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Creativity and Aging: What We Can Make With What We Have Left

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Three of the four authors of this book are older than 60, and the fourth, Chandra Sripada, is no longer a spring chicken. We believe, in spite of our age, that our advocacy of prospection is quite a creative turn for psychology, philosophy, and neuroscience. It is natural that the four of us should be invested in the issue of aging and creativity and that our concluding chapter should tackle this thorny issue.

Almost 40 years ago, Seligman was fortunate enough to spend an evening with psychologists Jerome Bruner and Donald Broadbent, who were both in their mid-60s. When asked, "Be honest. When were you really at your most creative?" both answered without hesitation: "Right now!" Similarly, Seligman meets once a month with Aaron Beck, age 93. His answer is exactly the same, "Right now!"

Are these self-serving delusions, or can creativity actually increase with age?

Much research suggests that neural conduction speed, memory, and stamina decline as we get older (Baltes & Lindenberger, 1997; Hoyer & Verhaeghen, 2006; Salthouse, 1996, 2004). In addition, historiometric studies have shown that creative productivity in the arts and sciences tends to peak within a few decades of the start of one's career, and then decreases gradually afterwards (Lehman, 1966; Simonton, 1977, 2012; Zuckerman, 1977). There are, of course, exceptions: Kant wrote his most famous work, *The Critique of Pure Reason*, at age 57, and Verdi composed *Falstaff* at around 80. Pavlov did not even begin his conditioning work until the second half of his life. This pattern, however, varies by field (youth seems to be more of an asset for mathematicians and poets than other scholars), and a second peak ("swan song") often occurs later in life (Feist, 2006; Simonton, 2006).

The conclusions that can be drawn from the current body of literature clearly indicate that creativity tends to decline with age, in spite of anecdotal reports to the contrary. Let us, however, propose a counterfactual thought experiment. Let us consider, for a moment, that some individuals are indeed able to maintain and even enhance their creative abilities as they age. How could this be? Trying to answer this question is in itself an exercise in creativity that can help us understand what factors are responsible for the negative age trend. It forces us to extrude a number of putative elements of creativity and to ask which elements do in fact deteriorate with age, which elements do not, and what factors enable them to do so. Answering this is not only a matter of consolation for the authors of this book, but it might even point the way toward how to train more creativity—even among youngsters.

Defining Creativity

We begin with a working definition of creativity and how this construct differs from related ones, including imagination, prospection, originality, and innovation. We clarify our working definitions of each to yield a framework for understanding creativity.

The first and the core skill is *imagination*, which consists of mental representations (visual, verbal, and auditory) of things that are not present to the senses. Imagination is about some alternative to present perception (Markman, Klein, & Suhr, 2009) and includes all of the following: mental imagery of things that may or may not exist, counterfactual conjecture, alternative pasts, daydreaming, fantasizing, pretending, mental simulation of other minds, mental rehearsal, and aspects of night dreaming. Although the term "imaginative" has positive connotations in everyday speech (e.g., an imaginative movie script), imagination itself is neutral. Imagination includes adaptive activities (like effective scenario planning in a business setting) and maladaptive activities (like frightening imagery that fuels phobic avoidance). Similarly, imagination implies novelty to the layperson, but imagination need not be original. Mentally rehearsing one's golf swing or repetitively worrying about leaving the oven on are examples of banal imagination. Imagination need not be about the future: The ancient cave painting of animals being hunted represents absent events, but in this case likely past events.

Prospection, the central topic of this book, is imagination about possible futures. By definition, these possibilities contain elements that are not present to the senses now. Prospecting can have visual, verbal, kinesthetic, and auditory representations (Buckner & Carroll, 2007; Gilbert & Wilson, 2007; Seligman, Railton, Baumeister, & Sripada, 2013; Taylor, Pham, Rivkind, & Armor, 1998).

Originality is prospecting that introduces *novelty*. One can prospect without originality by taking the past and merely projecting it into the future. Originality, conversely, introduces new variables, perspectives, and possibilities (Sawyer, 2012).

Creativity requires originality, which in turn requires prospection, which in turn requires imagination. Creativity, crucially, also requires usefulness and a good sense of the audience who will make use of the idea (Amabile, 1983; Sternberg & Lubart, 1999). "Audience" can refer to a literal audience, but at the highest levels of creativity, it is often the gatekeeping members of the discipline to which the original idea applies (Csikszentmihalyi, 1999). Importantly a sense of audience requires enough knowledge of the discipline to accurately evaluate the worth of one's novel idea and the likelihood of its success. Researchers have also argued that creativity requires that an idea or product is "surprising" or "nonobvious" (Boden, 2004; Bruner, 1962; Simonton, 2012), and we agree.

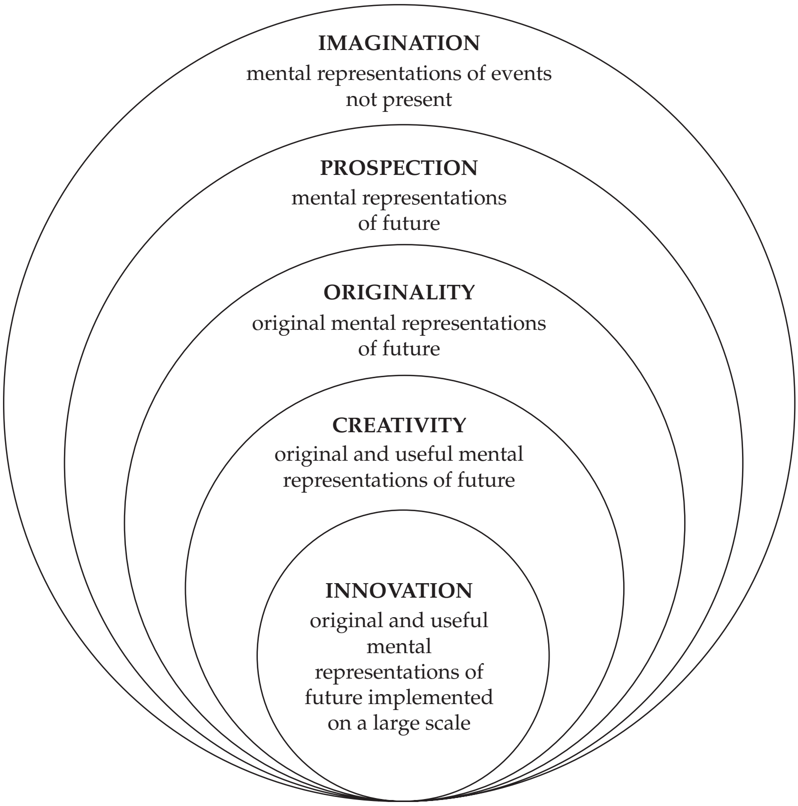

FIGURE 11.1. Creativity and Allied Terms

Finally, *innovation* refers to bringing a creative idea to scale by successfully implementing it on a large scale within an organization or society at large (Amabile, 1988; Sawyer, 2012). Figure 11.1 depicts the interconnected terms we use to describe creativity.

Because creativity consists of the generation of ideas or products that are both original and useful, it means that a wide array of separate but related cognitive processes are at play to satisfy both criteria. Thus, researchers have suggested that the creative process may best be characterized by a *generation* phase, in which original ideas are freely invented without scrutiny, followed by an *evaluation* or *exploration* phase, during which the value of ideas is examined, and ideas are elaborated and refined as needed (Finke, Ward, & Smith, 1992). When asked by a student how he was able to come up with so many good ideas, Linus Pauling famously replied, "You have a lot of ideas and throw out the bad ones" (Csikszentmihalyi, 1996, p. 116).

The creative process, of course, does not happen in such a clean sequence, as generative and evaluative processes often take place in an iterative and almost simultaneous fashion. Nevertheless, this framework suggests that a review of the factors at play in creativity should consider the relative contribution of each cognitive process to generative and/or evaluative processes. Some of the factors reviewed in the following sections may primarily influence generative processes, whereas others may primarily shape evaluative ones. Many probably contribute to both.

The Present Review

Based on the growing body of literature examining psychological elements at play in creativity, we propose that three sets of factors need considering in order to understand the effects of aging. We begin by reviewing factors related to (a) *cognition and expertise*, including cognitive abilities, originality, mind-wandering, knowledge and expertise, intuition, pattern recognition, and heuristics. Next, we consider the role of factors related to (b) *personality and motivation*, including flexibility, openness to experience, integrative complexity, strength of interest, intrinsic motivation, ambition, grit, optimism, confidence, self-efficacy, and energy. Finally, we examine the contribution of (c) *interpersonal processes*, such as having a good sense of the audience and engaging in collaboration.

Although this list of factors is not exhaustive, these are the most important and thoroughly researched psychological influences.

Cognition and Expertise

Cognitive Abilities

Over the past 100 years, intelligence researchers have done a remarkable job cataloging covariations among various cognitive abilities (Carroll, 1993). The modern synthesis takes the form of the Cattell-Horn-Carroll (CHC) theory of cognitive abilities, which consists of nine broad cognitive abilities that have been consistently validated during the past decade (Schneider & McGrew, 2012):

1. *Fluid reasoning (Gf)*: "The deliberate but flexible control of attention to solve novel 'on the spot' problems that cannot be

performed by relying exclusively on previously learned habits, schemas, and scripts."
2. *Crystallized intelligence (Gc)*: "Depth and breadth of knowledge and skills that are valued by one's culture."
3. *Short-term memory (Gsm)*: "The ability to encode, maintain, and manipulate information in one's immediate awareness."
4. *Long-term storage and retrieval (Glr)*: "The ability to store, consolidate, and retrieve information over period of time measures in minutes, hours, days, and years."
5. *Visual processing (Gv)*: "The ability to make use of simulated mental imagery (often in conjunction with currently perceived images) to solve problems."
6. *Auditory processing (Ga)*: "The ability to detect and process meaningful nonverbal information in sound."
7. *Processing speed (Gs)*: "The ability to perform simple repetitive cognitive tasks quickly and fluently."
8. *Quantitative knowledge (Gq)*: "Depth and breadth of knowledge related to mathematics."
9. *Reading and Writing (Grw)*: "Depth and breadth of knowledge and skills related to written language."

While partially distinct, all nine of these broad cognitive abilities are positively correlated with each other, and are positively correlated, in varying degrees, with a more global cognitive ability factor, *g* (Carroll, 1993; Jensen, 1998).

Cognitive abilities and creativity. How do these cognitive abilities relate to creativity? Early research examining the relationship between general cognitive ability and creativity resulted in the threshold theory, which holds that overall cognitive ability, *g*, only matters until a certain point proposed to be somewhere around 120 IQ points (Guilford, 1967; Jung et al., 2009; Yamamoto, 1964). Other findings, however, do not support the threshold theory (Kim, 2005; Preckel, Holling, & Wiese, 2006).

In evaluating the threshold hypothesis, we believe that it is useful to distinguish *creative cognition* (which is part of the cognitive ability nexus) from *creative achievement* (which depends on many other factors, including the noncognitive ones reviewed next). A recent study investigated the cognitive and personality predictors of creative achievement in the arts versus the sciences (S. B. Kaufman et al., 2015). Across four samples, comprising more than 1,000 demographically diverse participants, the researchers found that *g* and divergent thinking were much stronger predictors of creative achievement in the sciences (inventions and scientific discovery) than the arts (visual arts, music, dance, creative writing, humor, and theater and film). In fact, there appeared to be no cognitive ability threshold for the arts: Cognitive abilities were not significantly correlated with creative achievement in the arts.

Taken together, it appears that cognitive abilities facilitate creative cognition but only up to a certain point (depending on the domain). Beyond this threshold, cognitive abilities may still have an important influence on the extent to which creative ideas are translated into actual creative achievements, perhaps by aiding in the evaluation and usefulness of the ideas, although more research is needed to further examine this hypothesis.

Cognitive abilities and aging. More than 50 years of research has consistently found that fluid reasoning (*Gf*) and processing speed (*Gs*) are extremely vulnerable to aging, whereas crystallized intelligence (*Gc*)—knowledge—is maintained throughout most of adult life (Cattell & Horn, 1978; Salthouse, 1985, 1996). With the advent of contemporary IQ tests grounded in CHC theory, researchers have more recently been able to assess the developmental trajectories of a wider range of cognitive abilities. This research confirms that fluid reasoning (*Gf*), short-term memory (*Gsm*), processing speed (*Gs*), reading comprehension (a component of *Gc*), quantitative knowledge (*Gq*), math reasoning (*MR*), math calculation (*MC*), and writing abilities (*Grw-Writing*) all decline with age (A. S. Kaufman, Johnson, & Liu, 2008).

In contrast, large-scale studies conducted on contemporary IQ batteries have found that long-term retrieval (*Glr*), visual processing (*Gv*), auditory processing (*Ga*), verbal knowledge (the vocabulary and general knowledge components of *Gc*), academic knowledge (*AK*), reading abilities (*Grw*), oral expression (*OE*), and listening comprehension (*LC*) are maintained at least to the age of 65.

Therefore, we conclude that speed, fluid reasoning, and short-term memory all likely decline with age and that all of these declines contribute to a possible decline in creative thinking and creative achievement.

Originality

Another cognitive ability relevant to creativity is the ability to imagine and generate multiple possibilities, ideas, and solutions to a problem. E. Paul Torrance (1988) referred to this ability as "divergent thinking," John Carroll (1993) referred to it as "idea production," and J. P. Guilford (1984) referred to it as "divergent production." We call it "originality": the mental representation of novel ideas. Whatever its name, this ability is part of the general cognitive ability nexus (Silvia, 2008), and it is partially distinct from the broad cognitive abilities that form the core of the CHC model.

Originality declines after the age of 40 (McCrae, Arenberg, & Costa, 1987), which is probably caused by its reliance on fluid reasoning and executive functioning (Batey, Chamorro-Premuzic, & Furnham, 2009; Silvia & Beaty, 2012). Older individuals may, however, be able to retain their originality if they use a different cognitive strategy and rely on declarative memory to enhance their performance (Leon, Altmann, Abrams, Gonzalez Rothi, & Heilman, 2014). These findings suggest that accumulated knowledge may compensate for the effects of aging on cognitive abilities (as expanded on in following section). Nonetheless, we conclude that a second cognitive factor—originality—likely declines with age and might contribute to a decline in creative achievement.

Daydreaming and Mind-Wandering

More than 50 years ago, pioneering research by Jerome L. Singer and colleagues provided evidence that daydreaming is a widespread and normal aspect of human inner experience (McMillan, Kaufman, & Singer, 2013; Singer, 1966). In the past 10 years, there has been a resurgence of research on the costs and benefits of daydreaming, with the term "mind-wandering" showing a dramatic increase in the frequency of articles using this term (Callard, Smallwood, Golchert, & Margulies, 2013). This renewed interest in mind-wandering is partly caused by the discovery of the default network that we discussed at length earlier.

How are the default network and the self-generated cognitions that arise from it related to creativity? For one, the default network plays a role in imagination by "constructing dynamic mental simulations based on personal experiences such as used during remembering, thinking about the future, and generally when imagining alternative perspectives and scenarios to the present" (Buckner, Andrews-Hanna, & Schacter, 2008, pp. 18–19). It is for this reason that we are fond of thinking of it as the "imagination" network. Indeed, a recent large-scale review of the literature on the neuroscience of creativity suggested that the default network is a critical contributor to originality (Jung, Mead, Carrasco, & Flores, 2013). In conjunction with executive functions, such as cognitive control, inhibition, and flexibility, mental simulations of the future can be harnessed for practical value. Recent research suggests that the default network interacts with other large-scale brain systems (such as the executive attention network) to maintain an internal train of thought (Andrews-Hanna, Smallwood, & Spreng, 2014; Smallwood, Brown, Baird, & Schooler, 2012).

Second, the default network is related to mind-wandering (e.g., Mason et al., 2007), and this has implications for the generation of creative insights. The "Aha!" experience rarely comes while the mind is focused intensely on solving a problem. Instead, creative insights typically arise unsupervised, when the conscious mind has wandered away from the task at hand, enabling spontaneously generated novel connections. Unlike machine models of mind, the mind is likely in wild chaos much of the time. The mind wanders, is nimble, and is opportunistic, but it *can* focus—but only for limited periods of time.

In keeping with this, evidence suggests that the ability to generate original ideas, as well as actual creative achievement, is associated with diffuse, unfocused attention to the external environment (e.g., Jung et al., 2013; Martindale, 1981; White & Shah, 2006).

Mind-wandering and aging. Mind-wandering and task-unrelated thoughts have been found to decrease with age, at least under laboratory conditions (Giambra, 1989; Singer & McCraven, 1961; Tamplin, Krawietz, Radvansky, & Copeland, 2013). This finding is consistent with research showing reduced activity in the default mode network as people age (Damoiseaux et al., 2008).

So far we have reviewed five cognitive factors that decline with age and likely contribute to a decline in creativity:

1. Speed
2. Short-term memory

3. Fluid reasoning
4. Originality
5. Mind-wandering

This paints a dismal picture for Bruner, Broadbent, Beck, and the rest of us as we age. However, some cognitive factors are maintained into older age, including long-term retrieval, verbal and academic knowledge, reading abilities, oral expression, and listening comprehension. Because these abilities draw more on knowledge and expertise, we now look at additional knowledge-related factors that likely improve with age and, therefore, might contribute to a compensatory increase in creativity with age.

Knowledge and Expertise

Although acquiring knowledge in any domain is an important part of the creative process, not all forms of knowledge are well captured by the tests of cognitive ability reviewed earlier. One significant source of individual differences not assessed by traditional measures of cognitive ability is *domain-specific knowledge*, defined as knowledge of the particular dominant culture (such as occupational and avocational knowledge). Ackerman refers to this knowledge as the "dark matter" of adult intelligence (Ackerman, 2000), an under-appreciated yet crucial determinant of achievement.

Another term for domain-specific knowledge is "expertise." This knowledge takes two forms: *procedural knowledge* (knowing how to do something, heavily required for athletic domains such as sports and dancing) and *declarative knowledge* (factual information stored in long-term memory, necessary for more cognitive domains). K. Anders Ericsson and colleagues have studied the development of expertise in a wide variety of domains, including medicine, surgery, software design, professional writing, music, visual arts, acting, ballet, and chess (Ericsson, Charness, Feltovich, & Hoffman, 2006). They have found that mastering the tradition within a particular domain requires very long hours of learning and practice (Ericsson, Krampe, & Tesch-Römer, 1993; Ericsson & Ward, 2007).

Of course, creativity is not mere expertise. An idea is not typically judged as creative by an audience if it constitutes a *reasonable* extension of domain-specific knowledge. For example, the U.S. Patent

Office will not award patent protection if the invention represents no more than ordinary expertise in a domain. However, given that no work can be completely original (indeed, elements of tradition must always be present), creativity requires the creator to find the right balance between tradition and originality. The creator must be just the right distance ahead of the tradition: Too short and the idea is banal, too long and the idea is outlandish.

Also, the amount of expertise required to obtain world-class expertise varies dramatically between domains, and people differ dramatically in the rate in which they master the domain (Simonton, 1999). What's more, the success of training depends on many more factors than just time spent on task, including motivation, environment, and cognitive factors, such as working memory (Hambrick et al., 2014; S. B. Kaufman, 2013). For example, access to mentors and role models (Simonton, 1975) as well as family resources (think of Johann Sebastian Bach growing up in a family of musicians) likely have a great influence in determining whether training results in creative achievement.

Finally, the importance of accumulated knowledge for creativity is by no means limited to domain-specific expertise. Creative people often call on what they know from other domains—*general knowledge*—to penetrate problems. Paul Erdős, the celebrated Hungarian mathematician, for example, viewed mathematics as a social endeavor and published with 511 collaborators across almost the entire range of mathematical issues (Baker & Bollobás, 1999). He had knocked around mathematics long enough to know the entire field well enough to bring methods from one domain to bear on others. So general was his knowledge and his influence that almost all mathematicians have "Erdős numbers" to designate the degree of separation from Erdős himself: Someone who never published with Erdős but published with someone who did publish with Erdős has an Erdős number of 2. It is estimated that 90% of the world's academic mathematicians have an Erdős number below 8.

Knowledge, expertise, and aging. Not surprisingly, older adults have acquired more domain-specific knowledge than younger adults. In one study, Ackerman (2000) administered measures of cognitive ability alongside measures of knowledge in 18 domains (including art, music, world literature, biology, technology, and law) to a sample of 228 educated adults between the ages of 21 and 62. As expected, middle-aged adults displayed much higher domain-specific knowledge compared with younger adults.

The effect of age on expertise also depends on the nature of the accumulated knowledge (procedural or declarative). In general, success in domains that rely heavily on declarative knowledge tends to be correlated with cognitive ability (Ackerman, 2011; Schipolowski, Wilhelm, & Schroeders, 2014). There are between-domain differences, however. Fluid or nonverbal intelligence is more strongly related to knowledge in mathematics and the sciences, whereas verbal or crystallized intelligence is more strongly related to knowledge in the humanities (Ackerman, 2011; Park, Lubinski, & Benbow, 2007). In contrast, domains in which performance depends more on procedural knowledge (e.g., sports and dance) show diminished associations with cognitive ability as expertise increases, perhaps because of their reliance on perceptual-motor functions (Ackerman, 2011).

From a life span perspective, general knowledge, domain-specific knowledge, and procedural skills, once acquired, tend to be preserved over most of the life span (Ackerman, 2011), and the acquisition of knowledge has been shown to help compensate for the decline of cognitive ability in a wide variety of domains, from football to music to chess to science (Ericsson, 2013). In addition, the benefits of knowledge are cumulative: Early success provides advantages that initiate a virtuous cycle (Merton, 1968; Petersen, Jung, Yang, & Stanley, 2011), with early knowledge stimulating the discovery and use of more knowledge, so multiplying the chances that creative ideas will emerge.

While many cognitive abilities decline as we age, *knowledge and expertise increase*, and these factors play a major, necessary role in creativity. Increased knowledge may help compensate for decreased mental speed, decreased short-term memory, poorer fluid reasoning, and less originality as we age.

Intuition, Pattern Recognition, and Heuristics

Over the past 30 years, research has revealed that much information processing takes places *implicitly*—without intent, awareness, or conscious reasoning—and this implicit form of knowledge plays a crucial role in thinking, reasoning, and creativity (Kihlstrom, 1987; Polyani, 1966; Wagner & Sternberg, 1985). This has led to dual-process theories, which distinguish between two types or systems of thinking (Evans, 2008; Kahneman, 2011).

System 1 processes operate fast, automatically, and are not dependent on slower, conscious, and voluntary control systems. System 1 processes include affect, pattern recognition, intuition, heuristics, implicit learning, and latent inhibition. These processes are fast, unconscious, effortless, and involuntary. In contrast, system 2 processes require attention, are associated with *g*, and are voluntary, supervised, executive functioning. These processes are slow, linear, conscious, and effortful, and they come into play when and if we bother to question and then check the output of the system 1 processes. In this section, we discuss the relation of creativity to the following system 1 processes: intuition, pattern recognition, and heuristics.

Much well-practiced knowledge involves the automatic recognition of situations that resemble situations encountered previously. We sometimes call this kind of automatic recognition "intuition." For example, we have no trouble recognizing a table or a game when we see one, but how do we do this? Unlike circles, there is no one property that all games have in common (no necessary condition), and no one property that distinguishes a game from all other activities or a table from all other objects (no sufficient condition). Wittgenstein proposed that intuitive recognition is explained by "family resemblances" (1953/2009), but this explanation only substitutes one mystery for another. Seligman and Kahana (2008) suggested that the mind must perform three tasks to decide if a table is a table: First, identify all relevant dimensions to the decision (which, following Wittgenstein, are only *relevant*, but not necessary or sufficient); second, assign a value and a weight for each relevant dimension and each interaction; and third, create a decision rule for table-hood. This process results in *a mathematical model that weights each dimension (and their interactions) in such a way as to reliably distinguish past instances of tables from non-tables.* This model has been shown to work for recognizing faces, even when upside down or in different profiles (Lacroix, Murre, Postma, & van den Herik, 2006).

Thus, one of the core processes at play in intuition seems to be the recognition of patterns. Beyond recognizing tables, pattern recognition underpins analogical reasoning, which consists of mapping knowledge from a base domain to a target domain, for example, recognizing that the structure of an atom is understood by thinking about the structure of the solar system (Gentner, 1989). Isaac Newton's insight about gravity, for example, resulted from seeing an apple and the moon subtending the same visual angle. Armed with knowledge and expertise, Newton suddenly wondered if what draws the apple to the earth is the same force that holds the moon in orbit (Gleick, 2004). Many other creative moments illustrate the role of pattern recognition and analogical thinking in creativity: Benjamin Franklin's discovery that lightning contained the same stuff (electricity) that charged batteries is another example.

Pattern recognition is at the heart of Jeffrey Hawkins's theory of intelligence (and, in turn, of creativity). Hawkins and Blakeslee (2007) proposed that intelligence consists in the prediction of the future, not in the knowledge of the past. They used the visual cortex as their model (see also Clark, 2013). The visual cortex is layered, with activity of the neurons in the lowest layer (V1) reflecting the voluminous information that arrives at the retina. Each succeeding layer abstracts only some of the information from the layer below. Importantly, connections not only go up the layers, but also back down the layers, and in fact, there are 10 times as many downward connections as upward ones. In their theory, the downward connections tell the lower layers what pattern is *predicted* in the next moment's saccade (eye-movement): inhibiting unexpected connections and exciting expected connections.

Creativity, for Hawkins, resides in the patterns that are formed in the very top layers, the cross-modal layers that integrate all information available. How do creative insights emerge if unexpected information is inhibited and we only rely on memory to predict the future and act in the present? The answer, according to Hawkins's memory-prediction framework, lies in pattern recognition. When confronted with a novel problem, we conjure memories of similar situations, and find out how to solve it using analogical reasoning. Although Hawkins and Blakeslee (2007) deem all analogies creative, they explain that creativity is most obvious when "our memory-prediction system operates a higher level of abstraction, when it makes uncommon predictions using uncommon analogies" (p. 185). It must be remarked that Hawkins's theory is itself a theory that shows its sense. It argues that creativity proceeds by the discovery of very high order analogies, and it comes to this conclusion by using the visual system as a high order analogy of the creative process.

Heuristics. Closely related to intuition and pattern recognition are heuristics. Accumulated knowledge leads to the ability to use fast shortcuts, or "heuristics" to make decisions, rather than relying on effortful decision-making (Baron, 2000; Peters, Finucane, MacGregor, & Slovic, 2000). Importantly, heuristics are not algorithms (i.e., cookie-cutter methods for solving a problem), but involve a certain degree of flexibility that allows them to be useful for creative solutions (Amabile, 1996). Also, heuristics are often automatic (but still flexible) ways of processing information and making decisions. Thus, individuals may often not be able to verbalize what shortcut they are taking. Heuristics can be broadly categorized as "negative heuristics" (what to avoid) and "positive heuristics" (what to do) (Lakatos, 1970). Physicians' oath to *do no harm*, eight of the Ten Commandments (e.g., "Thou shalt not steal"), and of course, "If it ain't broke, don't fix it," are all examples of negative heuristics.

But a major caveat about negative heuristics is in order: *Not getting it wrong does not equal getting it right.* Imagine making a speech with no grammatical errors. Or writing a biography in which nothing untrue is said. Or serving a meal in which nothing tastes bad. Or proving a theorem in which every statement was true. Or playing the Beethoven Opus 109 with no mistakes. Or chairing a meeting in which no one was discourteous. None of these would guarantee a good speech, a good book, a good meal, a good proof, a good performance, or a good meeting.

This is where positive heuristics come in, by providing us with shortcuts to figure out the right thing to do. To complicate matters, however, such heuristics often lead to biases. The study of how ordinarily useful heuristics can go wrong has been the meat and potatoes of the work of Kahneman and Tversky (Gilovich, Griffin, & Kahneman, 2002; Kahneman, 2011). Consider the "availability heuristic": For example, a woman is asked to estimate the frequency with which physical assaults take place in her city. She replies that such assaults are extremely common. Following the availability heuristic, this person based her judgment on "the ease with which instances come to mind" (Kahneman, 2011). In this case, the woman had just read about an assault. If she lived in an unsafe city, the heuristic led to an accurate answer and saved time. If her city is indeed safe compared to most other cities, the heuristic saved cognitive processing time but led to an inaccurate answer. Thus, the availability heuristic often leads to a bias.

There is no doubt that the study of problems associated with heuristics is important given their occasional negative consequences. However, researchers should not neglect to further investigate adaptive heuristics and how they often lead to enhanced outcomes. Heuristics may not usually lead to errors in thinking. We believe that system 1 and the shortcuts it relies on are at the heart of the adaptive prospecting of possible futures. At the margins, heuristics make errors, but by and large, they are our first and most robust way of navigating the future (Seligman et al., 2013). When they do not lead to biases, positive heuristics allow goodness, rightness, beauty, and truth to occur over and above the mere absence of badness, wrongness, ugliness, or falsehood.

George Pólya's classic book *How to Solve It* (1945) provides shortcuts to help students learn to solve mathematical problems independently (e.g., "Do you know a related problem?"). Anne Lamott, the author of bestseller *Bird by Bird* (1994), begins all of her workshops by telling students that "good writing is about telling the truth." Gordon's (1961) *Synectics* encourages participants to "make the familiar strange and the strange familiar." The creative problem solving (CPS) approach suggests the virtue of "looking at something, and seeing something else" (Treffinger, Isaksen, & Dorval, 2000, p. 57). Although some creativity-training programs (e.g., CPS) have received empirical support (e.g., Puccio, Firestien, Coyle, & Masucci, 2006), the specific contribution of the use of positive heuristics for creative thinking has (to the best of our knowledge) not yet been dismantled.

In addition, the degree to which positive heuristics can be domain-general remains unclear. Many heuristics may be domain-specific and work because they succinctly convey domain-specific knowledge. Yet, some broad general principles may also apply across fields, and the creativity-training programs described earlier generally seek to offer such domain-general heuristics. Given that positive heuristics may constitute a major source of creativity and likely are a good part of what "wisdom" means, we commend science on positive heuristics to the future. Consider the following examples of additional potential heuristics for creativity in various domains:Above all be kind.A good tragedy "takes an ice-axe to the frozen sea inside of us."When in doubt, stand on principle.A good symphony comes to perfect resolution.In comedy the funniest line comes last. The next funniest comes first.A good meal brings out the best in its natural ingredients.

A good piece of science tells us that something we thought was false is true, or something we thought was true is false—or even just gets us to think about something we never thought about before. Consider the following:A good theory makes counterintuitive predictions.A good person shows us how to lead our lives.

Intuition, pattern recognition, heuristics, and aging. How do intuition, pattern recognition, and heuristics fare with age? As with all cognitive abilities, seeing patterns sometimes requires abstract integration and fluid reasoning (see Green, Kraemer, Fugelsang, Gray, & Dunbar, 2010, 2012) and so will show some deterioration with aging. But those aspects of pattern recognition that are automatic draw heavily on knowledge and domain-specific expertise, which are factors that likely improve with age.

Thus, analogies, pattern recognition, and intuitions may constitute paradigm cases of the "compensatory" mechanisms that Baltes and Baltes (1990) invoked in their theory of "optimization with compensation" as we age. The older we get, the more information and experiences are available to us, and the more examples of successful patterns, heuristics, and intuitions we have to draw on. As time passes, we may also be able to refine the dimensions along which we intuitively weigh information. Consider a lieutenant recognizing a likely ambush. The lieutenant intuitively and correctly decides that this bit of forest is a likely ambush site, based on weighing relevant dimensions. The more ambushes (or the more simulations of ambushes) the lieutenant has faced, (a) the more relevant dimensions of ambushes will be *identified,* (b) the more accurate is the mean value put on each dimension (insect quiet likely means ambush), and (c) the more accurate the weight of each dimension and their interactions are (insect quiet plus no adult men in the village almost surely means ambush). The accuracy of the decision rule in multidimensional space improves with experience, but with one major proviso. Useful experience must be at the knife edge of the decision process, close decisions that vary the relevant features of the dimensions. If the experience is only repeated clear-cut instances of ambush and non-ambush, experience adds nothing—20 years of experience versus 1 year of experience twenty times.

So we conclude our review of cognitive factors in creativity with three that likely improve with age and bode well for the aging authors:

1. Domain-specific knowledge
2. General knowledge
3. Intuition, pattern recognition, and heuristics

Personality and Motivation

Having reviewed the role of various forms of cognition, we now consider the influence of personality and motivation on creativity and the trajectory with age. Torrance's longitudinal study of creative achievement provided important information about the role of personality and motivation in creative achievement. Initial findings showed that cognitive ability and divergent thinking (originality) were both important predictors of creative achievement (Cramond, Matthews-Morgan, Bandalos, & Zuo, 2005; Plucker, 1999). At the 50-year follow-up, however, cognitive ability was a weak predictor of both personal and publicly recognized creative achievement (Runco, Millar, Acar, & Cramond, 2010). In contrast, what Torrance termed "beyonder" characteristics were important predictors of creative achievement above and beyond measures of scholastic performance (Runco et al., 2010; Torrance, 1993). These characteristics included "love of work," "persistence," "deep thinking," "tolerance of mistakes," "purpose in life," "diversity of experience," "high energy," "creative self-concept," "risk taker," "openness to change," and being comfortable being a "minority of one." Thus, the Torrance longitudinal study supports the importance of looking beyond cognition and expertise to understand how creativity fares with aging.

Diversity of Experience and Flexibility

Aging brings the risk of rigidity: Finding tradition more appealing than originality, and the delicate balance between the old and the new may shift as time passes. "The expert can become so entrenched in a point of view or way of doing things that it becomes hard to see things differently" (Sternberg, 1996, p. 347). Experts may have more difficulty adapting to changes than novices because of increased rigidity.

What can be done to prevent rigidity? Simonton (2000) investigated the careers of 59 classical composers and found that two factors were particularly good predictors of the differential aesthetic success of their operas: specialization ("overtraining") having a negative effect and versatility ("cross-training") having a positive effect.

The benefit of being exposed to diverse influences is well illustrated by history and the advantages conferred on civilizations "standing at crossroads." The immune system of 15th-century Europeans was strengthened by the diversity of people and diseases the continent had been exposed to for millennia. This likely explains why Columbus' sailors survived, even exposed to new Carib Indian diseases, but the Carib Indians were decimated. Going beyond health and into culture, Tasmanian Aborigines, who were cut off from trade routes by the almost impassable Tasman Strait, saw the sophistication of their tools deteriorate across 2,000 years while those of the more nomadic Australian Aborigines improved (Diamond, 1997). By standing at crossroads, civilizations are given opportunities to integrate and make connections between unrelated and disparate influences (Mednick, 1962).

At the individual level, increased flexibility is likely one of the main mechanisms explaining the benefits of diverse experience. Research suggests that living and adapting to foreign cultures facilitates creative thinking by enhancing integrative complexity, a thinking style we discuss in the next section (Simonton, 1994, 1997; Tadmor, Galinsky, & Maddux, 2012).

Other recent research suggests that *any* unusual and unexpected experience can increase cognitive flexibility. In a series of experiments, Ritter et al. (2012) exposed participants to unusual, schema-violating experiences in a virtual reality environment (e.g., as people walked closer to a suitcase standing on a table, the size of the suitcase *decreased*, but as they walked away, the size *increased*). Those who actively engaged in this unusual virtual world subsequently scored higher in cognitive flexibility (they switched categories more on a measure of divergent thinking) than a group of people who did not experience the unusual events.

Diversity, flexibility, and aging. As we age we have more opportunity to encounter diversity. To the extent that we stay open to experience, and to the extent more experience is not just more repetition, aging allows us to "stand at crossroads." Our propensity to welcome—instead of reject—such experience is likely influenced by some of the personality influences discussed next.

Openness to Experience, Flexibility, and Integrative Complexity

"Openness to experience," which is one of the Big Five personality traits, is consistently related to creativity (S. B. Kaufman, 2013; McCrae, 1987; Silvia, Nusbaum, Berg, Martin, & O'Connor, 2009). This trait reflects a drive toward exploration and includes openness to fantasy, feelings, actions, ideas, values, and "interest in varied experiences for their own sake" (McCrae, 1987, p. 1259). Thus, individuals who are open to new experiences are more likely to make connections among seemingly unrelated pieces of information, as well as to see new patterns.

Openness to experience can be separated into two main subcomponents (DeYoung, Quilty, & Peterson, 2007): *openness* (engagement with sensory and perceptual information) and *intellect* (engagement with abstract information, primarily through explicit reasoning). While intellect is associated with general cognitive ability and working memory, openness is correlated with implicit learning (S. B. Kaufman et al., 2010). This form of learning, defined as "the ability to automatically and implicitly detect complex and noisy regularities in our environment," is closely linked to intuition and can be measured by assessing reaction time on a probabilistic sequence-learning task among other methods (S. B Kaufman et al., 2010, p. 321; Shanks, 2005).

Recent research suggests that the openness versus intellect distinction has important implications for creative achievement. Nusbaum and Silvia (2011) found that openness (but not fluid reasoning), predicted total creative achievement, whereas intellect predicted fluid reasoning but not total creative achievement. Further research suggests that openness specifically predicts creative achievement in the arts, whereas intellect predicts creative achievement in the sciences (S. B. Kaufman et al., 2015)

Openness to experience is closely related to integrative complexity, the capacity and willingness to find links among multiple competing perspectives (Suedfeld, Tetlock, & Streufert, 1992). Many studies have found that openness to experience and integrative complexity are significantly correlated, but have not decomposed this personality trait into its two subcomponents (openness and intellect). In research examining life stories, McAdams et al. (2004) found that openness to experience predicted the extent to which participants wrote complex narratives including multiple points of view, mixed motivations, complex emotions, and contradictory aspects of the self. Significant correlations between integrative complexity and openness to experience have also been noted among U.S. presidents (Simonton, 2006) and Master of Business Administration students (Tetlock, Peterson, & Berry, 1993).

Openness to experience, integrative complexity, and aging. Staying open to experience with age may play an important role in maintaining cognitive abilities. Williams, Suchy, and Kraybill (2013) found that low openness to experience in older adults was a marker of cognitive decline over the next 12 months. This was especially true of older adults who scored low on aesthetics (i.e., participants who reported being insensitive to and uninterested in art and beauty), as well as values (e.g., participants who endorsed dogmatic and rigid social, political, and religious values).

Both correlational and longitudinal studies have shown, however, that people tend to either remain stable or decrease in openness to experience as well as tolerance of ambiguity with age (Costa et al., 1986; Diehl, Coyle, & Labouvie-Vief, 1996; Soldz & Vaillant, 1999; Wortman, Lucas, & Donnellan, 2012).

We are not aware of any aging studies that have separated intellect from openness, but we hypothesize that the intellect component will be more vulnerable to the effects of aging, because of its reliance on fluid reasoning, whereas openness will remain stable or increase with age, because of its independence of cognitive ability. This prediction is also in line with research showing that linguistic markers of cognitive complexity (e.g., using causation or insight words, etc.), as well as "wise reasoning" (a construct closely related to integrative thinking), significantly increase with age (de Vries & Lehman, 1996; Grossmann, Na, Varnum, Kitayama, & Nisbett, 2012; Pennebaker & Stone, 2003).

In addition, social factors may also foster more openness with age. In academic fields, scholars probably feel much freer to seriously consider new (and perhaps outlandish) ideas once they have established themselves and obtained tenure. Thus, social factors likely increase the extent to which people have the willingness to *voice* original ideas with age, while openness itself may decline. With that said, it is also possible that openness decreases with age, as older people tend to take less risks and tend to be less revolutionary in their ideas (Simonton, 1994). Thus, we cannot yet conclude how, on balance, openness to experience and integrative complexity fare with aging. Nevertheless, our review suggests that openness to experience may lead individuals to seek diverse experiences, which are in turn conducive to creative achievement.

Interest and Motivation

In keeping with Fredrickson's (1998, 2001) "broaden-and-build" theory, positive emotions may also guide us toward novel stimuli and help us "fall in love" with something (Torrance, 1983). One of these emotions is "interest," defined by Silvia (2001, p. 285) as "a basic emotion with significant long-term adaptational functions; it cultivates knowledge and diversifies experience at all stages of life," and thus leads to "covertly building skills and expertise." By defining interest as an emotion (with specific associated facial and vocal expressions, and subjective feeling), scientists can better understand how interest leads to engaging in meaningful activities (Izard & Ackerman, 2000; Silvia, 2006).

The emotion of interest, aside from helping diversify experiences and engage with intriguing unknown stimuli, also helps us work hard to build expertise in a domain. In keeping with this, the vast literature on the "social psychology of creativity" has shown that intrinsic motivation (i.e., the degree to which one engages in an activity for its inherent rewards, rather than for external outcomes) enhances creative thinking (Amabile, 1996). Intrinsic motivation can keep us going during otherwise daunting practice (Ericsson et al., 1993; Ericsson & Ward, 2007).

Intrinsic motivation may enable "flow" during the creative process. Csikszentmihalyi—a living example of general knowledge who brings his knowledge of the arts to bear on his science—first documented this phenomenon in the 1960s as a result of observing artists painting (Csikszentmihalyi, 1990). Flow is a psychological state defined by the presence of both high skills and high challenges, giving individuals a sense of control over the activity at hand. Flow is characterized by intense focus and concentration, a merging of action and awareness, and losing track of time. In a state of flow, individuals pursue and master novel yet manageable challenges. After experiences of flow, individuals report a sense of satisfaction and enjoyment.

Interest, motivation, and aging. Do interest and intrinsic motivation change with age? We can only speculate here. To the best of our knowledge, no study has followed creative adults across various domains to assess how their motivation—intrinsic or extrinsic—changes with age. The state of flow, which is facilitated by intrinsic motivation, is described similarly by individuals of varying ages (Massimini, Csikszentmihalyi, & Delle Fave, 1988; Nakamura & Csikszentmihalyi, 2005), but it is unknown if flow changes with age.

It is possible that one's intrinsic motivation for a particular domain remains stable, or even increases as skill levels increase. The specific questions examined and methods used within a domain may change over the course of decades, but the motivation to better understand probably remains unchanged. Conversely, the fires of ambition likely bank with age (although we know of no relevant research), so we do not know how age affects the balance of the entire complex of motivation.

Psychological Resources: Grit, Self-Efficacy, and Energy

We have so far tackled processes that have a direct and specific effect on creative processes. In addition, there are a number of important psychological resources that are not specific to creativity, but are critical for achievement in general. Among these are grit, optimism, and self-efficacy.

Grit, passion, and perseverance for long-term goals (Duckworth, Peterson, Matthews, & Kelly, 2007), enable us to remain focused and determined when obstacles get in our way. Gritty individuals do not give into helplessness readily and they persist in the face of obstacles. Optimism and self-efficacy have similar benefits (Bandura, 1997; Seligman, 1991). Individuals who do not have these find themselves discouraged early in the process, as they face the first of the countless rejections the creative career necessarily entails. As Bandura (1997, p. 239) noted, "above all, innovativeness requires an unshakable sense of efficacy to persist in creative endeavors."

These resources call on energy and stamina. Mental and physical energy enable cognitive processes requiring sustained effort and self-discipline (Baumeister, Vohs, & Tice, 2007; Chaiken & Trope, 1999). High mental energy and vigor predict higher levels of work involvement in the workplace (Atwater & Carmeli, 2009; Carmeli, McKay, & Kaufman, 2014). The existing literature, however, has surprisingly little to say about what physical energy is, how it can be measured, and how it contributes to creative achievement. An old literature examining "fatigue curves" in work performance assessed physical energy by measuring decrements in performance on a strenuous physical task, such as the ability to lift or move weights, as well as the duration of rest needed to maintain performance (e.g., Hockey, 2013), but this literature seems to have no modern counterpart, and notions of energy—both mental and physical—have unfortunately not played much of a role in theorizing since the demise of Freudian dynamics. Biographies of great achievers often emphasize their exceptional levels of energy (e.g., Jamison, 2004), and we commend the study of mental and physical energy for future research on creativity.

Grit, self-efficacy, energy, and aging. Duckworth et al. (2007) found that grit increased with age in a cross-sectional study of adults. This finding may be a cohort effect (i.e., younger generations are less gritty). Alternatively, older adults may learn through experience that perseverance pays off. In addition, self-efficacy undergoes important increases over the life span, increasing from childhood to adulthood, as we learn to master the demands of each life stage. Much variability exists in old age, but many, if not most, older adults retain a sense of personal efficacy in old age (Lachman, 1986). In addition, those who are able to maintain high self-efficacy and are in supportive and challenging environments, do better intellectually and emotionally (even if their objective capacities decline) (Bandura, 1994).

In contrast, findings on the effects of aging on energy and stamina suggest that these resources decline with age. With regards to physical energy, there is no doubt that aging brings about a decrease in stamina. Some researchers have even suggested that DNA mutations of the mitochondria, the cell's energy generator, may in fact cause the aging process (Miquel, 1992; Spirduso, Francis, & MacRae, 2005). In addition, physical changes to the body's composition and metabolism lead to declines in physical activity (e.g., Roberts & Rosenberg, 2006). Thus, the decline in energy and stamina with aging may well decrease creative achievement.

So the overall influence of aging on the psychological resources that facilitate creativity is murky, mostly because of a lack of research:

- It is not known if on average, increasing rigidity is counterbalanced by increased diversity of experience with age.
- It is not known how openness to experience and integrative complexity fare with age.
- Grit and self-efficacy likely increase with age.
- Physical and mental energy likely decrease with age, but there is a surprising lack of research on energy and how it fares with age.

Interpersonal Processes

Besides cognition, knowledge, personality, and motivation, research highlights the important role of interpersonal processes for creativity. We review one's sense of the audience, as well as the ability to collaborate, and we examine how these processes fare with aging.

Sense of the Audience

Creators think about how others will react. This "sense of the audience" probably plays a very large role in both the generation and the evaluation of creative ideas—the two defining components of creativity. Sense of the audience is at the heart of the crucial distinction between originality and usefulness. Creativity requires the accurate evaluation that the original idea will be useful, beneficial, and desired by the relevant audience (Csikszentmihalyi, 1999). "Audience" is meant both literally, as in the arts and technology, and figuratively. In science and academic disciplines, "audience" refers to people at the cutting edge of the discipline, embodied by the "gatekeepers," who are the group of individuals with the power to decide which contributions will be smiled upon (Csikszentmihalyi, 1999).

A good sense of the audience may rely on perspective taking, as it allows us to accurately judge what others will see as novel and valuable (Grant & Berry, 2011). Consistent with this idea, some of the default network brain regions associated with "theory of mind" (mental simulations of the minds of others) have been found to be crucial for a positive audience reception (Falk, Morelli, Welborn, Dambacher, & Lieberman, 2013). Adequate perspective-taking may explain why relatives of individuals who suffer from schizophrenia are more represented among creative trades than nonrelatives (Kinney et al., 2001; Kyaga et al., 2011). Indeed, the looseness of thought and surplus intrusions of schizophrenia may lead to the generation of very novel ideas, but not to their accurate evaluation. What the relatives may have, and the individuals with schizophrenia lack, is a better sense of the audience.

What does perspective-taking consist of? Perspective-taking has been defined as one's ability to imagine the world from another person's point of view (Galinsky, Ku, & Wang, 2005) and to understand other people's thoughts, motivations, and emotions (Parker, Atkins, & Axtell, 2008). Such sense of audience probably also uses domain-specific and general knowledge accumulated through experience, but it is important not to mistake a good sense of audience with the goal of merely pleasing the audience. Creators may use their sense of audience to anticipate acceptance or rejection, but its function is much broader than that. Having a well-developed sense of audience allows the creator to anticipate what the audience and the domain will *ultimately* benefit from, even if the audience may *not* find the idea to be "pleasing" in the short-run (Forgeard & Mecklenburg, 2013; Silvia, 2012).

A good sense of audience stems in part from prosocial motivation, defined as the "desire to expend effort based on a concern for helping or contributing to other people" (Batson, 1987; Grant & Berry, 2011). In keeping with this, a growing body of research shows that working for the benefit of others is linked to increased creativity (for a review, see Forgeard & Mecklenburg, 2013). Prosocial motivation and a good sense of the audience probably ultimately provide creators with the resources to effectively communicate their ideas to their audience.

Such "persuasion" is a major facet of perspective taking (Simonton, 1990). Creators can persuade indirectly, by letting their work convince and inspire others, or more directly, by persuading funders (Gardner, 2011). In keeping with this, Gardner (1993) suggested that the key similarity among the seven geniuses of the 20th century—Freud, Einstein, Picasso, Stravinsky, Eliot, Graham, and Gandhi—was effective and relentless self-promotion.

Sense of audience and aging. There are good reasons to believe that age helps perspective-taking. Some of this stems from an increasing concern for the well-being of others (and especially of future generations), thinking more about legacy. Erikson referred to this as *generativity* (1963), a primary focus starting in middle age and continuing into old age (Keyes & Ryff, 1998; Sheldon & Kasser, 2001). The role legacy may play in creativity is illustrated by the swan-song phenomenon that Simonton (1989) documented in classical composers. Not infrequently, creators produce successful works at the very end of their lives.

Aside from increasing concern and motivation for others, how does aging influence the cognitive processes at play in a good sense of the audience? The research on age differences in theory of mind has produced inconsistent results, with some studies finding increases (e.g., Happé, Winner, & Brownell, 1998), others no differences (MacPherson, Phillips, & Della Sala, 2002), and others decreases (Maylor, Moulson, Muncer, & Taylor, 2002; Pratt, Diessner, Pratt, Hunsberger, & Pancer, 1996) with age. A meta-analysis of these findings, however, suggests that aging is associated with reliable *deficits* in theory of mind and task modalities (Henry, Phillips, Ruffman, & Bailey, 2013). Research on the underlying mechanisms of this decline suggests that it is only partially explained by general decline in executive function and general cognitive ability, and that a specific decline in social cognitive abilities exist (Moran, 2013; Sullivan & Ruffman, 2004).

On balance, we suspect that aging likely leads to an enhanced sense of audience thanks to the accumulated knowledge of the audience. We suspect this outweighs the possible decline in theory of mind with age. This assumes, however, stability of the audience over time. Sometimes, however, the audience changes faster than the creator can accommodate. For example, Pietro Mascagni's greatest opera was his first, after which the audience response to his successive operas declined until he was eventually booed off the stage.

Collaboration

The last factor we discuss is also not specific to creativity, but general to success: the role of collaboration. Two-thirds of the nearly 300 Nobel Prize laureates named between 1901 and 1972 received the prize for work done collaboratively, and scientists who did not win were less likely to have collaborated (Zuckerman, 1967, 1977). In addition, the number of authors on an article predicts its number of citations (Nemeth & Goncalo, 2005).

Of course, what makes collaboration effective is probably the specific choice of collaborator: someone who is similar but different enough in personality and expertise, someone who will not hesitate to challenge you and ask you to justify your ideas and opinions (Shenk, 2014). Thus, collaboration may enhance creativity by providing diversity (as earlier). In addition, collaboration may be particularly useful when it comes to evaluating the sense of audience and usefulness of an idea. Most creators do not work alone, instead, they consult and discuss their ideas with others. These others help them refine and fully understand the germ of the insight. A fine example of this process was the intense collaboration between Danny Kahneman and Amos Tversky (Kahneman, 2011). For years the two researchers spent hours each day talking about anything and everything, enjoying each other's company, and devising ways to test their theories.

Aging and collaboration. How does collaboration fare with age? Older adults may use collaboration as a way to compensate for general cognitive decline by recruiting another's abilities (Dixon, 2000). In addition, maturation probably helps us be better able to pick the right collaborators—people who share a similar vision, yet offer different perspectives. We may also have a larger network of potential collaborators to choose from, and we may be better equipped to ride through difficulties in the process.

Summary and Discussion

We began the chapter by asking how creativity could possibly increase with age in the face of declines in speed, short-term memory, and fluid reasoning. We reviewed the role of three sets of factors at play in creativity. We found that while cognitive ability generally declines with age, knowledge, expertise, and other resources may generally increase with age.

In particular we found that the following elements likely decline with age:

- Speed
- Short-term memory
- Fluid reasoning
- Originality
- Mind-wandering
- Energy and stamina
- Openness to experience

whereas the following likely increase or remain stable with age:

- Domain-specific knowledge and expertise
- General knowledge
- Pattern recognition, intuition, and heuristics
- Diversity of experience
- Interest and motivation
- Grit and self-efficacy
- Effective collaboration

For some elements, including sense of the audience, perspective taking, and integrative complexity, the current state of empirical evidence is still murky.

Multiplying the Components

Lay theories of genius often seek to explain greatness through a single extremely rare talent: Beethoven for dreaming up grand melodies; Michelangelo for chiseling granite; Napoleon for anticipating where the enemy was weakest. Scientific theories of creativity, such as Amabile's (1983, 1996) componential conceptualization of creativity, Simonton's (1999) emergenic and epigenetic model of superior performance, or Sternberg and Lubart's (1991) investment theory of creativity, however, suggest otherwise.

Indeed, rare achievement can be arrived at when the individual is merely very good—say one in a hundred—at each of the several skills that are the components of composing or sculpting or knowing where and when to attack. Creative genius might, therefore, not reside in excelling surpassingly in just one component, rather it may occur when someone is "merely" *very good* in all of them. Because the components of golf are known, Tiger Woods makes this clear. He is not the best ever in putting, driving, or the short approach. But if he is merely one in a hundred on each of these, he will be one in a million in golf: 1/100 to the third power.

And while the distribution of each single components may be normal, the distribution of their multiplicative combination (and therefore, of creative achievement) is highly skewed (Lotka, 1926; Murray, 2003; Simonton, 2006). If creativity is indeed componential, creativity becomes much more trainable by improving each of the components to a high, but not superhuman, level. But *much* more research is needed to identify components within each domain.

In addition, the componential view suggests that the effects of aging depend on what the components turn out to be. One can imagine that each of the golf components—putting, driving, the short game—wanes with age, and so indeed there is a decline in Professional Golfers' Association tournaments won after age 35. But this is probably not true for basketball. Accuracy of the three-point shots may wane with age, but the passing game and the sense of where you are on the court might increase with age—at least for a while. It is said that Julius Erving was a great shooter at 20, but did not become a great passer and rebounder until age 30.

The number of components, as well as the importance of cognitive ability, may explain differences in developmental trajectories between domains. Creative achievement tends to peak early (in the early 30s) and drop off rapidly in domains such as lyrical poetry, pure mathematics, and theoretical physics, which tend to rely heavily on fluid reasoning. In contrast, creative achievement peaks later (in the early 40s) and exhibits a more gradual decline (if any) in fields that draw more on knowledge and expertise, such as novel writing, history, philosophy, and medicine. Psychologists fall in the middle of these two patterns, peaking around age 40 (Dennis, 1966; Simonton, 1997).

We conclude that it is likely that a componential analysis by domain will find that some components wane with age and others wax. To the extent the domain is like sprinting, which is essentially a single-component game, steady decline with age will be the rule. To the extent that the endeavor is a many-component game, like basketball or science, age might favor creativity.

Our review suggests that it is indeed possible that creativity *can* increase even as we age, a surprising hypothesis rarely discussed in the literature.

If this is so, why would evolution have favored more creativity at the very same time that many physiological functions start to decline? Recent theories seeking to explain menopause in humans provide an intriguing explanation. Humans, in contrast to other species, tend to live two decades after they stop being able to have children. Reproductive decline, thus, occurs much earlier than somatic decline.

What fitness benefits would this unusual, human-only feature imply? The answer may lie in economic productivity. Such productivity continues to grow over the entire life span, largely through acquired knowledge. In contrast, offspring often take 20 years to reach a level of productivity that will allow them to provide for themselves. Thus, adults must produce an economic surplus to provide for their children (either as parent or grandparent) and will be best equipped to do so if they stop reproducing early. By undergoing menopause, human adults can be alive and productive for the first 20 years of their children's lives and can generate the required surplus of resources. Kaplan, Gurven, Winking, Hooper, and Stieglitz (2010) reviewed evidence from a primate sample (chimpanzees) and a human sample (consisting of members of the Tsimane, an indigenous forager-gardening people living in lowland Bolivia). Reproductive senescence was closely linked to somatic senescence in chimpanzees but not in humans. In addition, among the Tsimane, the pattern of calories produced and consumed (as measured by food production and intake) by age matched the theory's predictions, as older adults produced sufficient surplus calories to allow for transfer to the next generations. Interestingly, this held both for women and for men; for in monogamous societies, a man's reproductive cessation occurs when his wife gives birth to their last child.

This theory relates closely to the conclusions of the present review, which is that several (but not all) processes central to human creativity likely remain stable or increase with age. Creativity benefits from the skills and experiences obtained prior to average reproductive cessation, and these continue to accumulate rather than decline with age. In addition, the theory states that the main function of reproductive cessation is to allow elders to provide economic surplus to the next generation, and creativity is in essence designed to increase productivity.

All this suggests that Beck, Broadbent, and Bruner may not be indulging in a self-serving illusion, and more importantly, it augurs well for teaching creativity. All of the capacities that likely improve with age may be teachable, and teaching them explicitly should make for a more creative world.

Jack Riemer (2001), a journalist at the *Houston Chronicle*, popularized the story of a 1995 performance allegedly given by violinist Itzhak Perlman. Having been affected with polio as a child, he struggled onto the stage. As he began to play, one of the violin's strings broke. To the audience's awe, Perlman went on to perform the piece with only three strings. We do not know whether this story really happened (it likely did not). What we recognize, however, is the importance of Perlman's conclusion: "Sometimes it is the artist's task to find out how much music you can still make with what you have left."

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