# Part III

# Attention and Imagination

# 9 Attention and Creativity

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I need solitude for my writing: not "like a hermit" – that wouldn't be enough – but like a dead man.

(Franz Kafka)

Marie Curie's focus allowed "no lapses of attention." She concentrated her attention "without even hearing the mounting roar of chatter."

(Curie & Scheean, 2001, p. 97)

Creativity is a way of embracing originality and making unique connections between seemingly disparate ideas. The root meaning of the word "create" means to "arise, grow," therefore creativity and innovation is a growing of sorts – from an individual to the entire civilization. Although not all creations are byproducts of novel or creative cognition, as some are "created" upon existing knowledge and routine building, nonetheless from the invention of the wheel to Mozart's sonatas some of the world's major achievements are the result of creative thinking.

Although they were arguably both creative individuals, Franz Kafka, one of the most influential authors of the twentieth century, was so distracted by noise that he needed complete solitude, "like a dead man," for his writing, while Marie Curie, a physicist and chemist who conducted pioneering research on radioactivity, was able to tune out noise so well that she didn't even hear "the mounting roar of chatter." Described below are three most prominent theories on the link between creativity and attention, followed by most recent evidence suggesting that, indeed, different forms of attention are linked with different types or measures of creativity.

## What is Attention?

The main function of attention amounts to the selection of relevant information, and rejection of irrelevant information (Posner, 1988). Without selective attention, we would have to process too many details, which, in consequence, would inevitably result in cognitive overload. Moreover, without selective attention we would have to process entirely irrelevant details, which could result in many cognitive faults and biases. In order to deal efficiently with cognitive tasks, we need to take into account only a small fraction of potentially available, and relevant, information. In other words, attention is necessary to select what is important and to ignore what is unimportant or irrelevant to a given situation. Attention, however, varies by type (e.g., diffused, focused, flexible), by degree, and by individual. A question posed here is: What type of attention is conducive to creativity?

## What is Creativity?

Creativity can be defined as the ability to produce work that is simultaneously novel and meaningful or useful, as opposed to trivial or bizarre (Sternberg & Lubart, 2002). People differ in the capacity to be creative, and there are various ways of measuring creative ability. One of the most commonly used measures to evaluate creative thinking is a test of divergent thinking (DT), which assesses the ability to generate ideas by exploring many possible original solutions to a given problem within a limited amount of time in laboratory settings (Guilford, 1950; Torrance, 1974). Although DT tests modestly predict real-world creativity (Runco & Acar, 2012; Torrance, 1969), it is not clear whether the type of attention required to perform well on DT tests is the same type of attention employed by people who are creative in the real world. Considering that DT tests are time-limited (typically 2–3 minutes per task), and often emphasize the number of responses (i.e., fluency as opposed to originality), they may require a different type of attention than does creativity in the real world.

While some consensus exists regarding how attention is associated with creativity, findings often seem to contradict one another. Here I briefly describe prior theories of how attention relates to creativity, and present three seemingly contradictory views: creativity through diffused or "leaky" attention, creativity through focused attention, and creativity through flexible attention. Indeed, all three forms of attention may contribute to the creative process. I highlight, however, that what matters is the operational definition of creativity – that is, how we measure it. I present behavioral and neurophysiological evidence suggesting that if we assess creativity with divergent thinking tests, we see a link between creativity and selective, yet flexible attention. Alternately, if we assess creativity with a more ecologically valid survey of people's real-world creative achievements, we see a link between creativity and "leaky" attention. I discuss this evidence in the context of a newly developed Model of Creativity and Attention (MOCA), and conclude with suggestions for future research.

## The Role of Attention in Creativity: A Review

A large body of literature suggests that creative people have diffused or leaky attention; that is, creative people show the propensity to notice information that may not be particularly relevant to the task at hand (Carson, Peterson, & Higgins, 2003; Mendelsohn & Griswold, 1964; Rawlings, 1985). On the other hand, some have suggested that creative people are more likely to pay attention to the fine-grained details, and thus have more focused attention than less creative people (Nusbaum & Silvia, 2011). Finally, evidence exists that creative people do not necessarily differ in their predominant mode of attention, but can switch between various modes of attention more easily, and therefore have flexible attention (Vartanian, Martindale, & Kwiatkowski, 2007; Zabelina & Robinson, 2010). Here I review evidence for each view, and suggest that these views need not compete. Rather, they may all operate, but on different types or measures of creativity, with different factors of attention at work.

## Creativity and Broad or "Leaky" Attention

Some empirical evidence suggests that creative people may have particularly diffused or leaky attention, or the propensity to notice information that other people may dismiss as irrelevant. Historical evidence suggests that there may indeed be an association between high levels of creativity and leaky attention. For example, in 1981 Gabriel Marcia Marquez did an interview for the winter issue of *The Paris Review*, and when asked to conclude with what his next project would be, he noted: "I'm absolutely convinced that I'm going to write the greatest book of my life, but I don't know which one it will be or when. When I feel something like this – which I have been feeling for a while – I stay very quiet, so that if it passes, I can capture it," highlighting the distracting nature of extraneous stimuli for the creative process. Numerous other eminent creators, including Richard Wagner, Marcel Proust, Charles Darwin, Edgar Allen Poe, Anton Chekhov, and Johann Goethe lamented about noise as a source of intrusion or distraction (see Kasof, 1997).

As a consequence of such leaky attention, creative people are prone to errors on typical attention tasks. For example, one study simultaneously presented participants with pairs of words under the instructions to repeat or shadow words presented to one ear, while attempting to remember words presented to the other ear (divided attention condition; Rawlings, 1985). Creative participants of the Wallach and Kogan (1965) test (Pattern Meanings: viewing abstract designs and suggesting interpretations of the patterns, and Similarities: generating ways in which pairs of objects were similar for 10 object pairs) experienced more intrusion errors from the non-shadowed ear than less-creative participants. This finding suggests that people who perform well on this creativity task may have leaky attention.

Leaky attention, however, may be a double-edged sword: it may serve as a cost in some circumstances; for instance, when people are trying to focus on a conversation in a noisy café. However, it may also serve as a benefit by helping people introduce unusual and original pieces of information into their cognition, resulting in a creative thought. In support, creative people incorporate seemingly irrelevant cues when solving word puzzles, such as anagrams (creativity assessed by the Remote Associates Test, RAT), on which participants are asked to come up with a word that forms a common compound or a phrase with the three presented words (Ansburg & Hill, 2003; Mednick, 1962; Mendelsohn & Griswold, 1964), recall words or phrases (creativity assessed by RAT; Russell, 1976), or perform auditory attention tasks (creativity assessed by the Creative Achievement Questionnaire, CAQ; Carson et al., 2003).

In support of leaky attention, creative people often say that they are sensitive or oversensitive. Indeed, highly creative people show several physiological and behavioral correlates of reactions to noise and efforts to block it: more-creative participants (creativity assessed by RAT × DT fluency), for example, show more alpha-blocking in response to onset of a tone than their less-creative counterparts (Martindale & Armstrong, 1974), suggesting that more-creative participants exhibit higher arousal to onset of tones than less-creative participants. They also show larger skin potential responses to moderately intense tones, and take twice as long to habituate to the tones than less-creative participants (creativity assessed by RAT × DT fluency; Martindale, Anderson, Moore, & West, 1996). These findings suggest that creative people may indeed have leaky attention, or potentially leaky sensory processing, making it more difficult to block out irrelevant stimuli, and/or increasing their physiological sensitivity.

Finally, there is evidence that exposure to arousing stimuli reduces breadth of attention (Easterbrook, 1959). Particularly, arousal is increased and breadth of attention is decreased by crowding (Evans, 1979; Nagar & Pandey, 1987), evaluation apprehension (Cottrell, Wack, Sekerak, & Rittle, 1968), time pressure (Karau & Kelly, 1992), and the presence of others (Bond & Titus, 1983). Correspondingly, creativity is generally hindered by crowding (creativity assessed by DT; Aiello, De Risi, Epstein, & Karlin, 1977), evaluation apprehension (creativity assessed by subjective ratings of collages; Amabile, Goldfarb, & Brackfield, 1990), time pressure (creativity assessed as a real-world five-year evaluation of innovation and productivity in scientists and engineers, Andrews & Farris, 1972; creativity assessed by groups generating planning tasks, rated by judges for originality and creativity, Karau & Kelly, 1992), and presence of others (creativity assessed by generating word associations, Matlin & Zajonc, 1968; creativity assessed by the Wallach & Kogan Creativity Battery, Milgram & Milgram, 1976).

Neuroimaging evidence provides partial support for the role of leaky attention in creative thinking. For example, a meta-analysis of functional imaging data reported activations in the brain regions associated with spontaneous imaginative processes, namely the precuneus (Gonen-Yaacovi et al., 2013). The precuneus, a core hub of the default mode network (DMN) – a set of midline and inferior parietal regions that activate in the absence of most external task demands (Gusnard & Raichle, 2001), has been implicated in both structural (Fink, Koschutnig, et al., 2014; Jauk, Neubauer, Dunst, Fink, & Benedek, 2015; Jung et al., 2010; Takeuchi et al., 2010) and functional (Benedek et al., 2014; Fink, Weber, et al., 2014; Takeuchi et al., 2011) imaging studies of creativity. Moreover, activation of the inferior parietal lobule (IPL), another core hub of the DMN (van den Heuvel & Hulshoff Pol, 2010), has been reported in several neuroimaging studies of creativity (Abraham, Beudt, Ott, & von Cramon, 2012; Benedek et al., 2014; Fink et al., 2009, 2010).

Thus, it appears that broad or leaky attention can be of particular importance for some forms of creativity, specifically for making connections between ideas, e.g. words on the RAT, and for producing creative achievements in the real world. Namely, leaky attention may help people be more sensitive to and make connections between distantly related concepts or ideas. Leaky attention may also afford people with a larger repertoire of potential stimuli for production of an unusual or creative idea.

## Creativity and Focused Attention

An alternative proposal of how attention relates to creativity suggests that creativity depends on the ability to focus attention. More generally, creativity may rely heavily on executive functions (De Dreu, Nijstad, Baas, Wolsink, & Roskes, 2012; Gilhooly, Fioratou, Anthony, & Wynn, 2007; Nusbaum & Silvia, 2011; Wiley & Jarosz, 2012), i.e., general-purpose control mechanisms such as the ability of the cognitive system to configure itself for the performance of specific task goals (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Miyake & Friedman, 2012). Indeed, in order to create a highly original thought or product, people have to focus and persist in the task at hand. For instance, the preparation stage of creativity involves information-gathering, mastering a knowledge base, and identifying the problem (Wallas, 1926). These behaviors surely benefit from focus and persistence. Leonardo da Vinci, for example, one of the most recognized creative polymaths, was said to have “obsessive attention to detail” (Lester, 2012, p. 191). Marie Currie described her focus during schoolwork as “allowing no lapses of attention” (Curie & Scheean, 2001, p. 72), as well as concentrating her attention “without even hearing the mounting roar of chatter” (Curie & Scheean, 2001, p. 97).

Persistence in the discovery process does not come easy. There are many conflicting demands, and creative ideas are often, by definition, incompletely formulated or of dubious utility. Even when ideas come in a flash, focus and persistence is required to put them to good use (Gabora, 2010). A considerable body of research suggests that creativity involves the ability to maintain an extended focus (Feist, 1999; Richards, Kinney, Lunde, Benet, & Merzel, 1988). Artists, for instance, spend more time reworking their drawings than do nonartists (Kozbelt, 2008).

Empirical evidence suggests that working memory capacity in particular may benefit some forms of creativity by enabling an individual to maintain attention focused on the task (Baas, De Dreu, & Nijstad, 2008). In support, working memory capacity predicts performance on the DT test, specifically because it allows persistent (rather than flexible) processing (De Dreu et al., 2012). Similarly, greater executive capacity is associated with greater fluency (number of ideas produced within a given time) on the DT task (Gilhoooly et al., 2007). Moreover, fluid cognitive abilities (Gf) predict performance on divergent thinking tasks, and giving people a helpful task strategy exaggerates the difference between people low and high in Gf (Nusbaum & Silvia, 2011).

An increasing body of research suggests that performance on the divergent thinking tests in particular involves task-driven top-down control of attention and cognition. Much of this evidence comes from latent variable studies showing effects of higher-order cognitive abilities, such as fluid intelligence (Beaty, Silvia, Nusbaum, Jauk, & Benedek, 2014; Nusbaum &

Silvia, 2011), working memory capacity (Lee & Therriault, 2013; Süß, Oberauer, Wittman, Wilhelm, & Schulze, 2002), and verbal fluency (Benedek, Könen, & Neubauer, 2012; Silvia, Beaty, & Nusbaum, 2013) on DT. Such abilities are hypothesized to support thinking in a divergent manner by providing the executive control needed to guide memory retrieval and inhibit salient but unoriginal ideas (Beaty & Silvia, 2012; Beaty et al., 2014; Benedek, Franz, Heene, & Neubauer, 2012; Silvia, Beaty, Nusbaum, Eddington, & Kwapil, 2014).

Behavioral evidence for the role of executive processes in performance on the DT tasks has received support from electroencephalogram (EEG) and functional magnetic resonance imaging (fMRI) research. Several studies report task-related activation in brain regions associated with interference resolution, response selection, and cognitive control in the inferior frontal gyrus (IFG) and inferior parietal cortex (Abraham et al. 2012; Benedek et al., 2014; Chrysikou & Thompson-Schill, 2011; Fink et al., 2009; Fink & Benedek, 2014). Fink and colleagues (2009), for example, conducted an fMRI study with a battery of DT tasks that varied in terms of the creativity-related demands required. Tasks with a high-creativity demand required generation of novel uses for common objects – the classic DT task – and tasks with low-creativity demands simply required the generation of typical object characteristics. Compared to tasks with low-creativity demands, performance on tasks with high-creativity demands was associated with increased activation of the left angular gyrus and decreased activation in the right inferior parietal cortex. Moreover, regardless of the task demands, idea generation was related to increased activation of the left IFG, the anterior cingulate cortex (ACC), and the precentral gyrus. Fink and colleagues (2009) interpreted their results as evidence for a role of controlled memory retrieval and internal attention in DT. Taken together, it appears that some forms of creativity, particularly creativity as assessed by timed laboratory tests of DT, may benefit particularly from selective attention.

## Creativity and Flexible Attention

Another view of how attention relates to creativity suggests that creative people have the attentional flexibility to adaptively shift between focused and broad attention (Gabora, 2010; Vartanian, 2009; Zabelina & Robinson, 2010). Indeed, creative acts may require the ability to see the large picture and its details, as well as the flexibility to switch between the two (Gabora, 2010; Martindale, 1995). Indeed, spontaneous shifts between analytic and associative modes of thought have been suggested to be necessary for creative production (Gabora, 2010).

Biographical and personality studies suggest that the problem-solving behavior of eminent scientists alternates between extraordinary levels of focus on specific concepts to playful exploration of ideas (see Feist, 1999; Martindale, 2001). This suggests that problem-solving may be a function of flexible strategy application in relation to task demands. Thus, attentional flexibility allows people to flexibly switch between broad and narrow levels of attention. It is unclear, however, what timescale of attentional flexibility is the most conducive to creative thinking. Rapid flexible attentional switching may be important for creativity in the short term, such as performance on timed tasks of insight problem solving (e.g., Bowden & Beeman, 1998) or DT tasks (e.g., Torrance, 1974), while real-world creative acts may operate on a longer timescale, requiring remaining in one type of attentional state for some time before switching to another.

It is also unclear what the mechanism of attentional flexibility is. There are at least two possible mechanisms of how people may flexibly switch their attention from one stimulus to another. One potential mechanism is bottom-up leaky attention. Specifically, when people attend to one stimulus, information from the other stimuli may still "leak in," allowing relatively easy processing of the stimuli outside of one's focus, and therefore rapid switching of attention to another target. Alternatively, it is possible that attentional flexibility stems from a sharp top-down focus of attention on one stimulus, followed by a rapid disengagement or inhibition, and rapid focus on a subsequent stimulus. In other words, this mechanism allows for high inhibition of attention, where attention capture is not as long or as lasting, allowing for rapid shifting of attention. This would be analogous to an effect found in the working memory literature, in which both high and low working memory capacity people exhibit attentional capture by distractors, but high-capacity people recover more quickly than their low-capacity counterparts, as indicated by behavioral and event-related potential (ERP) findings (Fukuda & Vogel, 2011). The mechanisms of flexible attention need to be elucidated in order to gain deeper understanding of the association between creativity and attentional flexibility.

## Different Types of Attention are Associated with Different Measures of Creativity

The hypotheses of how different types of attention – leaky, focused, and flexible attention – relate to creativity seem to contradict one another. They may not be mutually exclusive, however – they may all operate, but on different components, measures, and stages of creativity, with different factors of attention at work. Specifically, performance on the DT tests may rely on the task-driven (i.e., top-down) ability to rapidly focus, inhibit, and switch attention, supporting attentional flexibility. Real-world creative achievement, on the other hand, may benefit from the stimulus-driven (i.e., bottom-up) attention that is broad or leaky.

### Model of Creativity and Attention (MOCA)

Here I present a newly developed Model of Creativity and Attention (MOCA, Figure 9.1), which describes the associations between creativity (divergent thinking and real-world creative achievement) and attention (leaky, focused, and flexible). MOCA proposes that creativity measured by the DT tests is associated with flexible attention, which is driven by the rapid focus, inhibition, and rapid shifting of attention. This ability is evident very early in the processing stream, as DT is also linked with rather selective sensory processing, assessed by the P50 ERP. Further in the processing stream it is also associated successful upregulation of cognitive control, as assessed by the N2 ERP. Additionally, data from genetics studies provide evidence that DT is linked with dopaminergic polymorphisms associated with high cognitive flexibility and medium top-down control, or with weak cognitive flexibility and strong top-down control.

Creativity as defined by the assessment of people's real-world creative achievements, on the other hand, although weakly related to DT, is associated with leaky attention, as well as with leaky sensory processing early in the processing stream, as assessed by the P50 ERP. Additionally, high real-world creative achievement is linked with dopaminergic polymorphisms associated with weak cognitive flexibility and weak top-down control, and with psychopathology-spectrum personality characteristics of psychoticism and hypomania.

MOCA also proposes that the outcome of leaky attention and leaky sensory processing may depend on the level of cognitive control. In the presence of low cognitive control, leaky attention may potentially lead to the development of various attention disorders, and/or some forms of psychopathology. High cognitive control, on the other hand, would serve as a protective factor, and together with leaky attention may be precisely the mechanism that supports real-world creative achievement. Additionally, MOCA notes that more than leaky attention and high cognitive control are required for creative achievements – other factors, such as motivation, grit, and opportunity play a major role in achieving in creative domains in the real world (Amabile, 1985; Runco, 2005).

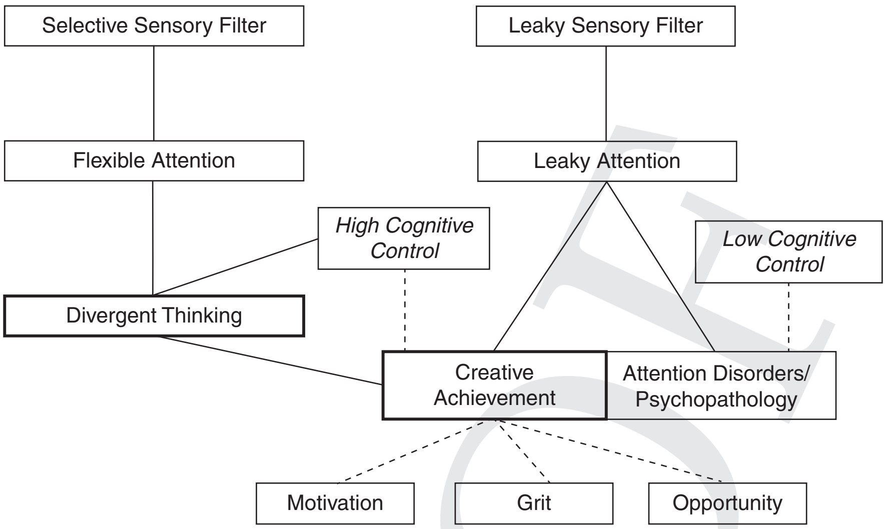


**Figure 9.1** Model of Creativity and Attention (MOCA), presenting relations between creative achievement, divergent thinking, and attention. Solid lines denote confirmed associations, dashed lines denote hypothesized associations.

## Divergent Thinking and Focused, Flexible Attention

### Behavioral Evidence

MOCA suggests that creativity as assessed by DT tests is linked with flexible attention, which is supported by the ability to focus, disengage, and switch attention rather than by leaky attention. This hypothesis was confirmed by two recent experiments examining how DT relates to visual attention (Zabelina, Saporta, & Beeman, 2016). In both experiments, participants identified target letters (S or H) within hierarchical stimuli (global letters made of local letters), after being cued to either the local or global level. In Experiment 1, in general participants identified the targets more quickly following valid cues (80% of trials) than following invalid cues. However, this smaller *validity effect* was associated with higher DT, suggesting that DT was related to quicker overcoming of invalid cues, and thus to flexible attention (Figure 9.2).

There are several possible mechanisms for why divergent thinking was associated with better overcoming of invalid cues. One possible mechanism is a leaky attention filter. Specifically, when people attend to one level, information from the other level may still "leak in," allowing relatively easy identification of non-cued targets after invalid cues. Experiment 2 tested whether DT is related to a leaky attention filter, which would be manifested in the size of the congruency effect, i.e., how selective people are when cued to selectively attend to either the local or global letter stimuli. Participants were again cued to a stimulus level, but unlike in Experiment 1, the cued level always contained a target (either S or H). However, the stimulus at the other level was congruent, incongruent, or neutral with the target. Thus congruency, not validity, was manipulated, as the cue was always valid. Specifically, there was always a target at the cued level of the stimulus, but the other level varied, containing congruent, neutral, or incongruent target information. For instance, when cued to the local level participants could see a local S; on congruent trials the global configuration formed the same letter (large S); on incongruent trials, the global letter was the other target (large H); and on neutral trials the global

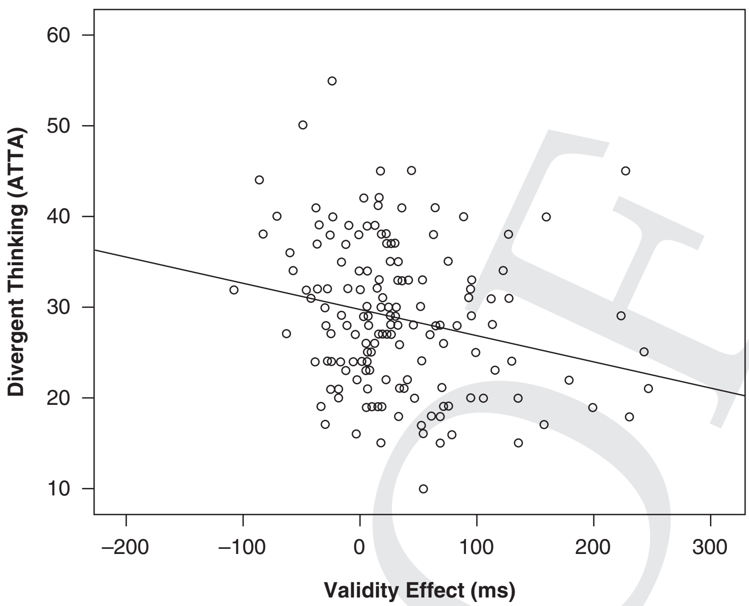


**Figure 9.2** A Pearson correlation between divergent thinking and validity effect (RT on invalid trials minus RT on valid trials), demonstrating that people with higher divergent thinking scores have more flexible attention ($r(152) = -.23$, $p = .004$).

letter was a nontarget letter (A's or E's). *The congruency effect* – how much faster people respond on congruent than on incongruent trials – is an index of how selective (versus how leaky) the attention filter is. If divergent thinkers have selective attention, they should be perfectly good at using the cues to attend to the target level, and the congruency of the distractor level should have no effect. On the other hand, if divergent thinkers have leaky filters, they should respond more slowly on incongruent trials. Thus, if DT in Experiment 1 was associated with better overcoming of invalid cues due to leaky attention, then high DT should also be associated with a large congruency effect in Experiment 2. In contrast, if better overcoming of invalid cues was associated with better overcoming of invalid cues not due to leaky attention in Experiment 1, then in Experiment 2 DT should not be related to the congruency effect.

As expected, divergent thinking did not relate to stimulus congruency. DT was not related to either interference or facilitation from stimuli at the uncued level. This finding rules out leaky attention as the explanation for flexible attention (i.e., overcoming invalid cues) displayed by divergent thinkers in Experiment 1. Therefore, an alternative mechanism may be responsible for divergent thinkers' flexible attention in Experiment 1. It is possible that a rather selective attention filter is the mechanism for flexible attention in divergent thinkers. In this view, high divergent thinkers, when cued, focus their attention as sharply as (or sharper than) low divergent thinkers. Thus, high divergent thinkers, when necessary, are adept at rapidly processing information at the cued level, rapidly disengaging from it, and/or rapidly shifting to the other level. In other words, even though they are highly selective at attending to cued information, their attention capture is not as strong or as lasting.

## Neurophysiological Evidence

Flexible attention supported by the mechanism of focusing, disengaging, and switching

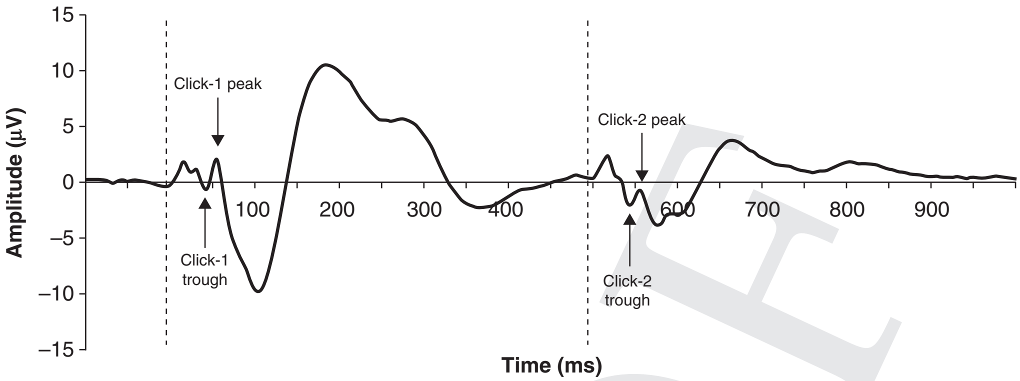


**Figure 9.3** Grand averages of the ERPs at Cz. Vertical dashed lines at 0 ms mark onset of Click 1, and at 500 ms mark the onset of Click 2. The P50 ratio is calculated as the P50 peak to trough difference of Click 2 over the P50 peak to trough difference of Click 1. Thus larger difference in the waveforms would result in a smaller ratio. Smaller ratios represent more selective sensory gating, while larger ratios represent leakier sensory gating.

attention is compatible with recent EEG data showing that DT is linked with an increased ability to filter out "irrelevant" sensory information (Zabelina, O'Leary, Pornpattananangkul, Nusslock, & Beeman, 2015), as measured by the P50 ERP – a neurophysiological response that occurs 50 ms after stimulus onset (for review, see Patterson et al., 2008). In this paradigm, two auditory clicks are presented to a participant, and the extent to which the second click is inhibited compared to the first click (P50 of the second click/P50 of the first click) is seen as a marker of sensory gating (see Figure 9.3). P50 is a very early, automatic, form of sensory gating, influencing which stimuli capture attention (Banich, 2004; Gjini, Burroughs, & Boutros, 2011). Some view the P50 marker of sensory gating as a marker of some forms of psychopathology, particularly schizophrenia (Olincy et al., 2010).

Data reveal that DT is associated with selective sensory processing very early in the processing stream. Only 50 ms after stimulus onset high divergent thinkers are more likely to inhibit "irrelevant" sensory information than low divergent thinkers (Figure 9.4). Given that the stimuli are meaningless and there are no task requirements, increased sensory gating may indicate that selective sensory processing is a general neural processing characteristic of divergent thinkers.

Additional evidence for the link between divergent thinking and selective attention comes from the study examining performance on the oddball paradigm (Zabelina & Ganis, 2016). Here, participants performed a somewhat standard oddball paradigm, in which they saw and responded to frequent and rare stimuli, and their behavioral and neurophysiological responses to both were measured. Specifically, on each trial participants had to look for a specific letter. Within each run most of the time the stimulus of interest (frequent stimulus) was at one level of attention (e.g., global), but on 10% of the trials the stimulus (rare stimulus) was at the other level of attention (e.g., local).

If divergent thinkers have selective attention, they should not slow down as much on the rare compared to the frequent trials. They should also show a larger N2 difference between rare and the frequent trials, as larger N2 serves as an indicator of upregulation of cognitive control (Folstein &

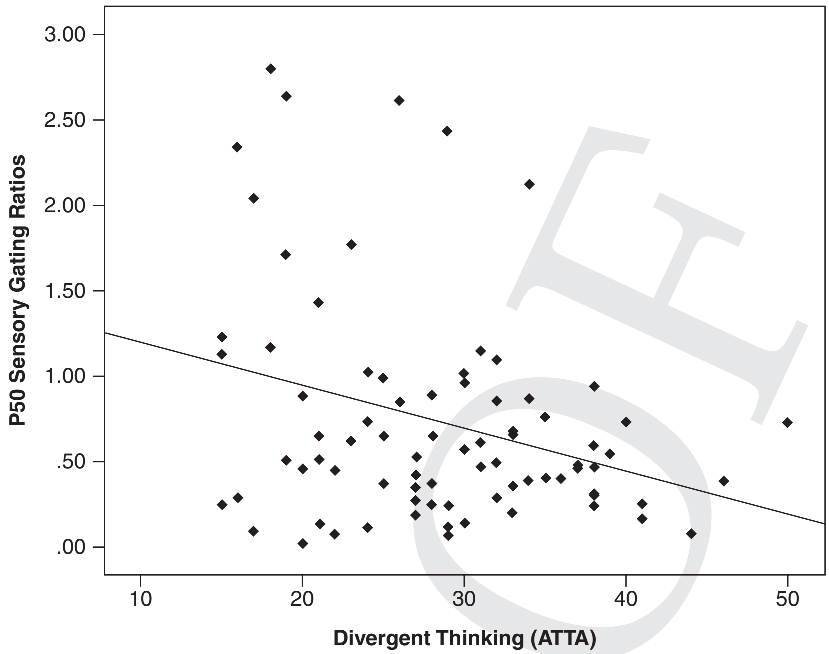


**Figure 9.4** Partial regression plot depicting partial correlations between divergent thinking (centered) and P50 sensory gating. This plot demonstrates that higher divergent thinking scores are associated with smaller P50 ratios, i.e., more selective sensory gating ($r(80) = -.30$, $p$ = 006; controlling for academic achievement, $p = .03$).

van Petten, 2008; see Figure 9.5a). Indeed, evidence from two experiments suggests that high divergent thinkers do not slow down as much on rare trials compared to the frequent trials. Additionally, and as expected, people with higher DT scores show larger N2 differences between the rare and the frequent trials, suggesting that they are particularly good at upregulating their cognitive control on rare targets, facilitating their faster responses to the rare targets compared to people with lower DT scores (Figure 9.5b).

## Biological Evidence

Finally, supporting evidence for the link between DT and selective attention comes from a genetics study which investigated the involvement of the dopaminergic system (DA) in divergent thinking. It was revealed that DT can be predicted from interactions between genetic polymorphisms related to frontal (COMT) and striatal (DAT) DA pathways. Importantly, successful performance on the DT test is linked with dopaminergic polymorphisms associated with good cognitive flexibility and medium top-down control, or with weak cognitive flexibility and strong top-down control (Zabelina, Colzato, Beeman, & Hommel, 2016; Figure 9.6).

Considering previous observations that the nine-repeat allele is related to various indications of good cognitive flexibility (Garcia-Garcia, Barceló, Clemente, & Escera, 2010), while the 10-repeat allele is related to low learning abilities and ADHD (Cornishet al., 2005), this pattern makes sense. DT tests require individuals to find new solutions and original answers, requiring some top-down guidance. DT also considers the role of flexibility, which fits rather well with the observation that the performance of individuals with a genetic makeup that supports cognitive flexibility (the 9/-carriers) benefit most from frontal top-down control that is effective, but not overly strong. Individuals with a less

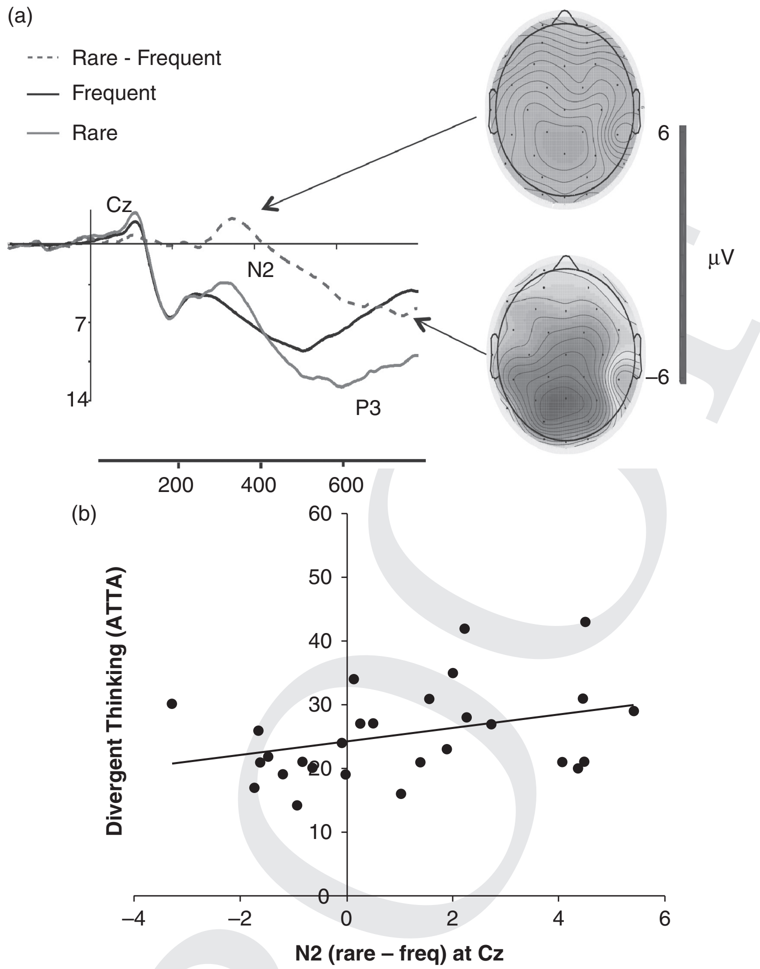


**Figure 9.5** (a) Neuropshysiological response to rare and frequent targets on an oddball paradigm, showing a larger N2 ERP on rare compared to frequent targets, particularly at parietal sites, indicating that more cognitive control is required on rare compared to frequent targets. For a color version of this figure, see the color plate section. (b) A Pearson correlation between divergent thinking and N2 difference (rare targets minus frequent targets), demonstrating that people with higher divergent thinking scores upregulate their cognitive control to a larger degree on the rare compared to the frequent targets compared to people with lower divergent thinking scores ($r(26) = .50$, $p = .004$).

flexibility-supportive genetic makeup, however, presumably require strong frontal guidance and attentional focus to overcome or compensate for the lack of flexibility. These findings are in line with the dual pathway to creativity model, which proposes that generation of original and appropriate ideas can indeed be achieved through either cognitive flexibility or through cognitive persistence (Nijstad, De Dreu, Rietzchel, & Baas, 2010).

## Real-world Creative Achievement and "Leaky" Attention

### Behavioral Evidence

In contrast to people who perform successfully on laboratory tests of DT, behavioral, neurophysiological, and genetics data provide evidence for leaky attention in people with high

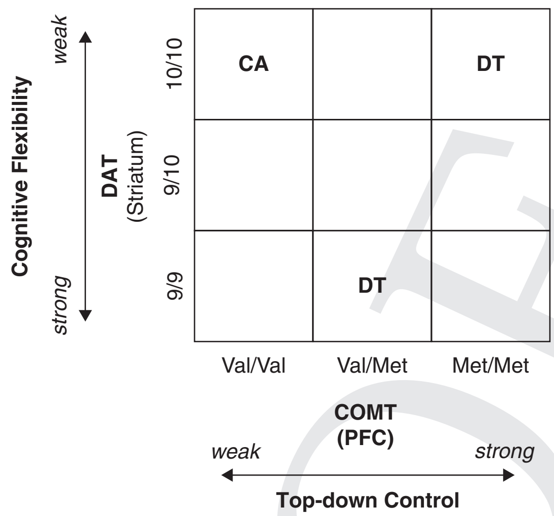


**Figure 9.6** Putative associations between COMT (tied to DA availability in the prefrontal DA pathways) and top-down cognitive control; and DAT (tied to DA availability in striatal pathways) and cognitive flexibility. Data presented in the figure suggest that divergent thinking is linked with DA polymorphisms associated with good cognitive flexibility and medium top-down control, or with weak cognitive flexibility and strong top-down control, while creative achievement is linked with DA polymorphisms associated with weak cognitive flexibility and weak top-down control.

real-world creative achievements. For example, whereas the congruency effect – how much faster people respond on congruent than on incongruent trials – does not relate to DT (see above), people with more real-world creative achievements exhibit a larger congruency effect – they respond slower on the incongruent compared to congruent trials, indicating leaky attention (Zabelina et al., 2016; Figure 9.7).

## Neurophysiological Evidence

Neurophysiological evidence provides further support that real-world creative achievers have leaky attention. In the study using the same P50 ERP paradigm as described above, where participants passively listen to auditory clicks, it was revealed that the more real-world creative achievements people had, the less likely they were to filter out the second click (Zabelina et al., 2015; Figure 9.8). This result indicates that people with real-world creative achievements have "leaky" sensory processing very early in the processing stream (as early as 50 ms after stimulus onset). Again, because the task is passive and involves meaningless stimuli with no task requirements, reduced sensory gating suggests that leaky sensory processing is the general characteristic of real-world creative achievers.

Additionally, unlike divergent thinkers, real-world creative achievers do not upregulate their cognitive control on rare compared to frequent targets on the oddball paradigm, as reflected in the N2 differences (see above, Zabelina & Ganis, 2016), suggesting that people with real-world creative achievements are not particularly good at engaging cognitive control. It may be that creative achievers exhibit poor self-control on laboratory tasks of attention, which are typically quite long and not very engaging. Were creative achievers to work on their own creative project, the one they found particularly interesting and worth investing in, they would be just as good, if not better, than divergent thinkers to engage their cognitive control. Further studies are needed to examine whether the link between creative achievement

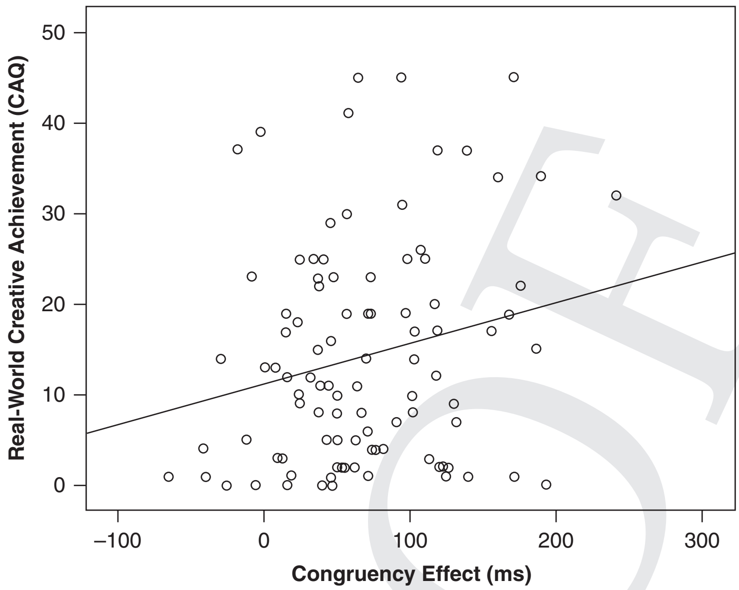


**Figure 9.7** A Pearson correlation between creative achievement and congruency effect (RT on incongruent trials minus RT on congruent trials), demonstrating that people with higher real-world creative achievements have more “leaky” attention ($r(94) = .22$, $p < .03$).

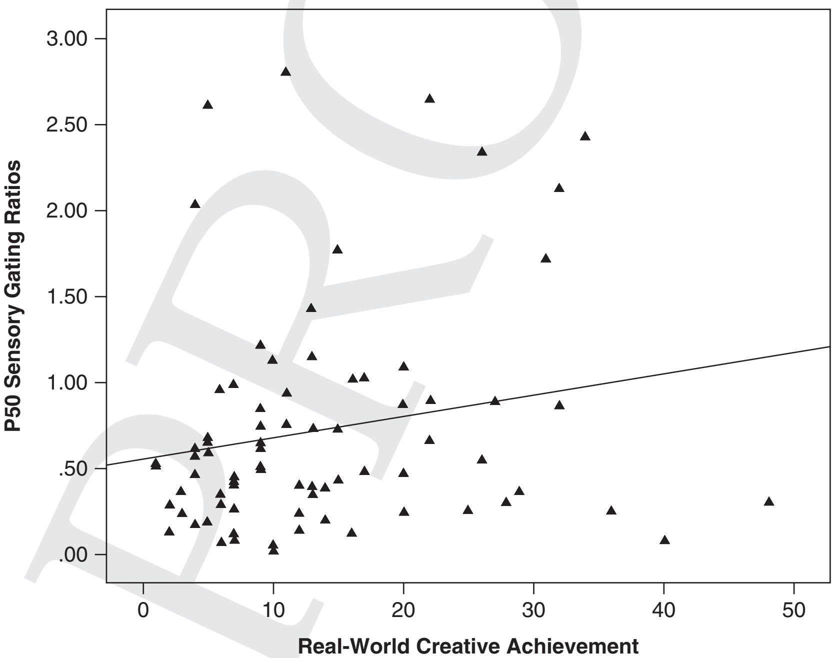


**Figure 9.8** Partial regression plot depicting partial correlations between creative achievement (centered) and P50 sensory gating. This plot demonstrates that higher creative achievement is associated with larger P50 ratios, i.e., leakier sensory gating ($r(81) = .20$, $p$ = 07); controlling for academic achievement, $p = .001$).

and cognitive control varies depending on the level of interest in the task at hand, as well on the stage of the creative process (e.g., creative achievers may show low levels of cognitive control during uninteresting tasks, as well as at the early stages of the creative process, while engaging tasks, as well as later stages of the creative process may be linked with higher levels of cognitive control in creative achievers).

### Biological Evidence

Finally, results from the study investigating involvement of the DA system in creative achievement reveal a particular benefit of the 10-repeat carriers associated with weak cognitive flexibility, in combination with the ValVal polymorphism associated with particularly weak frontal top-down control (Zabelina, Colzato, et al., 2016; Figure 9.6). Although the link between creative achievement and DA transmission has not been previously investigated (but it has been proposed [Carson, 2011]), this observation fits well with previous reports that excellent performance on the CAQ is associated with "leaky" attention (Zabelina, Saporta, & Beeman, 2016), with electrophysiological indications of reduced sensory gating (Zabelina et al., 2015), and with low latent inhibition (Carson et al., 2003). As pointed out above, leaky attention may help individuals to take into consideration nominally irrelevant information, and integrate it with relevant information to create new ideas and insights.

## Conclusion

Recent convergent evidence suggests that different aspects or measures of creativity are associated with different types of attention. Thus conflating different types or measures of creativity into a monolithic "creativity" may hinder our understanding of the sources of the apparent variability in the literature on the link between creativity and attention (see Dietrich & Kanso, 2010; Sawyer, 2011; but see Nijstad et al., 2010).

The Model of Creativity and Attention (MOCA) suggests that creativity as measured by two different measures – via laboratory tests of divergent thinking and via a survey of people's real-world creative achievements – relates to different forms of attention: divergent thinking is linked with flexible attention, driven by the ability to focus, inhibit, and switch attention, while creative achievement is linked with leaky attention. What is the source of these differences, considering that measures of divergent thinking and creative achievement exhibit small, but consistent correlations? It appears that divergent thinking tests with their focus on generation of as *many* creative uses for a common object as possible within a *limited amount of time* may rely on selective attention and good cognitive control more than previously thought. In fact, DT scores show consistent association with successful academic performance, specifically with enhanced performance on academic achievement tests (SAT and ACT; see Zabelina, Condon & Beeman, 2014).

Creativity as measured by surveying people's real-world creative achievements, on the other hand, appears to be linked with leaky attention. Such perceptual openness, or "open-mindedness" as the literature suggests (Feist, 1999) may help creative achievers notice information which others may disregard as irrelevant, thus leading to a creative idea. However, such leaky attention can also serve as a double-edged sword, and lead to heightened distractibility, as well as to predisposition to attention disorders and various forms of psychopathology.

Numerous open questions remain. Future investigations need to consider how attention relates to creativity within different stages of the creative process. For example, leaky attention may be associated with the initial stages of the creative process, such as idea generation, while more focused attention may be beneficial during the later stages of the creative process, such as idea implementation. Neuroimaging studies can help determine neural mechanisms associated with various forms of attention and how they relate to creativity. Additionally, future investigations need to explore temporal dynamics within the resting state connectivity to determine how it changes with attentional engagement. Finally, the involvement of external versus internal attention in creativity, although previously discussed (Zabelina & Andrews-Hanna, 2016), needs further examination.

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