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Introduction

According to some researchers (e.g., Abra, 1989), there is a decrease in creativity with aging. There is some support for this claim; for example, Simonton (1994) reported that there are age-related changes in creative productivity, with a sharp increase in productivity between the ages of 20 and 30 years, peaking between the ages of 30 and 50, followed by declining creative production over the next several decades. Lehman (1953) reported that poets and mathematicians typically reach their creative peaks at the earliest age, while philosophers and novelists develop their peak creativity at a later age. Even within these broad trends, there is uncertainty about the strength of the relationship between age and creativity. According to Lehman, scientists do their highest-quality work before the age of 40, but Cole (1979) found that age had only a minor impact on scientific performance. For the most part, however, there has been little study of how creativity may change with age. Remarkably, the term "aging" doesn't even appear in the index of a recent handbook on creativity (Kaufman & Sternberg, 2010). In this chapter we will discuss how aging may influence creativity and the changes in the brain that may be responsible for these changes; but first we will discuss the definition of creativity, the stages of creativity and the component cognitive processes that may be critical for creative productions.

Definition of Creativity

The Merriam Dictionary (1988) defines creativity as the ability to make new things. Similarly, the Encyclopedia Britannica defines creativity as the ability to make or bring into existence something new. These definitions are, however, somewhat inadequate. Artists, writers, and scientists who mechanically record facts might be productive but are not creative. Conversely, typing a list of nonwords, colors randomly applied to a canvas, or a random list of variables may be novel or original, but not creative. Some definitions also mention utility or the production of useful object; however, an artist may paint a beautiful picture but never display this painting. Thus, it is not useful, but this painting can be very creative.

Bronowski (1972) defined creativity as finding unity in what appears to be diversity. We agree that finding unity appears to be a major element or theme of much creative achievement. For example, great artworks have a myriad of colors and forms/shapes, and great musical works have a large variety of melodies and rhythms, but in both paintings and symphonies the artist is able to develop a thread that unites diverse elements and display order. Creative scientists such as Copernicus with his heliocentric hypothesis was able to see the thread that united what previously appeared to be a disorderly planetary system, and Einstein was able to see the thread that united matter and energy. Thus, in the arts as well as the sciences, creativity may be defined as a new understanding or novel development and systematic expression of orderly relationships (finding the "thread that unites"; Heilman, 2005; Heilman, Nadeau, & Beversdorf, 2003).

Stages of Creativity

Classic accounts of the creative process (e.g., Helmholtz, 1826, as cited by Eysenck, 1995; Wallas, 1926) proposed that creativity has four stages: preparation, incubation, illumination, and verification. *Preparation* is the acquisition of the skills and knowledge that allows a person to create. For example, Einstein developed superb skills in physics and math before he made his great discoveries, and Picasso learned to draw forms and mix colors before he painted his masterpieces. The acquisition of knowledge and skill is dependent upon brain development, and different skills require the development of different brain networks. The second stage is *incubation*, and there are probably several forms of incubation. For example, Kuhn (1996) noted that many important discoveries are initiated by the observation of an anomaly, and many important scientific discoveries are made when a scientist perceives significance in apparently accidental occurrences, such as Fleming observing that when penicillin mold fell into a Petri dish with bacteria, this mold killed these bacteria. The scientists who make these types of discoveries, such as Alexander Fleming, must be prepared to understand the importance of these accidents. Although these discoveries are based on an anomaly, it is the "prepared mind" that enables creators to perceive the importance of the phenomenon they observed. Thus, it is highly probable that creative people such as Fleming were incubating ideas about the phenomena prior to their observations. The experience of buoyancy is not an accidental occurrence and therefore when taking a bath Archimedes' discovery of the law of buoyancy was probably based on incubation. With discovery of this law Archimedes exclaimed "Eureka!" and others have called this burst of euphoria the "Aha!" experience. It is this "Aha" experience or epiphany that Helmholtz and Wallas termed *illumination*. Subsequently, creative people such as scientists perform experiments that attempt to test their hypothesis. This is the process of *verification*.

The constructs of incubation and illumination have received much criticism. The debate about the nature of incubation has centered on the question of whether "subconscious" problem-solving may occur, or whether a solution is more likely after a period of rest because incubation reduces the need for inhibition (Koppel & Storm, 2014). Metcalfe and Wiebe (1987) demonstrated that the subjective feeling of knowing (illumination) did not predict performance on insight problems. Weisberg (1986) suggested that creativity rarely requires great leaps (e.g., illumination), and the processes that lead to many great discoveries might not be subconscious incubation, but rather a series of conscious steps. Even according to Helmholtz and Wallas, rather than being an independent factor, illumination appears to be the culmination of the incubation process. As there is no consensus on these stages of creativity, instead of discussing incubation and illumination as independent stages, in this chapter we combine these stages and will use the term "creative innovation." In addition, innovators such as visual artists, composers, and authors do not verify theories but rather produce works of art. Therefore, in this chapter we call this last stage *verification–production*. Whereas verification–production are critical elements of creative achievement, these processes are specific to the type of creativity and they will not be further discussed in this chapter.

Neuropsychology of Creative Innovation

Creativity requires the novel understanding and expression of orderly relationships, and novelty requires that the creative person take a different direction from the prevailing modes of thought or expression, which is called divergent thinking. The concept of divergent thinking was put forth by William James (1890) who stated, "Instead of thoughts of concrete things patiently following one another in a beaten track of habitual suggestion, we have the most abrupt cross-cuts and transitions from one idea to another … unheard of combination of elements … we seem suddenly introduced into a seething caldron of ideas … where treadmill routine is unknown and the unexpected is the only law." Much of the empirical research on creativity since James' time has focused on divergent thinking as a critical element of creative innovation.

Frontal Lobes and Divergent Thinking

Denny-Brown and Chambers (1958) noted that all animals have two basic forms of behavior: approach and avoidance. With evolution of the brain, animals are able to perform a greater variety of behaviors, but many of these behaviors are still based on the approach–avoidance dichotomy. According to Denny-Brown and Chambers, whereas the frontal lobes are the part of the brain important in avoidance, the posterior temporal and parietal lobes are important for approach. To perform divergent thinking, a person has to disengage from currently known concepts and develop new ideas. Oliver Zangwell (1966) suggested that frontal lobe dysfunction would disrupt divergent thinking. Berg (1948) developed the Wisconsin Card Sorting test (WCS) in which participants are required to sort a deck of cards according to three main properties of images of objects illustrated on these cards (e.g., shape, color, and number). The subjects taking this test are not informed of the sorting principles (e.g., shape) but must deduce this from the response of the examiner after each sort. Throughout this test the sorting principles change (e.g., from shape to color) and the subjects must switch their strategy based on the responses of the examiner. Milner (1984) demonstrated that patients who had frontal lobectomies for the surgical treatment of intractable epilepsy were impaired at this test, suggesting that the frontal lobes might be critical for the ability to disengage and shift to new solutions. Cognitive perseveration, the inability to switch set or change the form of an activity, is often observed in brain-impaired individuals who have frontal lobe injuries. Luria (1969) demonstrated in a series of studies that patients with frontal lobe dysfunction are stimulus-(environmentally) dependent. For example, even on simple motor tasks ("When I put up one finger you put up two fingers and when I put up two you put up one") patients with frontal lobe injury have a propensity to produce behaviors that are entrained by the stimuli (a failure of disengagement) and therefore will put up the same number of fingers as the examiner.

William James (1890) suggested that the ability to switch strategies was important in divergent thinking. Converging evidence for the postulate that the frontal lobes are important for the ability to disengage and shift to new strategies (divergent thinking) comes from studies of regional blood flow in normal subjects who are performing the WCS or performing divergent-thinking creativity tests, similar to those described by Guilford (1967) and Torrance (1988). The dorsolateral prefrontal lobes were specifically more active during performance of the WCS than during a simple number-matching test, and the amount of increased activation correlated positively with WCS performance (Weinberger, Berman, & Zec, 1986). When creative subjects are providing alternative uses of bricks, their frontal lobes showed more activation than those who were less creative (Carlsson, Wendt, & Risberg, 2000).

While both studies of patients with frontal lobe lesions (Damasio & Anderson, 2003; Stuss & Knight, 2002) and functional imaging studies suggest that the frontal lobes are important for disengagement and developing alternative strategies (divergent thinking), the means by which the frontal lobes accomplish these functions remain unknown. The frontal lobes have strong connections with the polymodal regions of the temporal and parietal lobes (Pandya & Barnes, 1987). Perhaps these connections are important for inhibiting the activated networks that store semantically similar information while also exciting or activating the semantic conceptual networks that have been only weakly activated or not activated at all. Activation of these remote networks might be important in developing the alternative solutions so important in divergent thinking. Support for the postulate that the frontal lobes might be important in either activating or inhibiting semantic networks comes from a study using positron emission tomography (PET) that suggested different roles for medial and lateral rostral prefrontal cortex (Brodmann's area 10), with the former involved in suppressing internally generated thought, and the latter in maintaining these thought patterns (Burgess, Scott, & Frith, 2003).

Connectivity and the Cerebral Hemispheres

Creativity was defined in the beginning of this chapter as the new understanding or new development and expression, in a systematic fashion, of novel orderly relationships. Since the work of Paul Broca (1863) and using the lesion method, laterality studies such as dichotic listening and visual half-field, as well as electrophysiological (EEG) studies and functional imaging, it has been repeatedly demonstrated that the human brain is organized in modular fashion. Thus, the understanding, development, and expression of orderly relationships might require communication between these modules. Perhaps the strongest evidence for brain modularity is hemispheric specialization, the left hemisphere being dominant for language, even in the majority of left handed people (McGlone, 1984), dominant for motor control of skilled movements (Liepmann, 1920), and categorical processing (Kosslyn, 1998). In contrast, the right hemisphere appears to be important in spatial cognition (Benton, Hannay, & Varney, 1975), including spatial imagery (Butters, Barton, & Brody, 1970), face recognition (Benton, 1990), and coordinate coding (Kosslyn, 1998). The right hemisphere also appears to be important in emotional communication such as recognizing and expressing emotional speech prosody and emotional facial expressions (Heilman, Blonder, Bowers, & Crucian, 2000). The right hemisphere may also be dominant for mediating primary emotions (Heilman et al., 2000). Whereas the right hemisphere appears to have a global attentional perspective (Barrett, Beversdorf, Crucian, & Heilman, 1998; Robertson, Lamb, & Knight, 1988), the left hemisphere has a more focused attentional perspective. Many other right–left hemisphere dichotomies have been described that cannot be fully addressed in this chapter, but scientific or artistic creativity often requires that the creative person use the skills and knowledge mediated by both hemispheres. For example, the novelist who is writing about an emotional response of a character must use the knowledge of facial emotional expressions stored in their right hemisphere together with the verbal lexicon stored in their left hemisphere. The sculptor must imagine the rotation of spatial images such as a face where the representation is stored in the right hemisphere while she or he uses the motor skills mediated by the left hemisphere. The astronomer must combine the spatial computations mediated by the right hemisphere with arithmetic skills mediated by the left hemisphere. Thus, interhemispheric communication should be important for combining the knowledge and skills that are important for creative innovation.

William James (1890) suggested that creativity requires, "unheard of combination of elements and the subtlest associations." Spearman (1931) suggested that creative ideas result from the combination of two or more ideas that have been previously isolated. Because the right and left hemispheres store different forms of knowledge and mediate different forms of cognitive activity, different neuronal architectures probably exist within the association cortices of each of the hemispheres. A possible method of resolving a previously unsolved problem is to see this problem "in a new light" and a means of seeing a problem in a new light is to use the different forms of knowledge, and using cognitive strategies mediated by the opposite hemisphere may allow a person to gain this new insight. Although divergent thinking has been the main focus of research on creativity, the "convergent" thinking that the brain's connectivity allows – finding the thread that unites – has been seen as critical in many so-called "insight" tasks (e.g., Kounios et al., 2008).

The largest structure connecting these different hemispheric modular systems is the corpus callosum. Lewis (1979) administered the Rorschach test to eight patients before and after they had undergone a cerebral commissurotomy and reported that the disconnection of the two cerebral hemispheres "tended to destroy creativity" as measured by this test. It may be that because of its visuo-spatial nature, creative responses to this visually based projective test rely largely on right-hemispheric modules, while it would be these patients' left hemisphere that is responsible for the verbal responses. Bogen and Bogen (1988) noted that although the corpus callosum transfers high-level information, normally this interhemispheric communication is incomplete. Bogen and Bogen posited that incomplete interhemispheric communication permits hemispheric independence and lateralized cognition, and suggested that the momentary suspension of this partial independence could actually facilitate creative innovation. The Bogens, however, did not say what could account for this momentary suspension of partial independence.

The cerebral connectivity that is important for creativity might not only be interhemispheric, but also intrahemispheric. In addition to the myelinated axons that carry information between the hemispheres, there are myelinated axons that also carry information between cortical regions within the same hemisphere, as well as from the thalamus to the cortex, and from the cortex to the basal ganglia, thalamus, and brain stem. These intrahemispheric connections facilitate intrahemispheric communication that also might be important for creative innovation because widespread connectivity allows creative people to combine the representations of ideas that have been previously isolated.

Connectionist models, as well as parallel distributed processing models, suggest that the information stored in the brain is related to the strengths of connections between neurons and that a large number of units linked by a set of connections define a domain of knowledge from which any one of a large number of concepts can be generated. Psychological studies of priming effects on lexical decision latency provide a particularly clear demonstration of the capacity of this type of model to account for empirical results. In a lexical decision task, words or pseudo-words are flashed one at a time on a screen and the subject has to indicate, as rapidly as possible, if the word displayed is, or is not, a real word. In a priming paradigm, before the target word or nonword appears on the screen, a prime word appears. If the prime is strongly related to the target (e.g., the prime is *doctor* and the target is *nurse*), the response time is less than when the prime and target are unrelated (e.g., *doctor–zebra*). This is because, when a related prime appears, it generates a distributed concept representation that involves activation of many of the units that define the distributed representation of the target. To the extent that the target's neuronal representation is already activated when the target appears, response latency to the target is reduced.

We might look to these kinds of models for a more precise understanding of how connectivity might support creative thinking. There are two means by which connectionist architectures might account for creativity. Entities in the environment lead to activation of selected units, thereby leading to the generation of the patterns of activation that instantiate the concepts of these entities. There may, however, be the capacity for the discretionary–intentional activation, mediated by frontal executive networks, of selected units in a cognitive network,

thereby producing novel patterns of activation corresponding to novel concepts. In this way, the network represents an internal model of some domain of knowledge, and the discretional ability to activate selected units corresponds to the ability to ask "what if" questions.

A greater measure of creativity might be achieved by using networks representing knowledge in one domain to help organize a different domain that might nevertheless share some attributes. Such "structural concept mapping" is at the heart of current approaches to analogical reasoning and metaphor comprehension, which one could argue are prototypical examples of creative thinking (Gentner & Bowdle, 2008; cf. Glucksberg, 2008).

Many different network architectures exist within the association cortices of the brain. This raises the possibility that this aspect of creativity might involve the recruitment of networks of substantially different architecture in order to escape the constraints of existing (learned) models represented in the networks previously used for reasoning in a particular knowledge domain. The manipulation of concepts in a network of a completely different architecture would allow the investigator or artist to ask novel "what if" questions. For example, both Einstein and Richard Feynman, the Nobel Prize-winning physicist, often began with visual–spatial representations of ideas, which they subsequently translated into mathematical terms. Apparently the architecture of the networks supporting these visual representations permitted them the manipulative freedom to escape conventional formulations, thereby providing the basis for creative innovation.

Mednick (1962) suggested that in generating associative responses to stimuli, creative individuals are characterized by a "flatter" associative hierarchy than are less-creative individuals – that is, the connectivity in the semantic networks to the most common associations may be relatively weaker, and/or the links to the more "remote" networks may be stronger and thus these remote associations may be more readily activated. Hence, creative people might have the ability to activate more highly distributed networks. Support for Mednick's proposed theory, and partial support for the postulate that creative innovation is related to the recruitment of different networks, comes from EEG studies of normal subjects who, during creative thought, demonstrated an increase of anatomically distributed coherence of EEG oscillations (Jausovec & Jausovec, 2000; Kounios et al., 2008; Petsche,1996).

Changes in Creativity with Aging

As noted earlier, Simonton (1994) reported that creative productivity is a function of age, with the years of peak creativity varying widely across disciplines. Simonton (1994) suggests that "career age" (the number of years that a person has been creative in a domain) is an important factor in the reduction of creativity with aging because people simply run out of ideas. Although creative people's decreased productivity with aging might be related to the exhaustion of new ideas, there are many changes that occur in the brain with aging, and thus changes in creativity might also be related to biological factors making the generation of new ideas more difficult. For the remainder of this paper, we will consider some of those potential neurological factors.

Changes in Intelligence with Aging

There are many definitions of intelligence. Some people who do not like the construct of intelligence define intelligence as the score a person obtains on a test of intelligence (IQ test). However, to many psychologists, intelligence is the measure of a person's ability to acquire and apply knowledge. Sternberg and O'Hara (1999) suggested that, logically, there are four possible relationships between intelligence and creativity: (1) they are the same; (2) one is a subset of another (for example, creativity is a subset of intelligence); (3) they are unrelated; (4) they are overlapping but independent concepts. We would suggest a more complex and nuanced relationship: Whereas intelligence and creativity are independent concepts, creativity at the preparation stage requires the ability to acquire knowledge, and at the productivity stage to apply this knowledge. In addition, if intelligence is the measure of a person's cognitive ability to adapt, creativity is a gift that might allow one to better adapt, but this would only be true of certain forms of creativity.

One of the founders of intelligence tests, Alfred Binet, must have initially thought that creativity and intelligence were the same, or closely overlapping, because in the first intelligence test that he devised in 1896 he used inkblots to explore the imagination of children. Later, according to Sternberg and O'Hara (1999), he discontinued this inkblot test because he was unable to develop a means of scoring it.

The validity of many current tests of creativity and individual differences remains controversial. Whereas Guilford and Christensen (1973) suggested that creativity was a subset of intelligence, these investigators did attempt to develop psychometric tests that could measure creativity. These tests are similar to those developed by Torrance (1974) and primarily measure divergent thinking. One of the most widely adopted of divergent thinking tests assesses subjects' ability to develop novel uses of common objects (the Alternative Uses Test). For example, subjects would be asked to name, in a fixed time interval, the different ways in which they might be able to use a brick. Guilford found that students with low IQ consistently performed poorly on these tests, but for those students with high IQs, performance on creativity tests did not correlate highly with their performance on IQ tests. In an influential study, Wallach and Kogan (1965) compared the performance of a large number of school children on a battery of then-available tests of intelligence, and of creativity, including Guilford's Alternative Uses Test. Within each class of tests, correlations were strong, but overall, the correlation between intelligence and creativity tests was meager. After reviewing the relationship between intelligence and creativity, Torrance (1975) suggested that IQ and creativity are moderately related at best, a conclusion supported as recently as 2005 by a meta-analysis of an increasingly large literature (Kim, 2005).

Another means of studying the relationship between creativity and intelligence is studying creative peoples' intelligence. Barron and Harrington (1981) studied architects and found a weak relationship between the creativity of these architects and their IQ. They concluded that above an IQ of about 120, IQ does not predict creativity as much as it does if the IQ is below 120. These observations suggest that there might be an IQ threshold, such that a person needs to be above this threshold to have sufficient intelligence to learn the knowledge about the domain of their creativity and to acquire the skills needed to be creative in a domain. From this perspective, intelligence may be a necessary but not sufficient component of creativity.

Other investigators have also studied populations of known creative people and attempted to learn if there is a strong correlation between their estimated eminence as creators and their intelligence. Simonton (1994) and other investigators, such as Herr, Moore, and Hasen (1965), also found that the correlation between intelligence and creativity is weak. This weak correlation, however, might be related to the test that was used to measure intelligence.

Cattell (1963) posited that there are two types of intelligence, which he called "crystallized" and "fluid." Whereas crystallized intelligence is primarily declarative memories, such as knowing that Albany is the capital of New York State or lexical-semantic knowledge such as knowing what the word "impale" means, fluid intelligence is the ability to solve problems. Most modern intelligence tests, such as the Wechsler Adult Intelligence Scale (WAIS), test both crystallized (e.g., vocabulary definitions) and

fluid intelligence (e.g., How are a fly and tree similar?). Cattell thought that while crystallized knowledge may be important in enabling creativity, it is fluid intelligence that determines creativity.

There may be different domains of fluid intelligence, such as the ability to solve a mathematical problem or a visuo-spatial problem. Nonetheless, the most recent work examining the relationship between intelligence and creativity has focused on tests of fluid intelligence and "executive functions," broadly speaking; and consistent with Cattell's view, these studies have found a much stronger relationship between creativity and intelligence than previously reported. For example, Silvia (2008), using a composite latent-variable measure of fluid intelligence, found it to be strongly predictive of performance in Guilford's Alternative Uses test. Lee and Therriault (2013) also used latent-variable measures, and found support (through structural equation modeling) for fluid intelligence being significantly predictive of both divergent thinking (as measured by a battery of tests including Torrance's) and convergent thinking (as measured by Mednick's Remote Association Test as well as two "insight" problems). The relationship between intelligence and creativity was strongest when modeled through the mediating variable of "associative fluency" (as measured by three different word-production tasks). In a similar study, we found that a composite intelligence variable, based on the Wechsler Abbreviated Scale of Intelligence (WASI), which has both crystalized (vocabulary) and fluid (matrix reasoning) components, was predictive of self-reported creative behavior, but was mediated wholly through performance on convergent (Remote Associations) rather than divergent (Alternative Uses) thinking (Lee et al., 2012). Silvia (2015) has reviewed this literature, and concluded that the link between intelligence and creativity is stronger than previously thought.

With aging there is a decrease in the performance IQ, suggesting that fluid intelligence might decrease with aging. Many of the tests in the performance IQ of the WAIS are timed, and as people get older they often get slower. This slowing is both electrophysiological (e.g., evoked potentials) and behavioral. Thus, some investigators have asked whether the lower scores on the performance IQ that is associated with aging is related to slowing. While allowing older subjects more time did improve their performance, even without time constraints the older subjects did less well than the younger subjects (Storandt, 1977). Thus, with advancing age there appears to be a continuing increase in crystallized intelligence, but a decrease of fluid intelligence (Ryan, Sattler, & Lopez, 2000). The decrease of fluid intelligence as a function of age appears to mirror the changes in creativity seen with aging, but this relationship is correlative, not explanatory.

The Aging Brain

With aging there are many diseases that may alter brain function, such as stroke and degenerative diseases such as Alzheimer's disease and Parkinson's disease; however, independent of the many diseases of the brain that are more common in older people, there are many biological changes in the brain that occur with normal aging. The brain decreases in both size and weight with aging. These involutional changes usually start at the age of 50, and there is about a 5% decrease with each subsequent decade. Quantitative anatomical studies of the aging brain in nondemented people, using neurostereology (Pakkenberg et al., 2003), have revealed that the difference in total number of neurons in the brain of people who ranged from 20 to 90 years old is, however, less than 10%. This would suggest that the loss of brain substance is not predominantly due to the loss of neurons.

Although there is only a small percentage of neurons lost with aging, many of the neurons that are lost are located in brain areas that might be critical to creativity, including the prefrontal lobe (e.g., Brodmann's area 10) and the inferior parietal lobe (including Brodmann's areas 40 and 39). With aging one can see, even in the absence of a clinical diagnosis of dementia, the histological changes that are often associated with Alzheimer's disease, including the deposition of amyloid as well as changes in the neurons, including neurofibrillary tangles, and a loss of dendritic branching or arborization. Thus, some neurons that are not lost might be "sick" and not properly functioning. With a loss of dendritic arborization these neurons are less connected to other neurons. Other changes include granulovacuolar degeneration (little vesicles or holes in the neurons' cytoplasm) and the deposit of lipofuscin (a form of pigmented fat).

Some physiological research that studied blood flow with PET or dominant EEG rhythms suggests that with aging there might be metabolic changes that reduce the overall activity of the brain. When subjects with medical diseases such as hypertension or diabetes were excluded from these physiological aging studies, there appeared to be no major difference in blood flow (Duara et al., 1983) or brain activity, as measured by EEG frequency (Duffy & McAnulty, 1988). Therefore, it is unlikely that the decreased creativity associated with aging is caused by metabolic abnormalities.

Many of the intra- and interhemispheric connections that we mentioned above are mediated by axons that travel in the subcortical white matter. Studies which have compared the loss of gray matter (primarily composed of neurons and their dendritic processes) versus white matter (primarily composed of myelinated axons and supporting structures) have revealed that most of the brain volume and brain weight that is lost with aging is related to loss of white matter (Tang, Whitman, Lopez, & Baloh, 2001). In addition, in contrast to the minimal loss of cortical neurons associated with aging, the total myelinated fiber length of axons decreases with aging (Pakkenberg et al., 2003).

The areas that show the greatest white matter loss are those which myelinate late in development, such as those in the frontal lobes. When older people obtain magnetic resonance imaging (MRI) or computer tomographic scan (CT) of their brain, there is often evidence of enlarged ventricles, and it is the loss of subcortical white matter that is responsible for the increases in the size of their lateral ventricles. In addition, many older people who undergo MRI show evidence of injury to the subcortical white matter. Neuroradiologists often call these changes "ischemic demyelination" or "leukoaraiosis." The cause of this loss and damage to the white matter is not entirely known; however, the change in the brain that is most likely to result in leukoaraiosis is a loss of myelinated axons.

Earlier in this chapter we discussed the important role of the corpus callosum, the major connection between the left and right hemisphere, in creativity. The corpus callosum is primarily composed of myelinated axons that travel from one hemisphere to the other. With the loss of the white matter associated with aging there is also a thinning of the corpus callosum (Hopper, Patel, Cann, Wilcox, & Schaeffer, 1994). In addition to the anatomic alterations with aging there is also evidence of a functional decrease in interhemispheric communication that is mediated by the corpus callosum (Reuter-Lorenz & Stanczak, 2000).

Gall, the founder of the pseudoscience of phrenology, posited that the brain is organized in a modular fashion and that the larger the module, the more superior its performance. Geschwind and Levitsky (1968), using unselected brains from post-mortem examinations and without knowledge of these peoples' hand preference or language laterality, found that in more than 60% of these brains, the planum temporale in their left hemisphere was longer than that in their right hemisphere. Subsequently, in patients who were being evaluated for epilepsy surgery, by using selective hemispheric anesthesia to determine language laterality (the Wada test) and MRI to determine brain morphology, we demonstrated that almost all subjects who had left-hemisphere dominance for language also had a larger planum temporale in their left than their right hemisphere (Foundas, Leonard, Gilmore, Fennell, & Heilman, 1994). We also demonstrated that portions of the left inferior frontal areas (i.e., Broca area) that are important in speech production are also larger on the left (Foundas, Faulhaber, Kulynch, Browning, & Weinberger, 1999). Several other right–left hemisphere asymmetries have been described, including: the termination of the Sylvian fissure being higher in the right than left hemisphere (Rubens, Mahowald, & Hutton, 1976) and the right frontal lobe being wider (distance between the lateral wall of the frontal horn of the lateral ventricle and the surface of the cortex of the frontal convexity cortex) than the left. It is possible that people who are creative not only have greater functional asymmetries, but also have greater anatomic asymmetries.

As mentioned, dividing the hemispheres by cutting the corpus callosum has been shown to reduce creativity (Lewis, 1979). Based on this observation it is possible that the degree of interhemispheric connectivity might be directly related to creative potential. However, the cerebral connectivity important for creativity might not only be interhemispheric, but also intrahemispheric. As noted earlier, these intrahemispheric connections facilitate intrahemispheric communication, which may also be important for creative innovation because, as we have mentioned, creativity may require widespread connectivity. Support for this hypothesis comes from the work of Takeuchi et al. (2010a), who used diffusion tensor imaging and a test of divergent thinking to investigate the relationship between creativity and structural connectivity. These investigators found that integrated white-matter tracts between the association cortices and the corpus callosum, which connect the networks that store different forms of information in distant brain regions, support creativity. The reduction of creativity with aging may, therefore, be in part related to the age-related loss of intrahemispheric as well as interhemispheric white matter connectivity.

Frontal Lobes and Aging

Injury to the frontal lobes or interruptions of its subcortical connections, with structures such as the basal ganglia or thalamus, impairs the functioning of the frontal lobes. Many of the neurobehavioral deficits associated with frontal lobe functions are called executive deficits. Several studies suggest that in older people the frontal lobes might not function as well as they do in younger people. For example, Mittenberg, Seidenberg, O'Leary, and DiGiulio (1989) compared older and younger subjects on tests designed to assess frontal, parietal, and temporal lobe functions. These investigators found that it was frontal lobe functions that best correlated with the subject's age.

As mentioned, Denny-Brown and Chambers (1958) noted that the frontal lobes are critical for avoidance and disengagement. One of the most common executive deficits associated with frontal lobe dysfunction is perseverative behavior on tests such as the WCS. Creative innovation requires that a person disengage from previously used ideas-concepts, strategies, and products and then develop new ideas-concepts, strategies, and products. If a creative person gets "stuck in set" their creative careers will come to an end. Ridderinkhof, Span and van der Molen (2002) tested a population of older subjects with the WCS test and found that they are more likely to get stuck in set than are younger subjects. Hence, the problem the older subjects were having on this task was not related to their inability to develop rules of sorting, but rather their reluctance or inability to shift strategy after they found a sorting strategy. This form of perseverative behavior might also be termed "cognitive rigidity."

The reason why some older people have a propensity to get stuck in set or have cognitive rigidity is unclear, but one possibility concerns decreases in dopamine levels. As we mentioned earlier, neurons communicate by releasing chemicals called neurotransmitters. One of the major neurotransmitters that appears to decrease with aging is dopamine. For example, Volkow et al. (2000), using PET, noted that with aging there was a decrease of dopamine, together with a decrease of frontal lobe activation. The cells that release dopamine are found in the midbrain and from there travel to both the basal ganglia and cerebral cortex. Patients with Parkinson's disease have a reduced level of dopamine and they also have evidence for frontal lobe dysfunction (Green et al., 2002). For example, patients with Parkinson's disease often perform poorly on tests such as the WCS, frequently getting stuck in set. Thus, another possible hypothesis to account for the loss of creativity with aging is the presence of cognitive rigidity that is induced by an age-related loss of dopaminergic neurons.

One of the best ways to assess the presence of cognitive rigidity is by use of divergent thinking tests such as the Alternative Uses Test. Takeuchi et al. (2010b) used voxel-based morphometry (VBM) to identify the gray-matter correlates of individual creativity as measured by the divergent thinking test. They found positive correlations between regional gray-matter volume and individual creativity in several regions such as the right dorsolateral prefrontal cortex and subcortical areas such as the substantia nigra and ventral tegmental area. According to these investigators, their findings suggest that creativity, as measured by the divergent thinking test, is mainly related to a decrement in the regional gray matter of regions in the brain known to be associated with the dopaminergic system.

As mentioned above, with aging there is a loss of or injury to subcortical white matter. Patients who have diseases that injure their white matter, such as multiple sclerosis or multiple small strokes of the white matter, frequently show evidence of frontal lobe dysfunction and hence perform poorly on tests such as the WCS because they get stuck in set, whereas to be creative one has to break out of a set and think divergently.

As mentioned earlier, one of the most popular means to test divergent thinking is the Alternative Uses Test, where participants are asked to describe alternative uses of common objects such as bricks and to select uses that are the most creative. We tested 30 older and 30 younger subjects using the Alternative Uses Task and found, unexpectedly, that the older subjects performed better than the younger subjects (Leon, Altmann, Abrams, Gonzalez-Rothi, & Heilman, 2014). We posited that perhaps the older subjects had more experiences with these objects than did the younger subjects. It is possible that the Alternative Uses Test assesses not only divergent thinking but also acquired knowledge, but this hypothesis needs to be further tested.

Right Hemisphere Deterioration with Aging

The right hemisphere appears to be more important for mediating global than local processing (Fink et al., 1997), and global processing is often important in finding the "thread that unites." The right hemisphere is also important in visual–spatial functions, and many extremely creative people such as Albert Einstein have reported using visual–spatial strategies to help find creative solutions. Thus, another hypothesis as to why creativity decreases with aging suggests that right-hemisphere-mediated functions deteriorate more than those of the left (Dolcos, Rice, & Cabeza, 2002). The right-hemisphere deterioration hypothesis of reduced creativity with aging is supported by studies that gave older and younger subjects the WAIS. The visual–spatial tasks (e.g., block construction) on the WAIS are part of the performance IQ, whereas the language tests (e.g., vocabulary) are part of the verbal IQ. Investigators have found that with aging there is greater deterioration of the performance IQ than there is of the verbal IQ. As the right hemisphere appears to be dominant for visual–spatial functions, one could interpret this age-related decrease of visual–spatial abilities to a loss of right-hemispheric function with aging.

There are, however, several confounds to this interpretation. For example, many of the spatial tests that are part of the performance IQ are timed, and with aging there is slowing of response times independent of task. In addition, the performance IQ is also more of a test of fluid that crystallized intelligence, and as mentioned above with aging there might be a greater decrement of fluid intelligence. However, many visual–spatial functions have been shown to deteriorate with aging even when using untimed tests (Koss et al., 1991). For example, when shown incomplete drawings of objects, older subjects have more trouble recognizing these objects (Read, 1988), or when older subjects have to find figures which are embedded in larger figures, they also perform more poorly than the younger subjects. Recognition with incomplete information or finding a meaningful stimulus in a noisy background is similar to finding the "thread that unites." In contrast to the deterioration of spatial skills, as a function of age, the verbal IQ of older people appears to remain stable, and some studies even showed an improvement of verbal skills with aging. Whereas vocabulary seems to remain unchanged or even increase with aging, there are some suggestions that knowledge of grammar and syntax also appear to improve. Perhaps this is why novelists are more likely to remain creative to an older age than are mathematicians and theoretical physicists.

While the assessment of the right versus left hemisphere's cognitive functional efficacy as we age remains to be fully determined, Gur and associates (1980) studied the ratio of gray to white matter in the left versus right hemisphere and found that there is more gray matter relative to white matter in the left than in the right hemisphere. This observation suggests that the left hemisphere primarily transfers information within or between contiguous regions of the left hemisphere and that the right hemisphere transfers intrahemispheric information across regions that are greater distances apart. Therefore, the normal functions mediated by the right hemisphere may be more dependent on long myelinated axons. Because with aging there is a greater loss of white than gray matter, the right hemisphere should be more affected by aging than the left hemisphere, and therefore the decrease of creativity with aging might be related to a decrease in the functions mediated by the right hemisphere. However, Gur et al. (1980) also measured gray-matter atrophy as a function of age and found that there was more gray-matter atrophy of the left than the right hemisphere, especially in men, a finding that would be in conflict with the right-hemisphere hypothesis for reduced creativity with aging.

Depth of Processing

Objects can have functional and associative relationships or they might have conceptual relationships. Finding the unity in what appears to be diversity is critical for creativity, and finding this unity would appear to be more dependent on determining conceptual than associative relationships. When subjects were asked to group objects, Denney (1974) found that elderly people are more likely than younger subjects to group these objects by associative relationships than by semantic-conceptual relationships. For example, if participants are given three objects, a rifle, a bow, and an arrow, and are asked to group the two objects that are most closely related, a person could select a bow and arrow based on their strong associative relationship, or a bow and rifle because these two objects have a closer semantic-conceptual relationship (weapons that emit projectiles). The means by which the brain develops associative versus conceptual relationships is unknown; however, grouping by associative relationships can be done based on sensory (iconic) memories. Hence, a person might be able to imagine a bow together with an arrow easier than she or he could imagine a bow together with a rifle, because the former two items are more often seen together than the latter two items. The grouping at the semantic-conceptual level is more abstract (less dependent on sensory associations) than grouping on an associative level. The term abstract comes from the Latin term abstractus that means to "draw away," and in order to group at the semantic-conceptual level a person must draw away from the sensory-iconic level of processing and group by functions or shared properties. Therefore, determining associative relationships can be performed within a modality, but determining conceptual relationships often depends on the activation of widely distributed networks, and older people may have a reduction in connectivity that impairs the communication between anatomically distributed conceptual-semantic networks.

Hormones and Aging

Serum levels of total and bioavailable testosterone gradually decrease with age in men, and this change is associated with changes in cognition. Cherrier and co-investigators (2001) examined the relationship between exogenous testosterone administration and cognitive abilities in a population of healthy older men. Circulating total testosterone was raised an average of 130% from baseline at 3 weeks and 116% at 6 weeks in the treatment group. Because of aromatization of testosterone, in the treatment group estradiol increased an average of 77% at week 3 and 73% at week 6. Significant improvements in cognition were observed for spatial memory (recall of a walking route), spatial ability (block construction), and verbal memory (recall of a short story) in older men treated with testosterone compared with their baseline evaluation and the performance of the placebo group; however, it is not known whether hormonal treatment with testosterone can restore any age-related decrease of creativity.

Oxytocin is another neurohormone that may decrease with age (see Huffmeijer, van IJzendoorn, & Bakermans-Kranenburg, 2013) and has been associated with creative performance. In a series of studies reported by De Dreu et al. (2014), administration of intranasal oxytocin versus placebo increased holistic processing (Study 3, response time to "global" versus "local" targets in Navon figures), improved divergent thinking (Study 5, all three dimensions of performance in the Alternative Uses Test), and led to more solutions of insight problems, which have been used as tests of convergent creative thinking (Study 6). As with testosterone, it is not known whether administration of oxytocin could restore any age-related decrements in creativity, or what other impacts such administration might have in the elderly.

Conclusion

In this chapter, we have attempted to define creativity, review the stages of creativity, discuss the possible neuropsychological mechanisms that are important in creativity, and consider how these processes and mechanisms might change with aging. Although it has been repeatedly claimed that with aging there is a decrease in creativity, the specific changes – for worse, or better – in creative abilities and performance that may be associated with aging have not been systematically examined, and the possible alterations in brain functions that may alter creativity with aging also have not been fully studied. Creativity is one of the most important of human attributes, but historically it has not generated as much interest as other domains of cognition such as memory and language. Therefore, there is a great need for research that will allow us to understand the brain mechanisms that allow humans to be creative, as well as how creativity can be developed and enhanced. We also need to learn more about the adverse influence of diseases and aging on creativity and how these can be modified and mitigated.

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Part VIII

Artistic and Aesthetic Processes