Adaptive Decision Making and Aging

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It is a truism that different problems require different solutions. In other words, to maximize performance, individuals must select actions as a function of their fit to the problem at hand. But how does aging alter the ability to adapt behavior as a function of the problem? In this chapter, we adopt an ecological perspective on decision making that links life-span changes in core cognitive abilities to strategy use, and ultimately, decision performance in different environments or tasks. This perspective suggests that life-span changes in decision making may arise from changes in the ability to adaptively select and accurately execute decision strategies. In what follows, we first discuss the concept of decision strategies as well as potential effects of aging on strategy use. Second, we review similar concepts and empirical results from the aging literature on memory and arithmetic computation to help us inform decision-making research. Finally, we present a review of aging and adaptive decision making with an outlook on future research in this area.

AN ECOLOGICAL PERSPECTIVE ON LIFE-SPAN CHANGES IN STRATEGY USE

In Cicero’s de Senectute, Cato the Elder explains to two younger men that the key to successful aging lies not in struggling to regain the strength of youth but in using the available resources adaptively: “Nor, again, do I now miss the bodily strength of a young man... You should use what you have, and whatever you may chance to be doing, do it with all
your might.” Past and current research on aging emphasizes the importance of adaptation to the environment in dealing with changes brought about by aging (Bronfenbrenner, 1979; Lindenberger & Mayr, 2014). We aim to bring this adaptivity aspect to bear on the research on aging and decision making by introducing the perspective of ecological rationality (Gigerenzer & Todd, 1999; Mata, Pachur, et al., 2012). From this perspective, there is no domain-general answer to the question of how changes in cognitive capabilities—commonly, gain in childhood and adolescence but decline in old age—affect decision making. Our thesis is that the impact of changes in cognitive capabilities depends strongly on the demands of specific task environments and ecologies. In other words, the quality of decisions made by people of all ages is the result of how task demands and affordances interact with particular cognitive strategies. To better understand this interaction, we suggest, one needs to describe the structure of decision environments, the processes of strategy use, and the cognitive capacities that strategies exploit, including their developmental trajectories (see Figure 1).

Strategies can be defined as sequences of operations or processes that are goal-directed—that is, are aimed at accomplishing a particular task and therefore, mediate task performance (Pressley, Borowski, & Schneider, 1987; Reese, 1962). The strategy concept has been used to describe cognitive processes and mechanisms of human cognition in many domains including memory (Bjorklund & Harnishfeger, 1990; Dunlosky & Hertzog, 1998), arithmetic (Ashcraft, 1992; Lemaire, 2010), and decision making (Payne, 1976; Payne, Bettman, & Johnson, 1993). For example, use of different strategies has been found when participants encode pairs of words in associative recall tasks (Dunlosky & Hertzog, 1998), estimate the correct solution to an arithmetic problem in a computational estimation task (Duverne & Lemaire, 2004), mentally rotate objects (Cohen & Faulkner, 1983), verify sentences (Reder, 1982), integrate (e.g., add) multiple pieces of information in order to evaluate a decision alternative (Dawes, 1979), or reason about arguments (Bucciarelli & Johnson-Laird, 1999; Girotto & Gonzalez, 2001; Hartley & Anderson, 1983).

To summarize, the notion of ecological rationality sees decision making as the result of the fit between the human mind and the environment. In turn, the concept of strategy provides the mediating mechanism between environments and individuals’ core abilities, such as attention and memory (Marewski & Schooler, 2011; Stevens & Hauser, 2004). There are a number of useful distinctions arising from the strategy framework; that is, the idea that behavior of agents can be understood as the deployment of different strategies (cf. Gigerenzer & Todd, 1999; Lemaire & Siegler, 1995; Payne et al., 1993; Siegler & Lemaire, 1997). One important distinction that can be made within this context is that between strategy selection and strategy execution. From an ecological perspective, each strategy may
be seen as occupying a particular niche that is the product of particular environmental characteristics as well as the core cognitive abilities that are available to exploit the former (Marewski & Schooler, 2011). Given a toolbox or repertoire of strategies, each fitting particular tasks or environments, it becomes crucial to adaptively select a strategy that suits the challenge at hand to do well in a particular situation—the issue of strategy selection. Another related but potentially orthogonal aspect of strategy use concerns the ability of agents to execute a strategy successfully—the issue of strategy execution; that is, the ability to carry out all subcomponents correctly, in the appropriate order, and at the right time. Note that, in principle, strategy selection and execution processes are dissociable: Agents may know which strategies to select and yet not be able to execute them correctly, or vice versa. More central to the issue of how aging impacts the
use of decision strategies is the question of which cognitive mechanisms underlie these components of strategy use. In particular, do age-related changes in basic cognitive abilities impact strategy selection and execution and, if so, do they do so differentially?

In the remainder of this chapter, we first present two classes of abilities that plausibly underlie age differences in strategy selection and execution, cognitive control and reward processing, and then review work from the memory, arithmetic computation, and decision-making domains to evaluate the role of these cognitive processes in determining the link between aging and strategy use.

**COGNITIVE AGING: THE ROLE OF COGNITIVE CONTROL AND REWARD PROCESSING**

Aging is associated with a large range of structural and neuromodulatory brain changes, which in turn are associated with detectable decline in behavioral measures of fluid abilities, such as those measuring working-memory, episodic memory, or reasoning (Nyberg & Bäckman, 2010; Rodrigue & Kennedy, 2010; Verhaeghen & Salthouse, 1997). The links between these basic abilities and strategy use are not yet understood, but past work suggests that there are at least two general aspects of cognitive function that may lead to changes in strategy use: (1) cognitive control, including manipulation of information in working memory and the selective and strategic retrieval of information from long-term memory; and (2) reward processing, including the ability to compute prediction errors associated with learning from probabilistic feedback.

First, regarding cognitive control, there is some consensus that cognitive control involves fronto-parietal neural systems and that these may be significantly affected by aging. Cognitive control is an umbrella term for the system or class of processes that are involved in controlling or managing other cognitive processes such as maintaining and updating information in working memory, focusing attention in the face of interference, or the strategic retrieval of information from memory (e.g., Diamond, 2013; Gazzaley & Nobre, 2012). In this vein, cognitive control can be understood as the link between traditionally disparate cognitive domains or abilities, such as inhibitory function, memory, and potentially, decision making (Gazzaley & Nobre, 2012; Lenartowicz, Kalar, Congdon, & Poldrack, 2010; Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004). Recent research shows that the ability to adapt behavior to specific task demands results from the flexible interaction of this fronto-parietal brain network with other brain regions (Cole et al., 2013). In turn, aging research has shown that cognitive control mechanisms may suffer from substantial age-related decline due to aging of frontal regions of the brain (West, 1996).
For example, researchers have suggested that age deficits in episodic and working memory may be explained, at least partly, by the impact of aging on the strategic manipulation and control of information guided by frontal structures (Sander, Werkle-Bergner, & Lindenberger, 2011; Shing, Werkle-Bergner, Li, & Lindenberger, 2008).

Second, regarding reward processing, results from behavioral experiments, computational modeling, and neuroimaging studies suggest that age-related deficits in reward processing are central to age differences in adapting decision behavior to specific task structures (Eppinger, Hämmerer, & Li, 2011). Recent work has directly related these limitations to dopaminergic function in striatal regions of the brain (Chowdhury et al., 2013; Samanez-Larkin, Kuhnen, Yoo, & Knutson, 2010). For example, Samanez-Larkin et al. (2010) examined age differences in dynamic financial decisions with functional neuroimaging: Older adults made more suboptimal choices than younger adults when choosing risky assets, and this age-related effect was mediated by a neural measure of temporal variability in nucleus accumbens activity, a neural structure related to reward processing. More generally, prior research on age differences in neural reward processing has revealed that the representation of reward magnitude in the striatum and medial prefrontal cortex remains intact in old age (Cox, Aizenstein, & Fiez, 2008; Samanez-Larkin et al., 2007; Samanez-Larkin et al., 2010), but that the computation of expected value during tasks that require probabilistic learning are disrupted in these same regions; however, it can be restored with dopaminergic supplementation in older adults (Chowdhury et al., 2013). All in all, age-related deficits in reward processing seem likely to affect adaptive behavior when representations must be built from feedback.

In sum, research on age-related cognitive change suggests that there are significant alterations of structural and neuromodulatory efficiency that may underlie age differences in cognitive control and learning. But what are the implications of such cognitive changes to adaptive strategy use? In what follows, we provide a first attempt at answering this question by considering the aging literature on strategy use in different domains. Our goal is to obtain a broad picture of the link between aging and strategy use, and to evaluate the extent to which deficits in cognitive control and reward processing may underlie age differences in strategy selection or execution.

**AGING AND STRATEGY USE**

Our main focus below is on reviewing the literature on aging and strategy use in the decision-making domain. However, we first review related work on memory and arithmetic computation. Indeed, there is considerable research in the latter areas using the strategy framework and thus
concerned with identifying age differences in different aspects of strategy use, such as selection and execution. Unfortunately, there is little cross-talk between research areas, and so it is unclear to what extent the behavioral patterns and prevailing explanations generalize across domains. Yet the cognitive processes underlying strategy use in memory, arithmetic, and decision making likely overlap. Therefore, the review below offers an opportunity to assess the degree of overlap in findings and mechanisms of age differences in strategy use across domains.

**Aging and Strategy Use in Memory**

There is a long tradition of considering the role of strategies in the development of memory performance, as well as distinguishing different components of strategy use, such as selection and execution (Flavell, 1976; see Schneider, 2011, for an overview). Before we proceed, however, let us make a terminological clarification. The term *production deficiency* has been often used in memory research to refer to difficulties in generating (producing) a strategy for a given problem (cf. Schneider, 2011). This concept is analogous to the concept of strategy selection, albeit the former has the connotation that strategies are formed online rather than selected from a preexisting repertoire or toolbox (Gigerenzer & Todd, 1999). In turn, the concept of *utilization deficiency* has been used to refer to difficulties in the ability of individuals to produce adequate performance given that a particular strategy was used; we call this *strategy execution*. Note, however, that *mediation deficiency* has also been used in the memory literature to refer to the lack of strategic behavior in memory tasks (cf. Schneider, 2011). In what follows, we adopt the common usage in decision research of distinguishing between strategy selection and execution.

The concept of strategy in memory research is typically associated with mnemonic procedures devised to enhance memory performance during either encoding or retrieval. For example, different strategies may be used to encode pairs of words in an episodic memory task, such as when memorizing paired associates, including rote repetition, the use of imagery, or sentence generation. Research in this domain suggests that older adults engage in memory-relevant strategy processes less often and less efficiently than do younger adults, but there is still debate concerning the extent to which strategic processes can fully account for age differences in several aspects of memory functioning (see Hertzog & Dunlosky, 2004, for an overview). For example, Dunlosky and Hertzog (1998) (see also Touron & Hertzog, 2004; Touron, Hertzog, & Frank, 2011) showed that age differences in episodic memory are not fully described by a deficiency in older adults to select (produce) effective strategies and that other issues, namely, strategy execution (utilization) deficits, may be needed to account for age
differences in memory performance. Indeed, most current views on memory performance assign “blame” to at least two components of memory. Specifically, aging is thought to impact both the strategic manipulation and control of information (strategic component) and the basic encoding and storage of information as a bound memory representation (associative component; Bouazzaoui et al., 2010; Sander et al., 2011; Shing et al., 2008). Whereas the strategic component is thought to be more localized in frontal brain areas, the associative memory components are thought to be posterior (parietal, temporal), and it is commonly assumed that the posterior activations during memory retrieval are controlled by the prefrontal cortex (e.g., Badre & Wagner, 2014; Buckner & Wheeler, 2001). These views dovetail nicely with the cognitive control hypothesis, which suggests that age differences in frontal brain areas are responsible for age differences in strategy use, such as those strategies involved in memory encoding and retrieval.

In sum, the literature on age differences in strategy use in memory suggests that age differences in decision performance may be partly attributed to differences in the selection and execution of different strategies. Importantly, the deficits in strategy selection and execution are partly attributable to age-related deficits in cognitive control abilities and thus go beyond aging decline in associative memory.

### Aging and Strategy Use in Arithmetic

Strategic variations and age-related differences have been the object of numerous investigations in arithmetic. Studies have shown that both young and older participants use a wide variety of strategies to accomplish arithmetic tasks, whether they have to find the exact (e.g., $8 \times 7 = 56$) or approximate (e.g., $23 \times 47 = 1000$) answers to problems. Previous research also found that young and older adults differ in some but not in other arithmetic tasks in terms of which strategy they use, how often they use each available strategy, and how they execute and select strategies.

Regarding the repertoire of strategies, Lemaire and Lecacheur (2007) identified the same set of nine strategies to solve two-digit addition problems (e.g., $23 + 58$) in groups of young and older adults. These nine strategies included strategies such as rounding both operands down (i.e., doing $20 + 50 = 70 + 3 + 8 = 70 + 11 = 81$), sometimes both operands up (i.e., $30 + 60 = 90 - 9 = 81$), sometimes one operand up (i.e., $23 + 60 = 83 - 2 = 81$), sometimes one operand down (i.e., $20 + 58 = 78 + 3 = 81$). Lemaire and Arnoud (2008), however, found that individual older adults tended to use only a subset of these nine strategies and overall fewer relative to young adults. Similarly, Duverne and Lemaire (2004) found that young adults used two types of verification strategies for arithmetic problems, namely the plausibility strategy for problems such as $8 + 4 < 59$ (true/false?) and the exhaustive verification strategy for problems such as $8 + 4 < 13$, whereas
older adults used only one (exhaustive verification) strategy. Thus, age-related differences in the repertoire of strategies used are often found in the arithmetic domain.

More often reported in the literature are age-related differences in strategy distributions. Even when young and older adults use the same set of strategies, they may use each available strategy in different proportions and show different strategy preferences, above and beyond older adults tending to more often use the easier strategy. For example, in a series of experiments on numerosity estimation tasks (i.e., in which participants are shown collections of dots on a computer screen and have to quickly estimate the number of dots, without counting the dots exactly), Gandini and colleagues investigated strategy distributions while controlling strategy repertoire by allowing participants to use only one of two available strategies on each problem (Gandini, Lemaire, Anton, & Nazarian, 2008; Gandini, Lemaire, & Dufau, 2008; Gandini, Lemaire, & Michel, 2009). The authors found that young adults used the perceptual strategy (i.e., scanning the whole pattern or a subset of dots, searching a corresponding numerosity in memory, and adding or subtracting a small amounts to this retrieved numerosity before stating a response) and the anchoring strategy (i.e., counting groups of dots and adding the number of groups before estimating the remaining dots) equally often whereas older adults used the perceptual strategy more often than the anchoring strategy. Such age differences in strategy distributions have been found in a number of other arithmetic studies (e.g., Geary & Lin, 1998; Lemaire, Arnaud, & Lecacheur, 2004).

In almost all studies assessing age differences in strategy execution, older adults were less efficient (either slower or less accurate, or both) than young adults. These differences were found even when strategy selection biases (i.e., differences over participants and/or over items in strategy use) were controlled via the choice/no-choice method proposed by Siegler and Lemaire (1997). In this method, participants are tested under a choice condition (in which they can choose whichever strategy they want among available strategies on each problem) and under no-choice conditions (in which they are asked to use a given strategy on all problems). For example, in their studies on numerosity estimation, Gandini et al. (Gandini, Lemaire, Anton, et al., 2008; Gandini, Lemaire, & Dufau, 2008; Gandini et al., 2009) found that older adults were slower than young adults while executing the anchoring strategy but both age groups were equally fast when executing the perceptual strategy. These age differences in strategy execution have also been found when participants are asked to calculate the exact or approximate answer to simple (e.g., $3 \times 6$) or more complex (e.g., $43 \times 28$) problems (e.g., Ardiale & Lemaire, 2013; Geary & Lin, 1998; Lemaire & Hinault, 2014; Uittenhove & Lemaire, 2013).
Finally, age differences have been found in strategy selection. For example, when asked to select the best strategy for each problem during a computational estimation task, older adults were less able to select the best strategy than young adults, and tended to repeatedly use the same strategy, even when it would have been better to switch (e.g., Ardiale & Lemaire, 2013; Lemaire & Leclère, 2014). To illustrate, Lemaire et al. (2004) asked young and older adults to find approximate products for arithmetic problems (e.g., $46 \times 52$). For each problem, participants were asked to choose the best between two strategies, the rounding-up and rounding-down strategies. As the names suggest, the rounding-up strategy involves rounding both operands up (e.g., $50 \times 60$), whereas the rounding-down strategy involves rounding both operands down (e.g., $40 \times 50$). The two strategies have, however, distinct ecologies or niches: The rounding-down strategy yields the best product for problems involving smaller unit-digits ($<5$, small-unit problems), such as $51 \times 62$, whereas the rounding-up strategy is best for problems involving larger unit digits ($>5$, large-unit problems), such as $57 \times 69$. Lemaire and colleagues found that young adults selected the best strategy for each problem type significantly more often than did older adults (65% vs 57%). These results match other findings in memory research suggesting that older adults show reduced meta-awareness of when particular strategies should be deployed (e.g., Brigham & Pressley, 1988).

The mechanisms of age differences in strategies are still under investigation, but some findings suggest that cognitive control deficits may be one source of age differences in arithmetic problem-solving. For example, Duverne and Lemaire (2004) found that 70% of age-related variance in strategy use in arithmetic problem-solving tasks is mediated by processing speed, a fluid ability measure. Similarly, Hodzik and Lemaire (2011) found that 91% of age-related variance in strategy repertoire (i.e., mean number of strategies used by individuals) and 44% of age-related variance in strategy selection (i.e., mean number of best strategy use on each problem) were accounted for by general executive control processes (e.g., inhibition, switching). One open issue is the exact mechanism whereby cognitive control limits available strategies, and whether it does so by affecting strategy selection, strategy execution, or both.

In sum, the literature on age differences in strategy use in arithmetic suggests that age differences may be attributed to differences in strategy use, including the adaptive selection and efficient execution of specific strategies. Importantly, the strong association between individual differences in strategy use and fluid cognitive abilities supports the idea that cognitive control abilities may underlie age differences in strategy selection and execution.
AGING AND STRATEGY USE IN DECISION MAKING

The strategy approach has a long tradition in decision research, with various strategies having been proposed, each with its particular cognitive demands and domain of execution (see Shah & Oppenheimer, 2008, for an overview). But what are the mechanisms underlying the adaptive selection of decision strategies? Decision research has proposed cost–benefit approaches to explain how people select from a repertoire of strategies (e.g., Beach & Mitchell, 1978). According to this view, decision makers weigh the different costs (e.g., the cognitive effort and time involved in executing a strategy) against the benefits (e.g., its accuracy in making decisions) to make a decision about which strategy to select. In line with this idea, research has shown that, for example, in conditions under which the selection of complex decision strategies is cognitively costly (e.g., under time pressure or when search in memory is necessary), people rely on simpler strategies that reduce cognitive load (e.g., Bröder & Schiffer, 2003; Ford, Schmitt, Schechtmann, Hults, & Doherty, 1989; Payne, Bettmann, & Johnson, 1988, 1993). In some cases, this cost–benefit calculus may be learned on a trial-by-trial basis, when decision makers learn about the relative value of particular strategies over time. In this case, strategy selection may be considered a reinforcement learning process at the level of strategies, and formal theories have been proposed to account for this process (Rieskamp & Otto, 2006).

What about age differences in strategy use? One intuition is that aging may lead to increased reliance on simpler strategies. Anecdotal evidence supports this view: Franz Müntefering, a leading political figure in Germany, when asked, at age 67, how he coped with his job, answered that “although one is no longer so fast, or innovative, one knows the shortcuts” (Haselberger & Solms-Laubach, 2012). Earlier work identified age differences in either information search or final choices, which are possible indicators of strategy selection (e.g., Johnson, 1990; see Mather, 2006, for an overview). However, only more recently has there been resurgent interest in this line of work. More recent studies have systematically varied task demands, used specially designed stimuli, and employed more specific strategy assessments (e.g., via verbal protocols or computational modeling) to discriminate between strategies and thus more reliably capture age differences in strategy selection (e.g., Mata, Schooler, & Rieskamp, 2007; Queen, Hess, Ennis, Dowd, & Grühn, 2012; Worthy & Maddox, 2012). As an overview, Table 1 provides a list of decision strategies and their niches of execution, as well as some of our own studies that have investigated age differences as a function of task characteristics. We also provide references for studies investigating the neural bases of these strategies because, as we will argue later, this is a promising avenue for future work aimed at understanding age differences in strategy use.
### TABLE 1  Overview of Prototypical Decision Strategies, Their Ecological Niches, and Example Studies Investigating Age Differences and Neural Correlates of Strategy Use

<table>
<thead>
<tr>
<th>Strategy Description (Seminal Study)</th>
<th>Ecological Niche</th>
<th>Differences Between Young and Older Adults</th>
<th>Neural Correlates</th>
</tr>
</thead>
</table>
| **RECOGNITION**
If one of two alternatives is recognized, infer that it has the higher value on the criterion (Goldstein & Gigerenzer, 2002). |
Little knowledge available, validity of recognition is larger than chance |
Older adults show a tendency to rely on recognition (Pachur, Mata, & Schooler, 2009). |
Volz et al. (2006) |
| **TAKE-THE-BEST**
To infer which of two alternatives has the higher value, (1) search through cues in order of validity, (2) stop search as soon as a cue discriminates, and (3) choose the alternative this cue favors (Gigerenzer & Goldstein, 1996). |
High cue redundancy |
Older adults rely more on take-the-best (Mata et al., 2007). |
Khader et al. (2011); Gluth et al. (2014) |
| **TALLYING**
To infer which of two alternatives has the higher value, count the number of positive cues of each alternative and choose the one with the higher sum (Dawes, 1979). |
Low cue redundancy, uncertainty about the cue weights |
Older adults rely more on tallying (Mata, von Helversen, & Rieskamp, 2010). |
Gluth et al. (2014) |
| **WEIGHTED ADDITIVE**
To infer which of two alternatives has the higher value, multiply each cue value by the respective cue weight, sum the results for each alternative, and choose the one with the higher sum (Payne et al., 1993). |
Low cue redundancy, good knowledge of cue importance |
Older adults rely less on the weighted additive strategy (Mata et al., 2007; 2010). |
Pachur et al. (2009) investigated age differences in the adaptive use of recognition in decision making. Specifically, Pachur and colleagues examined this issue by asking younger and older adults to make inferences regarding pairs of cities (“Which city has more inhabitants?”) and infectious diseases (“Which disease is more prevalent?”). A prominent model of a simple inference strategy, the recognition heuristic (Goldstein & Gigerenzer, 2002), assumes that in those cases for which individuals recognize only one of the objects they may base their judgments on whether or not the options are recognized (see Table 1). This heuristic or strategy often leads to accurate inference because it exploits the phenomenon that known objects differ from unknown ones in statistically systematic ways in many real-world environments (e.g., larger cities, more successful athletes, and higher mountains tend to be recognized more often; Pachur, Todd, Gigerenzer, Schooler, & Goldstein, 2011). However, this is not true for all environments, and indeed recognition validity is low (about 0.6) in the case of disease prevalence (compared to above 0.9 in the cities environment). The main question of interest was whether young and older adults showed similar levels of environment or task adaptivity, in particular, whether participants chose the recognized object more often in the cities relative to the diseases environment. Pachur et al. found that both young and older participants chose recognized objects more frequently over unrecognized ones in a domain with high recognition validity (cities) than in a domain with low recognition validity (diseases), and thus that both younger and older adults were adaptive decision makers. However, older adults also showed a (weak) tendency to use the recognition cue more than younger adults.

Similar age differences have been reported regarding more complex strategies. Mata et al. (2007) asked older adults to make inferences about which of two diamonds is more expensive based on a number of cues (see Figure 2). Mata and colleagues asked participants to make inferences in an environment in which either all cues were equally predictive of the criterion (equal validities), or alternatively, some cues were significantly more informative than others (dispersed validities). Using a simple strategy, such as take-the-best, would yield the higher payoff in the dispersed validities condition. A weighted-additive strategy, which weighs the attribute values based on how well they predict price, would yield the higher payoff in the equal-validities environment. Participants were classified according to which strategy described their decisions best. The results suggest that both young and older adults were able to adjust their strategy selection as a function of task structure. However, older adults showed a tendency to rely on simpler strategies regardless of environment (see Figure 3). In fact, such a pattern of age differences may extend to other inference problems, such as estimation and categorization tasks, with older adults defaulting to less cognitively demanding strategies,
FIGURE 2  Experimental display and example of executing the take-the-best strategy in Mata et al. (2007). Mata et al. conducted an experiment in which the participants had to infer which of two diamonds was more expensive. When making their inferences, participants were able to look up information about each diamond using a computerized display (eight dichotomous attributes, such as size, cut, clarity). (A) The participant presses a button to see information concerning Diamond A. (B) The participant observes the cue value for 2s. (C) The participant presses a button to see information concerning Diamond B. (D) The participant observes the cue value for 2s. (E) The participant chooses Diamond A by pressing the appropriate button.

FIGURE 3  Proportion of young and older adults classified as users of different strategies in Mata et al. (2007). The results show that older adults are adaptive decision makers but rely more on simpler strategies relative to young adults.
for example, those that do not rely heavily on memory retrieval (Mata, von Helversen, Karlsson, & Cüpper, 2012).

It is plausible to assume that cognitive control deficits brought about by aging may underlie the increased tendency to rely on simpler strategies. After all, reliance on simple strategies has been related to individual differences in fluid abilities, such as working memory (Mata et al., 2007). However, several mechanisms may underlie such deficits, including failure to identify environment–strategy fit, difficulty integrating costs and benefits of particular strategies, and an inability to execute particular strategies. Unfortunately, to our knowledge, there are no studies that have explicitly addressed each of these mechanisms. Future studies employing the choice/no-choice method (Siegler & Lemaire, 1997)—that is, in which participants are tested under a choice condition (in which they can select which strategy to execute) and under a no-choice condition (in which they are asked to execute a specific strategy)—could be particularly useful in distinguishing the impact of strategy execution on selection, and vice versa.

Age-related changes in reward processing may also affect strategy selection. Mata et al. (2010) investigated the ability of younger and older adults to adapt their decision strategies as a function of environment structure when provided with massive performance feedback. Participants made inferences about which of three stocks would be more profitable given a number of cues. After an initial block of choices without feedback, participants received trial-by-trial feedback in 170 inferences. Other work with a similar task suggests that reinforcement learning at the level of strategies provides a good description of how participants adjust behavior through reward-based processes (Rieskamp & Otto, 2006). Also, as expected, learning in the task seems to have a distinct neural signature associated with prediction errors in striatal structures (Gluth, Rieskamp, & Buechel, 2014). Mata et al. (2010) showed that, although both younger and older adults were adaptive in choosing a strategy that matched the task environment, older adults showed poorer learning relative to younger adults, particularly in an environment favoring the use of a more cognitively demanding strategy, the weighted-additive rule, which requires extensive information integration (see Figure 4). The results from Mata et al. (2010) match other work using simpler probabilistic learning tasks focusing on model-free learning that show that age-related changes in reward processing can lead to failures in adapting behavior to the statistical structure of the environment, possibly due to deficits in dopaminergic neuromodulation (e.g., Chowdury et al., 2013).

Decision researchers have investigated the cognitive demands of executing particular decision strategies (e.g., Bettman, Johnson, & Payne, 1990). However, only a few studies have investigated age differences in strategy execution. Those studies that have explicitly instructed young and older adults to apply specific decision strategies suggest that aging
is associated with error rates (Bruine de Bruin, Parker, & Fischhoff, 2007). However, these studies have not typically considered the role of strategy or interactions with task complexity. The study by Mata et al. (2010) described above relied on computational modeling to decompose the decision process of younger and older adults, which included a strategy execution component. The results suggest that age differences do differ by strategy: Older adults showed increased strategy execution errors relative to younger adults, particularly in an environment favoring complex strategies that require extensive integration and weighing of information.

Executing decision strategies may be particularly effortful and error prone when this involves manipulating and retrieving information from memory (Bröder & Schiffer, 2003). Khader et al. (2011) monitored the activation of specific representations of attribute knowledge with functional magnetic resonance imaging (fMRI) while participants made decisions using take-the-best. The amount of information required for a decision was reflected in activation of the dorsolateral prefrontal cortex and this activation modulated posterior areas responsible for memory storage. Given older adults’ difficulties in strategic retrieval and manipulation of information (Park & Reuter-Lorenz, 2009; Shing et al., 2008), it is natural to assume that age-related deficits in cognitive control have a direct impact on strategy execution in decisions from memory.

One open issue in the literature is to what extent age differences in information search and strategy selection change as a function of the number of options in the decision task. In general, empirical results concerning the role of number of options is equivocal. The too-much-choice hypothesis (Iyengar & Lepper, 2000) predicts that people forego choice...
or choose simpler options as set sizes increase. However, recent analyses suggest that choice overload is not to be taken for granted but could depend on particular details of the task and perhaps on individuals’ abilities (Hills, Noguchi, & Gibbert, 2013; Scheibehenne, Greifeneder, & Todd, 2010). Results of a meta-analysis with a small number of studies suggest that older adults search less information relative to younger adults before making a decision, and that this difference may increase when informational demands are high (Mata & Nunes, 2010). Likewise, studies have consistently found that older adults often prefer having less choice relative to younger adults (Mikels, Reed, & Simon, 2009). However, such effects are not always found (e.g., Queen et al., 2012) and the mechanisms underlying age differences are not well understood (cf., Reed, Mikels, & Lockenhoff, 2013). Some have suggested that age differences arise only in situations that are of low-motivational investment for older adults (Hess, Queen, & Ennis, 2013). Other work found that incidental positive affect may also account for age differences in information search (von Helversen & Mata, 2012). Overall, the heterogeneous findings suggest that considerable work still needs to be done to uncover the causes underlying age differences in choice-rich environments.

In sum, the literature on age differences in strategy use in decision making suggests that there are significant age differences in the adaptive selection and efficient execution of decision strategies. The results from this literature further emphasize the potential moderating role of both environment and strategy characteristics; specifically, age differences seem to be particularly evident in those tasks or for those strategies that have high memory demands or require learning from probabilistic feedback. These results favor theories that emphasize the role of age differences in cognitive control and reward processing on age differences in the use of decision strategies.

**IMPLICATIONS OF AGE DIFFERENCES IN STRATEGY SELECTION AND EXECUTION**

Judging from the average age of people in the Forbes 2013 World’s Most Powerful People—61 years—political and economic power is concentrated in the hands of people who are, on average, considerably older than the general population (Howard, 2013). Older adults’ overrepresentation in influential roles may be intensified in the future by demographic aging across the globe (Christensen, Dobhlhammer, Rau, & Vaupel, 2009). The extent to which older adults rely on simpler strategies that ignore information could have important implications for a number of domains, including consumer (e.g., Johnson, 1990), financial (Agarwal, Driscoll, Gabaix, & Laibson, 2009), and health domains (e.g., Szrek & Bundorf, 2011).
Against this backdrop, the following question is more pertinent than ever: Given that, as we have seen above, aging is associated with decline in many cognitive abilities and these may lead to changes in strategy selection and execution, how do these changes impact decision quality?

The ecological rationality framework proposes that reliance on simpler strategies does not necessarily lead to diminished decision performance (Gigerenzer & Todd, 1999; see Figure 1). Indeed, the ecological perspective gives room to the idea that simple cognitive mechanisms can exploit the structure of the environment in which they operate to achieve successful outcomes (see Table 1 for an overview of ecologies in which the strategies discussed here perform well). The question that one must ask, however, is to what extent the natural environments that young and older adults encounter in their daily lives are amenable to the successful use of simple strategies.

Mata and Nunes (2010) used simulation methods to investigate the possible consequences of relying on simpler strategies in the consumer domain. They used data from a range of products (e.g., home appliances, credit cards) under the assumption that decision makers use different strategies varying in whether they make use of little or all information available. The results of their simulations suggest that less may be enough—older adults may lose less than 10% of value on average by selecting simpler strategies, a significant yet relatively small decrease in choice quality. Unfortunately, we still know little about the statistical structure of many other real-world environments faced by young and older adults. Future work is needed to conduct systematic environment analysis and assess the performance of the strategies that are likely available to older adults. One particularly important step in this regard is to evaluate to what extent strategy-execution deficits may lead to interesting trade-offs such that decision makers are better off using simple, less error-prone strategies, relative to complex strategies that could, in principle, be more accurate but also lead to higher error rates.

**SUMMARY AND CONCLUSION**

Research on aging and strategy use in the memory, arithmetic, and decision-making domains suggests that there are significant age differences in strategy use. Overall, both young and older adults seem to adapt their behavior to task characteristics. However, older adults seem to rely more on simpler strategies and make more execution errors relative to young adults. The extent to which strategy selection of simple strategies is an adaptive decision based on a cost–benefit computation or an inability to use more complex strategies is, however, an open question. Also, the neural mechanisms underlying age differences in such aspects are not
completely understood, and considerable work is needed to understand the boundary conditions of adaptive strategy selection. More importantly, the implications for real-world decision making are yet to be determined. Although simple strategies may do well in some environments, it remains an open question to what extent particular simple strategies allow older adults to achieve satisfactory decisions in real-world environments.

References


6. ADAPTIVE DECISION MAKING


2. BEHAVIORAL MECHANISMS


2. **BEHAVIORAL MECHANISMS**


