such as the unusual uses task, is associated with deactivation in frontal control regions [33] and is enhanced with disruption of the left dorsolateral PFC [34].

In sum, although enhanced cognitive control confers benefits in largely goal-based contexts, it is clear that in particular memory, learning, and problem-solving contexts reduced control can provide a benefit, such that individuals with lower control are at an advantage. We next shift our focus to aging and provide examples of how the cognitive pattern of older adults is optimal for tasks that depend on reduced control, which may well be the types of tasks that are encountered often in daily life.

One Moment's Distraction Is Another Moment's Solution

A major illustration of reduced cognitive control is a decreased ability to filter out distractors or irrelevant information encountered in the presence of goal-relevant or target information [1]. Behavioral [35,36] and neural [37–39] evidence provides compelling support for the notion that older adults are more susceptible to distracting information than are younger adults. While the processing of such information can disrupt performance on a concurrent task [15–18,40], recent evidence indicates that knowledge of distractors can actually boost the performance of older adults.

One study [41], for example, showed that, unlike younger adults, older adults who performed a one-back task on pictures with superimposed distractor words showed a benefit from the distractors on a word-fragment completion task presented after a delay period. This finding suggests that older adults maintain perceptual knowledge of previous irrelevant information and can use that knowledge to benefit performance. In addition, recent evidence has shown that older adults benefit from conceptual knowledge of distractors on subsequent conceptually based general knowledge tasks [42], providing more support to the notion that they can generally take advantage of previous irrelevant information despite changing contexts and the passage of time. Finally, studies have demonstrated that the broader attentional field and processing of distractors of older adults can be used as a rehearsal tool to boost their learning of new information and reduce age-related forgetting (Figure 1) [43,44], suggesting alternative intervention strategies aimed at capitalizing on the reduced control of older adults (Box 1).

Learning More about the Surrounding Environment

Arguably, one of the biggest advantages of an inefficient cognitive control system is the ability to implicitly detect statistical patterns embedded in perceived stimuli. As noted earlier, this ability is associated with language learning in infants and children who have yet to develop a mature control system [24–26].

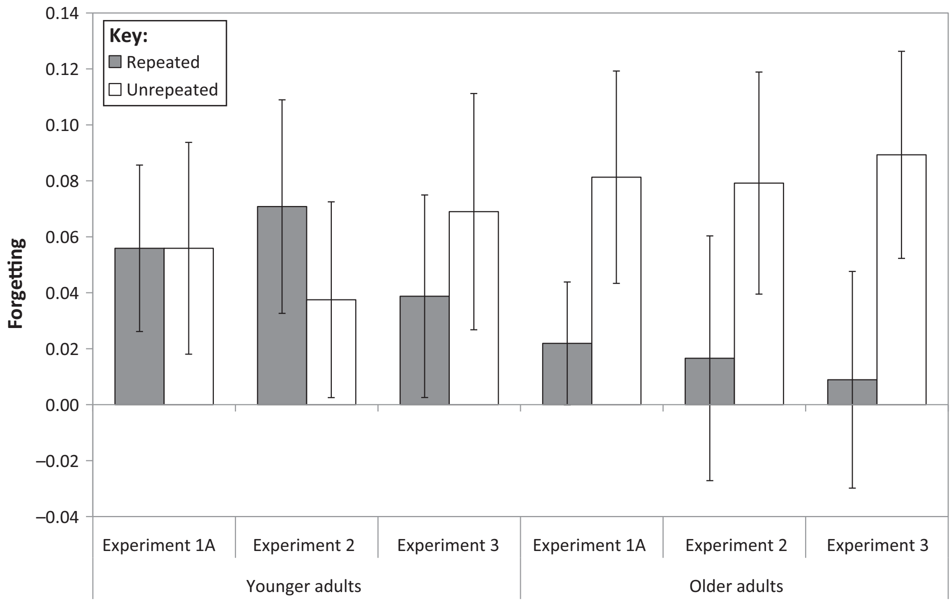

Figure 1. Reduced Forgetting of Words Repeated As Distractors Between an Initial and a Delayed Free-Recall Task in Older, But Not Younger, Adults. Across three experiments, older and younger adults recalled a list of words on an initial test and again on a surprise test after a 15 minute delay period. Half of the words on the list were repeated as distractors on a one-back task during the delay period, and the other half were unrepeated. Forgetting-scores for both word types were calculated by subtracting the proportion of words recalled on the surprise test after the delay period from the proportion of words recalled on the initial test. Relative to younger adults, who showed forgetting for both repeated and unrepeated words, older adults showed no forgetting for words repeated as distractors. This suggests that the tendency of older adults to process irrelevant information can be used to enhance memory for previously learned information. Error bars show 95% confidence intervals of the mean. Figure adapted from [43].

Box 1. Capitalizing on Reduced Cognitive Control

Reduced cognitive control is typically seen as a source of cognitive failure. Brain-training programs, which form a growing multimillion-dollar industry, focus on improving cognitive control to enhance general cognitive function and moderate age-related cognitive decline. While several studies have reported positive training effects in both old and young adults [2–5,92,93], the efficacy and generalizability of these training programs has been a topic of increasing debate. For example, several reports have demonstrated a lack of far-transfer effects, or general improvement in cognitive function, as a result of cognitive training [94–97]. In healthy older adults, in particular, a recent meta-analysis (which does not even account for unpublished negative results) showed small to non-existent training effects, depending on the training task and procedure [98], and other studies demonstrated a lack of maintenance [99] and far-transfer [100] effects. Moreover, even when modest intervention effects are reported, there is no evidence that these improvements influence the rate of cognitive decline over time [100].

Collectively, these results question whether interventions aimed at restoring youth-like levels of cognitive control in older adults are the best approach. One alternative to training is to take advantage of the natural pattern of cognition of older adults and capitalize on their propensity to process irrelevant information. A recent set of studies demonstrated that distractors can be used to enhance memory for previously or newly learned information in older adults. For example, one study illustrated that, unlike younger adults, older adults show minimal to no forgetting of words they learned on a previous memory task, when those words are presented again as distractors in a delay period between the initial and subsequent, surprise memory task [43]. That is, exposure to distractors in the delay period served as a rehearsal episode to boost memory for previously learned information (Figure 1). Similarly, other studies showed that older adults show better learning for new target information that was previously presented as distraction [44,101]. In one study [44], for example, older adults showed enhanced associative memory for faces and names (a task which typically shows large age deficits [102]) when the names were previously presented as distractors on the same faces in an earlier task. Taken together, these findings suggest that greater gains may be made by interventions that capitalize on reduced control by designing environments or applications that enhance learning and memory through presentation of distractors.

Box 2. Cognitive Aging and Decision-Making

Old age and wisdom are commonly linked to one another. While research on this topic has yielded mixed findings, considerable evidence suggests that older adults make better decisions than young adults when they can incorporate their knowledge and experiences into those decisions. For example, although several studies have found an association between declining cognitive abilities and poor decision-making in older adults [103–105], other studies have demonstrated that this association is context-dependent (i.e., restricted to decisions that are highly dependent on cognitive control or 'fluid' cognitive abilities [106,107]). For other decision types, the knowledge or 'crystallized' cognitive abilities of older adults offset their lower levels of cognitive control and can result in better and more informed decisions relative to young adults [53,54,86]. Hence, in particular circumstances, the greater knowledge of older adults can provide an alternative route to better decisions.

Given the natural tendency of older adults to carry previously acquired relevant or irrelevant information into new contexts [41,42,45,46], it is possible that such a tendency provides them with an advantage when making decisions that rely on applying accumulated knowledge. Indeed, one study [52] demonstrated that older adults outperform young adults on decision-making tasks when the optimal choice depends on holistic learning of a reward structure based on previous trials (see also [55]). Other studies have also demonstrated that older adults are better than young adults at approximating the value of future rewards, which ultimately leads to more optimal decisions and is possibly linked to their greater experience. In particular, in tasks involving immediate versus future monetary gains and losses, older adults show a lesser tendency to discount future rewards than do young adults [108]. Neurally, older adults show equivalent activity in the nucleus accumbens (which processes reward) for both immediate and delayed rewards, while young adults show greater activity for immediate relative to future rewards [109,110]. Finally, the accumulated experiences of older adults likely contribute to their reduced susceptibility to the sunk-cost fallacy; relative to young adults, older adults are better at making decisions to discontinue failing commitments when prior investments have been made [111,112]. Taken together, these studies suggest that the extended knowledge or 'wisdom' of older adults may support decision-making that relies on prior experience. Given that real-world decisions rarely occur in isolation and often depend on past experiences, older adults may be better equipped than young adults to make such decisions.

In the case of older adults, reduced cognitive control engagement can represent an instance of an increased opportunity to learn more than younger adults about the world around them. Indeed, there is evidence that older adults show more learning than younger adults of item co-occurrences in space and time [45–47]. Furthermore, older adults not only show learning of statistical regularities in attended streams of information [48], but they also do so for non-attended streams [49], consistent with the notion that they possess more information about their surroundings relative to younger adults. Hence, older adults may know more about how events covary in everyday life, and this may allow them to more easily infer causation [50]. In support of this hypothesis, recent evidence suggests that children (with their reduced cognitive control) are better at learning causal relationships than are young adults [51]. Finally, as discussed in Box 2, there is evidence that the superior ability of older adults to extract structure and patterns over time and changing contexts contributes to their wise decision-making [52–55].

Creativity and Problem Solving

Given that cognitive control narrows the focus of attention to a limited set of stimuli, and minimizes the impact of external and internal sources of distraction, control can hinder performance on open-ended tasks that benefit more from spontaneous, uninhibited thought. Tests of creativity fall under that category. Creativity is partly mediated by an ability to approach tasks or problems in a novel manner and reach solutions by relying on broad associations formed between diverse bits of information from a wide variety of sources [56]. This suggests that engagement of cognitive control may impede creativity by focusing attention on a limited number of non-optimal strategies. Lending support to this hypothesis, studies have demonstrated that creative thinking and musical improvisation are associated with decreased activity in control regions [33,57]. Even more compelling support comes from patients with lateral frontal lesions who outperform controls on insight problems [58], and from patients in the early stages of frontotemporal dementia who develop new creative musical and artistic skills [59].

Collectively, the evidence suggests that reduced cognitive control in older adults may boost creativity and their ability to solve insight problems [60]. Their lack of ability to downregulate distractors from the past or present might actually provide a benefit to creative, open-ended tasks because they might contain useful hints. For example, unlike younger adults, older adults show improved performance on a remote-associates task (a creativity task that requires participants to produce a fourth word distantly related to word triplets – e.g., 'space' for the three words ship, outer, and crawl) when current or previous distracting information provides hints or solutions to the problems [61,62]. Similarly, evidence suggests that, in young adults, creativity is associated with the tendency to process distractor cues presented in the periphery of awareness [63,64] – a cognitive disposition that is common among older adults (i.e., young

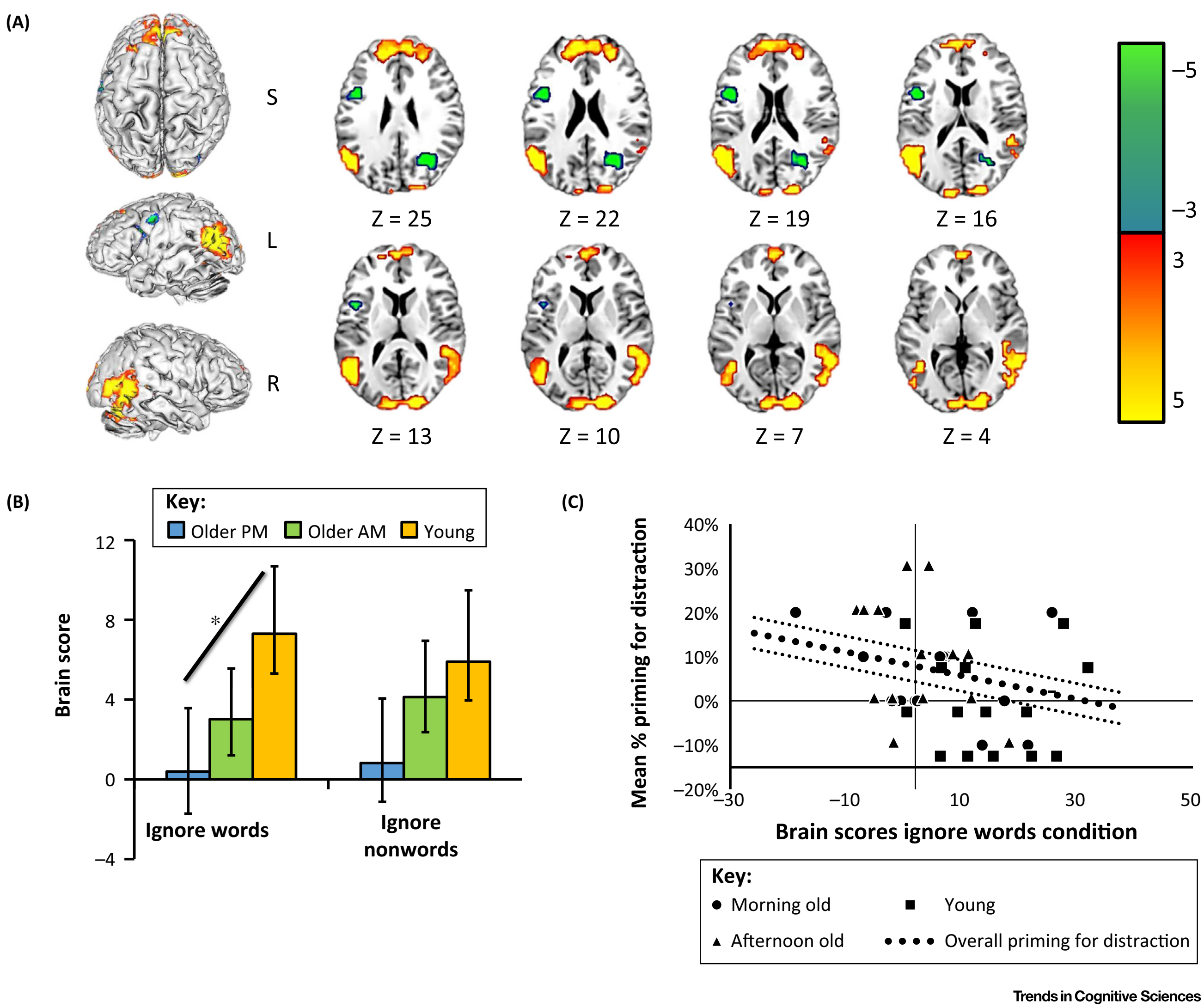

Figure 2. Increased Activation in Control Regions in Older Adults Tested at a Peak Time of Day. Three participant groups (young adults, older adults tested at a peak time of day or morning, and older adults tested at a nonpeak time of day or evening) completed a distraction control task while being scanned. Participants first performed a one-back task on pictures with superimposed irrelevant words or nonwords, and then performed a word-fragment completion to test their knowledge for the previous distractor words. A set of control regions – warm-colored regions in (A) – showed increased activation during the one-back task. As demonstrated in (B), only young adults and older adults tested in the morning showed significant activation (indicated by the 'brain score') in those regions, with young adults showing the greatest activation. For all three groups there was a linear increase (statistically significant for the more difficult ignore-words condition only) in activation from the older adults tested in the evening, to those tested in the morning, to young adults. Greater activation in those regions was associated with reduced knowledge or priming for previous distractors across all three groups, as illustrated in (C). This shows that the level of cognitive control is influenced by factors such as synchrony between time of performing a task and individual circadian arousal patterns. Error bars show 95% confidence intervals of the mean. Figure adapted from [78]. Abbreviations: L, left; Older PM/AM, older adults tested in the evening/morning; R, right; S, sagittal.

adults who behave more like older adults tend to be more creative). In addition, neuroimaging evidence [65,66] demonstrates that the generation of creative ideas is associated with activation of the default mode network (a network of brain regions involved in internally based cognition that is typically deactivated during externally oriented tasks [67]) and interaction with the executive control network (a network involved in the top-down selection of stimuli based on task demands [68]). Older adults show preserved coupling between the default and executive control networks when attention must be directed inward (e.g., during autobiographical planning) [69,70], and this may contribute to the maintained performance of older adults on tests of creativity [60,71], given the similarity in network interaction patterns. Finally, it is worth noting that, although reduced control may contribute to the generation of creative ideas, creativity is typically considered to be a twofold process that relies on a generative component as well as an evaluative component that assesses the usefulness of the generated ideas [65,66,72–74]. The latter component is thought to depend on heightened cognitive control, which allows individuals to evaluate whether the generated ideas fit the demands of the task at hand and to select those that are relevant to the task. Thus, although the reduced control of older adults may boost the generative component, it may also hinder the evaluative component that is essential for some creativity tasks.

The Dynamic Nature of Cognitive Control

Although the degree of cognitive control is associated with general trends, such as its decline with age, it is far from being a stable construct. Multiple factors influence the efficiency of cognitive control in both older and younger adults, and these factors play a role in the magnitude of the age differences seen on a variety of widely used tasks. This suggests the interesting possibility that individuals from each age group can show tendencies more characteristic of the other group based on those factors. A growing number of studies support this idea.

One of the factors that impacts on cognitive control is the synchrony between the time of performing a task and individual circadian arousal patterns (see [75]). Numerous studies demonstrate that control varies in a circadian fashion, with older adults generally showing peak efficiency in the morning and younger adults in the evening [76]. When younger adults are tested at an off-peak time of day (morning), they display older adult-like cognitive patterns. These include greater encoding of irrelevant information [61], greater implicit memory for such information [41], and enhanced creativity and insight in problem solving [77]. On the other hand, improving cognitive control function in older adults by testing them at a peak time of day reduces implicit memory of irrelevant information, and is associated with increased activation of fronto-parietal control regions during a selective attention task (Figure 2) [78].

In addition to time of day, cognitive control is influenced by other factors including mood and alcohol consumption. Moderate alcohol intoxication and positive mood induction have both been shown to provide younger adults with some of the benefits of reduced cognitive control. Positive mood, for example, widens the scope of attention of younger adults [79], and increases their encoding of distractors and their ability to use those distractors when they become relevant on a future task [80]. Moderate alcohol intoxication has a similar effect and improves creative problem solving [81] and the ability to quickly detect changes in a complex visual scene [82].

Concluding Remarks

Several lines of evidence indicate that a reduction in cognitive control actually facilitates performance in particular learning, memory, and problem-solving contexts. Although high levels of control are necessary for goal-based tasks that depend on a narrow focus of attention and on interference resolution, low levels of control can boost performance on open-ended tasks that rely on the use of information from diverse sources and after delays (Figure 3, Key Figure). This lower level of control, which is typical of older adults, is associated with automatic forms of

Outstanding Questions

What is the contribution of reduced cognitive control to everyday behavior? Although reduced control can contribute to idea generation in a range of situations, evaluation is also required for success, and this process likely relies on control. Thus, how do these different processes interact across a range of everyday situations, and what is the overall benefit of reduced control to performance?

Very much of what we remember in everyday life comes to mind involuntarily, cued by environmental stimuli. Does the frequency of these memories, which require no cognitive control, increases with old age, and are these memories more or less accurate than intentionally retrieved memories (shown to be susceptible to falsehoods)?

What is the role of the default mode network in the tendency of older individuals to carry previous information into new tasks? Given that older adults generally show less deactivation of the default network than young adults, could it be the likely source of continued influence of recently encountered information on current task performance?

Although older adults often show poorer performance than young adults on intentional laboratory-based tasks, the degree of disruption is influenced by both general knowledge and by the personal relevance of the task. Age differences can disappear even on difficult tasks for familiar stimuli (e.g., grocery prices). Do older adults selectively engage high levels of control on meaningful tasks, and, if so, does that tendency conserve their declining control abilities?

Little is known about the tradeoff, if any, between the processing of irrelevant versus relevant information. Does the encoding of distracting information (e.g., non-relevant words in a one-back task on pictures) come at the expense of relevant information (e.g., memory for the pictures themselves)?

Key Figure

Relationship between Task Performance and Level of Cognitive Control

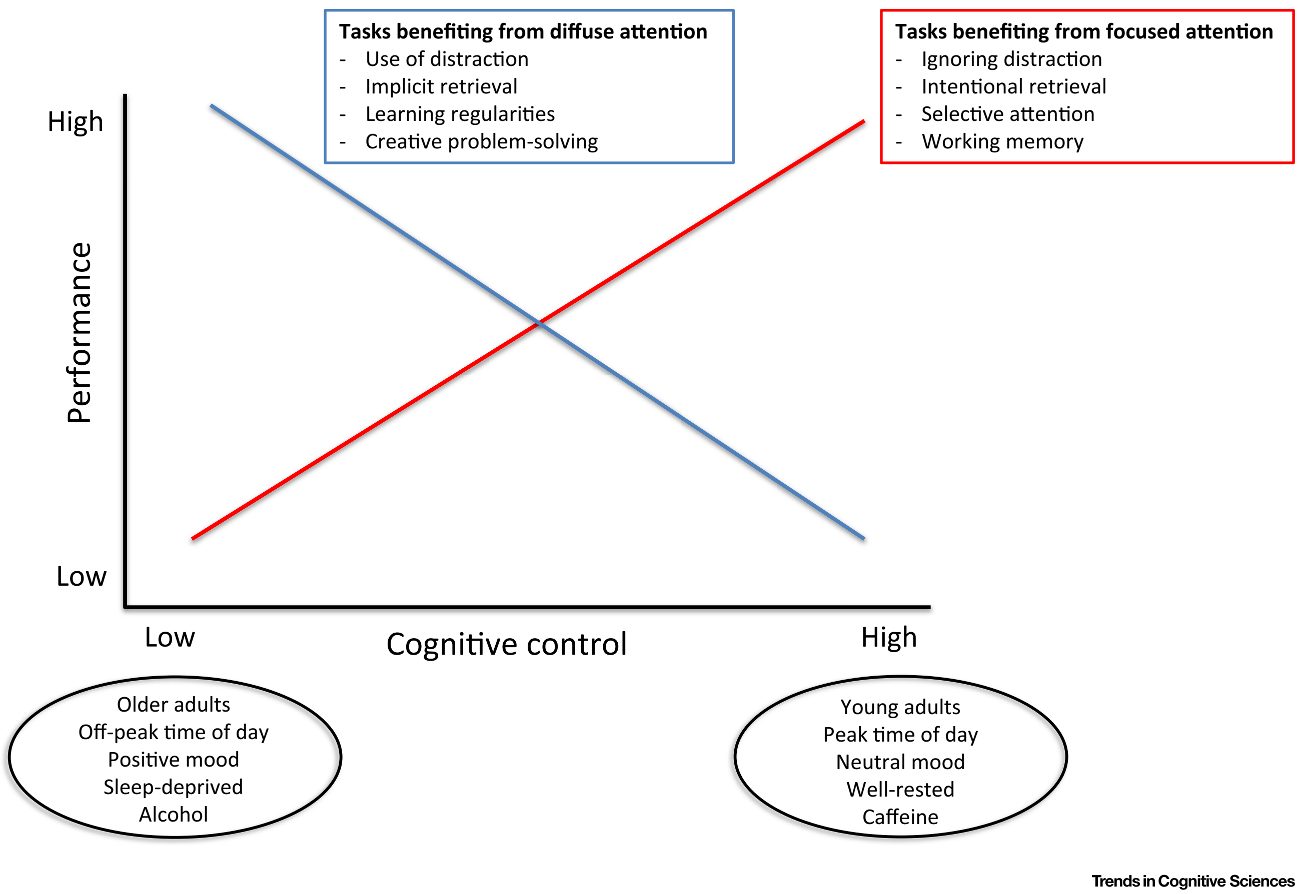

Figure 3. Different levels of cognitive control are optimal for different types of tasks. Reduced cognitive control resulting from factors such as old age and alcohol intoxication aids tasks that benefit from diffuse attention. By contrast, high cognitive control, typical of young adults and of being tested at a peak time of day, aids tasks that benefit from focused attention. Engaging a non-optimal level of control (based on task requirements) hurts performance.

learning that guide everyday behavior [83,84] and influence intuitive judgment and decision-making [85]. In support of that notion, old age is associated with the ability to incorporate lifelong experiences into wise decision-making [52–54,86]. While it is important to acknowledge that these benefits may come at the expense of performance deficits on various tasks that depend on selective attention (see [87–89]), one can argue that the cognitive pattern of older adults is well suited for many challenges encountered in everyday life. For example, an individual does not know whether environmental stimuli irrelevant in one context will become relevant in a future one, and they do not know *a priori* what environmental patterns or co-occurrences need to be learned. Implicit learning of that information, afforded by reduced control, may aid problem solving in those settings, although further work will be necessary to show a direct link between reduced control and performance (see Outstanding Questions). It is no surprise then that age-related deficits often observed on laboratory-based tasks do not always extend to everyday life [54,90], where many healthy older adults are not only high-functioning but also strong contributors to society [91].

Acknowledgments

We are grateful to Jordana Wynn for her comments on earlier versions of the manuscript and John Anderson for his assistance with the figures. This work was supported by the Canadian Institutes of Health Research (Grant MOP89769 to Lynn Hasher), and by the National Sciences and Engineering Research Council of Canada (Grant 487235 to Lynn Hasher and Alexander Graham Bell Canada Graduate Scholarship–Doctoral to Tarek Amer).

References

1. Hasher, L. *et al.* (1999) Inhibitory control, circadian arousal, and age. In *Attention and Performance XVII, Cognitive Regulation of Performance: Interaction of Theory and Application* (Gopher, D. and Koriat, A., eds), pp. 653–675, MIT Press
2. Anguera, J.A. *et al.* (2013) Video game training enhances cognitive control in older adults. *Nature* 501, 97–101
3. Mahncke, H.W. *et al.* (2006) Memory enhancement in healthy older adults using a brain plasticity-based training program: a randomized, controlled study. *Proc. Natl. Acad. Sci. U. S. A.* 103, 12523–12528
4. Zendel, B.R. *et al.* (2016) The impact of attentional training on event-related potentials in older adults. *Neurobiol. Aging* 47, 10–22
5. Toril, P. *et al.* (2014) Video game training enhances cognition of older adults: a meta-analytic study. *Psychol. Aging* 29, 706–716
6. Vogel, E.K. *et al.* (2005) Neural measures reveal individual differences in controlling access to working memory. *Nature* 438, 500–503
7. Lustig, C. *et al.* (2001) Working memory span and the role of proactive interference. *J. Exp. Psychol. Gen.* 130, 199–207
8. Shipstead, Z. *et al.* (2014) The mechanisms of working memory capacity: primary memory, secondary memory, and attention control. *J. Mem. Lang.* 72, 116–141
9. Healey, M.K. *et al.* (2010) Direct evidence for the role of inhibition in resolving interference in memory. *Psychol. Sci.* 21, 1464–1470
10. Healey, M.K. *et al.* (2014) Below-baseline suppression of competitors during interference resolution by younger but not older adults. *Psychol. Sci.* 25, 145–151
11. Healey, M.K. *et al.* (2013) The role of suppression in resolving interference: evidence for an age-related deficit. *Psychol. Aging* 28, 721–728
12. Murayama, K. *et al.* (2014) Forgetting as a consequence of retrieval: a meta-analytic review of retrieval-induced forgetting. *Psychol. Bull.* 140, 1383–1409
13. Anderson, M.C. and Hanslmayr, S. (2014) Neural mechanisms of motivated forgetting. *Trends Cogn. Sci.* 18, 279–292
14. Benoit, R.G. *et al.* (2015) Adaptive top-down suppression of hippocampal activity and the purging of intrusive memories from consciousness. *J. Cogn. Neurosci.* 27, 96–111
15. Darowski, E.S. *et al.* (2008) Age-related differences in cognition: the role of distraction control. *Neuropsychology* 22, 638–644
16. Mund, I. *et al.* (2012) Aging and interference in story recall. *Exp. Aging Res.* 38, 20–41
17. Dey, A. and Sommers, M.S. (2015) Age-related differences in inhibitory control predict audiovisual speech perception. *Psychol. Aging* 30, 634–646
18. Lustig, C. *et al.* (2006) Distraction as a determinant of processing speed. *Psychon. Bull. Rev.* 13, 619–625
19. Unsworth, N. *et al.* (2015) Working memory delay activity predicts individual differences in cognitive abilities. *J. Cogn. Neurosci.* 27, 853–865
20. Anderson, M.C. *et al.* (1994) Remembering can cause forgetting – retrieval dynamics in long-term-memory. *J. Exp. Psychol. Learn Mem. Cogn.* 20, 1063–1087
21. Roman, P. *et al.* (2009) Retrieval-induced forgetting and executive control. *Psychol. Sci.* 20, 1053–1058
22. Penolazzi, B. *et al.* (2014) Human memory retrieval and inhibitory control in the brain: beyond correlational evidence. *J. Neurosci.* 34, 6606–6610
23. Lee, T.G. *et al.* (2013) Disruption of dorsolateral but not ventrolateral prefrontal cortex improves unconscious perceptual memories. *J. Neurosci.* 33, 13233–13237
24. Aslin, R.N. (2014) Infant learning: historical, conceptual, and methodological challenges. *Infancy* 19, 2–27
25. Chrysikou, E.G. *et al.* (2014) A matched filter hypothesis for cognitive control. *Neuropsychologia* 62, 341–355
26. Thompson-Schill, S.L. *et al.* (2009) Cognition without control: when a little frontal lobe goes a long way. *Curr. Dir. Psychol. Sci.* 18, 259–263
27. Casey, B.J. *et al.* (2000) Structural and functional brain development and its relation to cognitive development. *Biol. Psychol.* 54, 241–257
28. Finn, A.S. *et al.* (2014) When it hurts (and helps) to try: the role of effort in language learning. *PLoS One* 9, e101806
29. Cochran, B.P. *et al.* (1999) Too smart for their own good: the disadvantage of a superior processing capacity for adult language learners. *J. Mem. Lang.* 41, 30–58
30. Nemeth, D. *et al.* (2013) Boosting human learning by hypnosis. *Cereb. Cortex* 23, 801–805
31. Fletcher, P.C. *et al.* (2005) On the benefits of not trying: brain activity and connectivity reflecting the interactions of explicit and implicit sequence learning. *Cereb. Cortex* 15, 1002–1015
32. Beilock, S.L. and DeCaro, M.S. (2007) From poor performance to success under stress: working memory, strategy selection, and mathematical problem solving under pressure. *J. Exp. Psychol. Learn. Mem. Cogn.* 33, 983–998
33. Chrysikou, E.G. and Thompson-Schill, S.L. (2011) Dissociable brain states linked to common and creative object use. *Hum. Brain Mapp.* 32, 665–675
34. Chrysikou, E.G. *et al.* (2013) Noninvasive transcranial direct current stimulation over the left prefrontal cortex facilitates cognitive flexibility in tool use. *Cogn. Neurosci.* 4, 81–89
35. Rabbitt, P. (1965) An age-decrement in the ability to ignore irrelevant information. *J. Gerontol.* 20, 233–238
36. Tsvetanov, K.A. *et al.* (2013) Age-related differences in selection by visual saliency. *Atten. Percept. Psychophys.* 75, 1382–1394
37. Campbell, K.L. *et al.* (2012) Age differences in the frontoparietal cognitive control network: implications for distractibility. *Neuropsychologia* 50, 2212–2223
38. Chadick, J.Z. *et al.* (2014) Structural and functional differences in medial prefrontal cortex underlie distractibility and suppression deficits in ageing. *Nat. Commun.* 5, 4223
39. Schmitz, T.W. *et al.* (2010) Failing to ignore: paradoxical neural effects of perceptual load on early attentional selection in normal aging. *J. Neurosci.* 30, 14750–14758
40. Fisher, A.V. (2014) Visual environment, attention allocation, and learning in young children: when too much of a good thing may be bad. *Psychol. Sci.* 25, 1362–1370
41. Rowe, G. *et al.* (2006) Attentional disregulation: a benefit for implicit memory. *Psychol. Aging* 21, 826–830
42. Amer, T. and Hasher, L. (2014) Conceptual processing of distractors by older but not younger adults. *Psychol. Sci.* 25, 2252–2258
43. Biss, R.K. *et al.* (2013) Distraction can reduce age-related forgetting. *Psychol. Sci.* 24, 448–455
44. Weeks, J.C. *et al.* (2016) Face–name learning in older adults: a benefit of hyper-binding. *Psychon. Bull. Rev.* 23, 1559–1565
45. Campbell, K.L. *et al.* (2010) Hyper-binding: a unique age effect. *Psychol. Sci.* 21, 399–405
46. James, T. *et al.* (2016) Age-related deficits in selective attention during encoding increase demands on episodic reconstruction during context retrieval: an ERP study. *Neuropsychologia* 86, 66–79

47. Campbell, K.L. *et al.* (2014) Hyper-binding across time: age differences in the effect of temporal proximity on paired-associate learning. *J. Exp. Psychol. Learn Mem. Cogn.* 40, 293–299
48. Schwab, J.F. *et al.* (2016) Aging and the statistical learning of grammatical form classes. *Psychol. Aging* 31, 481–487
49. Campbell, K.L. *et al.* (2012) Age differences in visual statistical learning. *Psychol. Aging* 27, 650–656
50. Griffiths, T.L. and Tenenbaum, J.B. (2005) Structure and strength in causal induction. *Cogn. Psychol.* 51, 334–384
51. Lucas, C.G. *et al.* (2014) When children are better (or at least more open-minded) learners than adults: developmental differences in learning the forms of causal relationships. *Cognition* 131, 284–299
52. Worthy, D.A. *et al.* (2011) With age comes wisdom: decision making in younger and older adults. *Psychol. Sci.* 22, 1375–1380
53. Li, Y. *et al.* (2013) Complementary cognitive capabilities, economic decision making, and aging. *Psychol. Aging* 28, 595–613
54. Li, Y. *et al.* (2015) Sound credit scores and financial decisions despite cognitive aging. *Proc. Natl. Acad. Sci. U. S. A.* 112, 65–69
55. Worthy, D.A. *et al.* (2016) Neural correlates of state-based decision-making in younger and older adults. *Neuroimage* 130, 13–23
56. Wiley, J. and Jarosz, A.F. (2012) Working memory capacity, attentional focus, and problem solving. *Curr. Dir. Psychol. Sci.* 21, 258–262
57. Limb, C.J. and Braun, A.R. (2008) Neural substrates of spontaneous musical performance: an fMRI study of jazz improvisation. *PLoS One* 3, e1679
58. Reverberi, C. *et al.* (2005) Better without (lateral) frontal cortex? Insight problems solved by frontal patients. *Brain* 128, 2882–2890
59. Seeley, W.W. *et al.* (2008) Unravelling bolero: progressive aphasia, transmodal creativity and the right posterior neocortex. *Brain* 131, 39–49
60. Leon, S.A. *et al.* (2014) Divergent task performance in older adults: declarative memory or creative potential? *Creat. Res. J.* 26, 21–29
61. May, C.P. (1999) Synchrony effects in cognition: the costs and a benefit. *Psychon. Bull. Rev.* 6, 142–147
62. Kim, S. *et al.* (2007) Aging and a benefit of distractibility. *Psychon. Bull. Rev.* 14, 301–305
63. Ansburg, P.I. and Hill, K. (2003) Creative and analytic thinkers differ in their use of attentional resources. *Pers. Individ. Dif.* 34, 1141–1152
64. Carson, S.H. *et al.* (2003) Decreased latent inhibition is associated with increased creative achievement in high-functioning individuals. *J. Pers. Soc. Psychol.* 85, 499–506
65. Ellamil, M. *et al.* (2012) Evaluative and generative modes of thought during the creative process. *Neuroimage* 59, 1783–1794
66. Beaty, R.E. *et al.* (2016) Creative cognition and brain network dynamics. *Trends Cogn. Sci.* 20, 87–95
67. Raichle, M.E. *et al.* (2001) A default mode of brain function. *Proc. Natl. Acad. Sci. U. S. A.* 98, 676–682
68. Vincent, J.L. *et al.* (2008) Evidence for a frontoparietal control system revealed by intrinsic functional connectivity. *J. Neurophysiol.* 100, 3328–3342
69. Spreng, R.N. and Schacter, D.L. (2012) Default network modulation and large-scale network interactivity in healthy young and old adults. *Cereb. Cortex* 22, 2610–2621
70. Turner, G.R. and Spreng, R.N. (2015) Prefrontal engagement and reduced default network suppression co-occur and are dynamically coupled in older adults: the default–executive coupling hypothesis of aging. *J. Cogn. Neurosci.* 27, 2462–2476
71. Madore, K.P. *et al.* (2016) Divergent creative thinking in young and older adults: extending the effects of an episodic specificity induction. *Mem. Cognit.* 44, 974–988
72. Campbell, D.T. (1960) Blind variation and selective retentions in creative thought as in other knowledge processes. *Psychol. Rev.* 67, 380–400
73. Weisberg, R. (1986) *Creativity: Genius and Other Myths,* WH Freeman/Times Books/Henry Holt & Co
74. Gabora, L. (2010) Revenge of the 'neurds': characterizing creative thought in terms of the structure and dynamics of memory. *Creat. Res. J.* 22, 1–13
75. May, C.P. *et al.* (2005) Implicit memory, age, and time of day – paradoxical priming effects. *Psychol. Sci.* 16, 96–100
76. Yoon, C. *et al.* (1999) Aging, circadian arousal patterns, and cognition. In *Aging, Cognition and Self Reports* (Schwarz, N. *et al.*, eds), pp. 117–143, Psychological Press
77. Wieth, M.B. and Zacks, R.T. (2011) Time of day effects on problem solving: when the non-optimal is optimal. *Think. Reason.* 17, 387–401
78. Anderson, J.A.E. *et al.* (2014) Timing is everything: age differences in the cognitive control network are modulated by time of day. *Psychol. Aging* 29, 648–657
79. Fredrickson, B.L. and Branigan, C. (2005) Positive emotions broaden the scope of attention and thought–action repertoires. *Cogn. Emot.* 19, 313–332
80. Biss, R.K. and Hasher, L. (2011) Delighted and distracted: positive affect increases priming for irrelevant information. *Emotion* 11, 1474–1478
81. Jarosz, A.F. *et al.* (2012) Uncorking the muse: alcohol intoxication facilitates creative problem solving. *Conscious. Cogn.* 21, 487–493
82. Colflesh, G.J.H. and Wiley, J. (2013) Drunk, but not blind: the effects of alcohol intoxication on change blindness. *Conscious. Cogn.* 22, 231–236
83. Chun, M.M. and Jiang, Y. (1998) Contextual cueing: implicit learning and memory of visual context guides spatial attention. *Cogn. Psychol.* 36, 28–71
84. Chun, M.M. and Jiang, Y. (2003) Implicit, long-term spatial contextual memory. *J. Exp. Psychol. Learn Mem. Cogn.* 29, 224–234
85. Sedlmeier, P. (2005) From associations to intuitive judgment and decision making: implicitly learning from experience. In *The Routines of Decision Making* (Tilmann, B. and Haberstroh, S., eds), pp. 83–99, Lawrence Erlbaum Associates
86. Grossmann, I. *et al.* (2010) Reasoning about social conflicts improves into old age. *Proc. Natl. Acad. Sci. U. S. A.* 107, 7246–7250
87. Craik, F.I. and Salthouse, T.A. (2011) *The Handbook of Aging and Cognition,* Psychology Press
88. Grady, C. (2012) The cognitive neuroscience of ageing. *Nat. Rev. Neurosci.* 13, 491–505
89. Lustig, C. and Jantz, T. (2015) Questions of age differences in interference control: when and how, not if? *Brain Res.* 1612, 59–69
90. Salthouse, T. (2012) Consequences of age-related cognitive declines. *Annu. Rev. Psychol.* 63, 201–226
91. Gonzales, E. *et al.* (2015) Increasing opportunities for the productive engagement of older adults: a response to population aging. *Gerontologist* 55, 252–261
92. Jaeggi, S.M. *et al.* (2008) Improving fluid intelligence with training on working memory. *Proc. Natl. Acad. Sci. U. S. A.* 105, 6829–6833
93. Klingberg, T. (2010) Training and plasticity of working memory. *Trends Cogn. Sci.* 14, 317–324
94. Owen, A.M. *et al.* (2010) Putting brain training to the test. *Nature* 465, 775
95. Shipstead, Z. *et al.* (2012) Is working memory training effective? *Psychol. Bull.* 138, 628–654
96. Redick, T.S. *et al.* (2013) No evidence of intelligence improvement after working memory training: a randomized, placebo-controlled study. *J. Exp. Psychol. Gen.* 142, 359–379
97. von Bastian, C.C. and Eschen, A. (2016) Does working memory training have to be adaptive? *Psychol. Res.* 80, 181–194
98. Lampit, A. *et al.* (2014) Computerized cognitive training in cognitively healthy older adults: a systematic review and meta-analysis of effect modifiers. *Plos Med.* 11, e1001756

99. Ballesteros, S. *et al.* (2015) A randomized controlled trial of brain training with non-action video games in older adults: results of the 3-month follow-up. *Front. Aging Neurosci.* 7, 45

100. Salthouse, T.A. (2015) Do cognitive interventions alter the rate of age-related cognitive change? *Intelligence* 53, 86–91

101. Thomas, R.C. and Hasher, L. (2012) Reflections of distraction in memory: transfer of previous distraction improves recall in younger and older adults. *J. Exp. Psychol. Learn Mem. Cogn.* 38, 30–39

102. Naveh-Benjamin, M. *et al.* (2004) The associative memory deficit of older adults: further support using face-name associations. *Psychol. Aging* 19, 541–546

103. Boyle, P.A. *et al.* (2012) Poor decision making is a consequence of cognitive decline among older persons without Alzheimer's disease or mild cognitive impairment. *PLoS One* 7, e43647

104. Boyle, P.A. *et al.* (2013) Cognitive decline impairs financial and health literacy among community-based older persons without dementia. *Psychol. Aging* 28, 614–624

105. Henninger, D.E. *et al.* (2010) Processing speed and memory mediate age-related differences in decision making. *Psychol. Aging* 25, 262–270

106. Frey, R. *et al.* (2015) The role of cognitive abilities in decisions from experience: age differences emerge as a function of choice set size. *Cognition* 142, 60–80

107. Samanez-Larkin, G.R. and Knutson, B. (2015) Decision making in the ageing brain: changes in affective and motivational circuits. *Nat. Rev. Neurosci.* 16, 278–289

108. Loeckenhoff, C.E. *et al.* (2011) Age differences in temporal discounting: the role of dispositional affect and anticipated emotions. *Psychol. Aging* 26, 274–284

109. Samanez-Larkin, G.R. *et al.* (2011) Age differences in striatal delay sensitivity during intertemporal choice in healthy adults. *Front. Neurosci.* 5, 126

110. Eppinger, B. *et al.* (2012) Reduced sensitivity to immediate reward during decision-making in older than younger adults. *PLoS One* 7, e36953

111. Strough, J. *et al.* (2008) Are older adults less subject to the sunk-cost fallacy than younger adults? *Psychol. Sci.* 19, 650–652

112. de Bruin, W.B. *et al.* (2014) Getting older isn't all that bad: better decisions and coping when facing 'sunk costs'. *Psychol. Aging* 29, 642–647