The role of attention in the development of creativity

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Abstract

Creativity is typically defined as an output that is both novel and effective, and creative ability in adults is strongly linked to attentional processes. Creative thinking requires the attentional flexibility to combine information from internal and external inputs and to switch between ideas and representations, together with the attentional control to resist distraction and persist with an idea over time. There are also indications that attention style may be qualitatively different in highly creative people, although we do not yet have a complete picture of the optimal attentional profile for creativity. However, the relationship between attention and creativity has hardly been explored in children. Consequently we have little understanding of what the developmental attentional milestones for creativity might be. Here we consider the evidence that the development of attention in children is as integral to the development of creativity as it is to other aspects of cognition, and suggest potential avenues for future research.

Keywords: Attention, Creativity, Development, Creative Achievement, Divergent Thinking, Latent Inhibition, Attentional Control, Flexible Attention, Sustained Attention, Distraction

Introduction

Creativity: Core Concepts

Creative outputs are commonly regarded as involving the conjunction of at least two key elements. These are that a creative output should be both novel and also effective (Plucker, Beghetto & Dow, 2004; Runco & Jaeger, 2012). Either one of these elements alone is not sufficient for an output to be regarded as creative (Simonton, 2012). However, the extent to which an output is novel has to be judged in relation to the context in which it is produced. For instance, a child's discovery that cheese can be melted to make tasty food, might be novel to them but not to their parents. On the other hand, the discovery of an affordable, scalable, renewable, means of meeting our entire energy needs would be novel to the entire world population. Thus, it has been suggested that creativity can be represented along a continuum (Kaufman & Beghetto, 2009). *Mini-c* creativity represents an output that is novel and effective for an individual and that might change their view of the world. *Little-c* creativity represents outputs that might impress one's friends and family. *Pro-c* creativity would be outputs that are at a level of achievement generally only acquired after many years of mastering domain specific skills and knowledge and that would be recognised as creative by experts working in that domain. Finally, *Big-C* creativity are those outputs that have an enduring influence on humanity, often long after a creator's life is over. Given the time taken to achieve at Pro-c or Big-C levels of creativity, these would generally not be a feature of the creativity seen during childhood (although there are exceptions; cf Drake & Winner, 2009).

Consequently, the present chapter focuses most closely on mini-c and little-c creativity. In addition to creative outputs or achievement, we also discuss the concept of creative potential, where 'potential refers to a latent state which may be considered part of an individual's "human capital" (Walberg, 1988)' (Lubart, Zenasni & Barbot, 2013, p41), and is typically operationalised through measurement of aptitude at tasks requiring processes such as convergent and divergent thinking and varies across domain. Further, whilst research on creativity typically explores factors that influence creative outputs or products, if we are to understand and influence creativity itself, we must attempt to understand the underlying creative process.

A range of theories propose that creativity might be the product of ordinary cognitive and affective processes (Finke, Ward & Smith, 1992). This gives rise to a research approach that seeks to understand these constituent processes and, in particular, how their combination gives rise to creativity in a manner that is ubiquitous to humans and enables us to flexibly adapt to everyday situations to which we don't have a pre-determined, previously tried, response. These research approaches have begun to make significant strides in recent years. One particularly promising recent body of work (Beaty, Benedek, Silvia & Schacter, 2016; Ellamil, Dobson, Beeman & Christoff, 2012; Pringle & Sowden, 2017) suggests that when thinking creatively, cognitive processes involved in associative and analytic thinking, which have often been regarded to work competitively (Evans, 2008), begin to work co-operatively and that this co-operation is predictive of creative outcomes. These processes and their interaction have been mapped to three underpinning brain networks, namely the default mode network, the executive control network and the salience network (Beaty et al., 2018).

A key element of the associative processing that contributes to the generation of creative ideas is the retrieval of information from memory and combination of this information with inputs from the external environment. Novel combinations of these information sources can then be analysed for their potential to produce an effective response to a presented situation. Thus, we might expect both inwardly and externally directed attention to be key elements in the creative process because of their role in the control of memory search and the filtering of external inputs from the environment. Consequently, the focus of the present chapter is to consider how the development of attention might be expected to interact with the development of creativity.

Attention: Core Concepts

Attention is a core cognitive function that controls the selection of relevant information and maintenance of focus (Carrasco, 2011; Driver, 2001). Although the precise way in which attention differentiates between relevant and irrelevant information remains an issue of debate, it is generally accepted that attention is the set of mechanisms resulting from the human brain's limited capacity for processing information, and that its allocation can be controlled (Buschman & Kastner, 2015; Desimone & Duncan, 1995). Although there are many different models of attention, there is largely agreement that there are two main processes:

'early' attention, which is exogenous, a bottom up process, and occurs at the earliest attentional level of sensorial perception; and 'late' attention, which follows early attention in the timecourse, is endogenous, and a top-down process related to attentional control and executive function. More recent work in neuroscience has suggested that these attentional processes are not only cognitively but also anatomically distinct from one another. The processes of sensory perception and the shifting of attention appear broadly to be handled by a ventral frontoparietal system, while top-down and voluntary attentional processes are largely controlled by a dorsal frontoparietal system (Corbetta & Shulman, 2002). These two sets of processes do not run in isolation, but interact flexibly in order to enable rapid and dynamic switching between bottom-up sensory stimuli and top-down goals (Petersen & Posner, 2012; Vossel, Geng & Fink, 2014).

The development of attentional control, also called 'executive attention', has been a particular focus of developmental research, as it determines the extent to which an individual is able to ignore distracting information and choose to maintain an attentional focus on achieving task goals. Attentional control appears primarily to be governed by frontal areas of the brain, particularly the anterior cingulate cortex, as well as to be closely linked to executive functions such as working memory (Astle & Scerif, 2011; Posner & Petersen, 1990)

In this chapter we discuss both the 'early' processing of sensory stimuli and the 'late' attentional control processes in relation to creativity and its development, as well as considering more recent attentional 'network' approaches. We also consider the role of sustained attention, a long-term form of attentional control.

Attention and its Relationship to the Development of Creativity

Creativity in adults has been strongly linked with certain attentional processes including permeable early attention, attentional control and flexibility in switching between attentional foci. In adults, it has been suggested that these attentional processes may differentially predict both creative potential and creative achievement (Zabelina, Saporta & Beeman, 2016; Zabelina & Robinson, 2010) but, at present, we have little understanding of whether this same relationship is found in children and what the developmental trajectory of attention from child to creative adult might be. While some attentional differences emerge early, others such as working memory and attentional control continue to develop throughout childhood and adolescence, in association with maturation of the prefrontal cortex (Booth et al., 2003). However, at present we have yet to explore how the combination of attention patterns that appear linked to creative achievement in adults, manifests throughout cognitive development.

Understanding the developmental trajectory of creative attention is now an important research goal, as creativity is increasingly seen as a vital skill for success in the rapidly automating job market of the fourth industrial revolution (Boston Consulting Group, 2015; McKinsey Global Institute, 2017; Department for Digital, Culture, Media & Sport, 2017; Frey & Osborne, 2013; Roberts, 2006; Robinson, 1999). Creativity was recently listed by the World Economic Forum as one of the top three most important skills for the job market of the future, with the other two being the closely related skills of problem solving and critical thinking (World Economic Forum, 2016). Unsurprisingly therefore, the Programme for International Student Assessment (PISA) has decided to include creative thinking tests in 2021, alongside those for reading, maths and sciences (Lucas & Spencer, 2017). However, this is set against a background of what is argued to be plummeting levels of creativity among school leavers, together with an increasing inequality of opportunity (Durham Commission, 2019; Johnes, 2017; Kim, 2011; Warwick Commission, 2015). It is clear, therefore, that developing creativity needs to become an integral part of mainstream education as a matter of urgency. However, considerably more research is also needed in order to identify the most important precursors of creativity before targeted teaching strategies to promote creativity can be developed, in conjunction with interventions to support creative children.

In what follows, we first consider the evidence for the relationship between attention and creativity in adults, before proceeding to consider the implications of the development of attention during childhood on creative potential.

Attention and Creativity in Adults

Early attention and creativity

Early visual and auditory attention are the precursors to thought, memory, learning and action. Therefore, it is not surprising that individual differences in early attention mechanisms appear to influence a person's level of creativity. In particular, broad early attention is often linked to real-world creative achievement. Broad attention was first described by Mendelsohn and Griswold (1964) as being characterised by a wide focus, which simultaneously notices or takes in a large range of stimuli. They contrasted this with narrow attention, which focuses on a smaller range of stimuli and effectively screens irrelevant information from awareness. Broad early attention appears to allow seemingly irrelevant information to leak into awareness, or be noticed, which is believed to keep the mind open to a wider range of possibilities, enabling the generation of more creative ideas (Abraham, 2013).

This notion has been supported by empirical work. For example, a recent eye-tracking study found that the increased attentional processing of apparently irrelevant objects on the periphery of a display, resulted in the generation of more original and creative solutions among participants asked to generate original uses for common objects (Agnoli, Franchin, Rubaltelli, & Corazza, 2015). The incorporation of seemingly irrelevant information into the idea generation process may support the formation of remote associations as proposed by Mednick (1962), who argued that creative individuals were characterised by a propensity to synthesize elements into new combinations and that the more remote or unusual the associations between the elements, the more creative the idea or solution. Similarly, Gabora (2010) proposes that when thinking associatively to support creative idea generation, attention is spread over a wider, more diffuse, set of neural cliques[1], thereby supporting the formation of more remote associations between items and therefore greater creativity.

There is considerable anecdotal evidence that this kind of broad attention may be a characteristic shared by many eminent creative achievers (see Kasof, 1997 for a review);

[1] A neural clique is a cell assembly that collectively responds to an experience with some cliques responding to situation specific elements and others to abstract properties (Lin, Osan, & Tsien, 2006).

Charles Darwin for example noted that he felt himself to be unusual in ‘noticing things which easily escape attention’. Extreme sensitivity to the environment, and to noise in particular, also seems to be a common complaint, with Darwin, Proust, Wagner, Schopenhauer and Elgar, among others, all having reported a need for intense quiet and solitude as the result of their inability to screen out distracting sounds.

Numerous behavioural studies have provided further evidence of a link between creativity and this type of permeable attention. For example, on dichotic listening tasks, creative participants made more errors of intrusion when being asked to repeat the information heard in one ear while also remembering the information presented to the other ear (Rawlings, 1985). Creative individuals were also more likely to incorporate irrelevant information in solutions to anagrams and when recalling phrases (Mendelsohn & Griswold, 1964).

It has been suggested that this tendency for irrelevant information to leak into the awareness of creative individuals is because they do not pre-categorize stimuli as irrelevant. In support of this theory, highly creative individuals have been found to exhibit reduced galvanic skin response habituation rates to auditory stimuli, compared with less creative individuals (Martindale, Anderson, Moore & West, 1996). Continuing to pay attention to stimuli that have previously been shown to be irrelevant, rather than screening them from awareness, also results in faster learning on Latent Inhibition tasks by creative individuals (Carson, Peterson, & Higgins, 2003). Once again, the mechanism responsible for this appears to be broad versus selective attention. In line with this, individuals high in Openness to Experience, a trait closely related to creativity and also characterised by ‘permeable’ attention, have been shown to combine visual information more flexibly, even at a low perceptual level (Antinori, Carter, & Smillie, 2017), suggesting that they may experience the world in a qualitatively different way. Recent neuroscientific studies have also provided evidence that these individual differences may be due to genetic variation in sensory gating mechanisms. For example, the P50 event related potential (ERP) is an index of early sensory gating that shows considerable inter-person variation, has been measured in infants as early as one-month old (de Haan, 2013), and has been directly linked to real-world creative achievement (Zabelina, O'Leary, Pornpattananangkul, Nusslock, & Beeman, 2015).

Permeable, or ‘leaky’ sensory gating has been linked to reduced density of dopamine D2 receptors in the thalamic area (Takahashi, Higuchi, & Suhara, 2006). This same neural architecture has been found in high performers on divergent thinking tasks (a laboratory measure of creative potential) and it has been suggested that this generates a state of 'creative bias' (de Manzano, Cervenka, Karabanov, Farde, & Ullén, 2010). This is because a lower density of these receptors appears to have the effect of reducing thalamic gating thresholds, thereby decreasing the automatic regulation and filtering of sensory information (Yasuno et al., 2004). The resultant increase in sensory information flow is likely to widen the range of potential associations that can be combined into new ideas, leading to more original and fluent idea generation (de Manzano et al., 2010). As the researchers note, 'thinking outside the box might be facilitated by having a somewhat less intact box' (de Manzano et al., 2010).

Creativity and disorders of early attention

The fact that both a reduced P50 response and reduced density of thalamic D2 receptors are also markers of schizophrenia, may indicate an element of shared neural architecture between the two groups, together with a common pattern of permeable attention or reduced cognitive inhibition (Green & Williams, 1999). Suggestions of a common link are far from new (Kozbelt, Kaufman, Walder, Ospina, & Kim, 2014); indeed there is a long and controversial history of associating professional creativity and mental illness that goes back at least as far as Aristotle (Eysenck, 1993; Richards, Kinney, Lunde, Benet, & Merzel, 1988) and which remains persistent to this day (J.C.Kaufman, 2014). As well as anecdotal evidence that the relatives of creative achievers, such as Albert Einstein and James Joyce, suffered from schizophrenia (Andreasen, 1987, 2011), there has also been evidence from twin studies that both creativity and schizophrenia have a heritable basis (Piffer & Hur, 2014; Vinkhuyzen, van der Sluis, Posthuma, & Boomsma, 2009). This has been further supported by two large-scale studies in Sweden using longitudinal population registry data (Kyaga et al., 2011, 2013). Interestingly, these showed that people in the majority of creative professions were *less* likely to be diagnosed themselves with psychiatric disorders than matched controls, with the exception of bipolar disorder, which was somewhat more common amongst those in creative occupations. However, people in the majority of creative professions were more likely to be first-degree relatives of patients with schizophrenia, bipolar disorder and anorexia nervosa, as well as siblings of individuals with autism. The one exception was writers, who themselves were moderately more likely than controls to be diagnosed with unipolar depression, schizophrenia, anxiety disorders, substance abuse and to commit suicide. So far there has been little exploration of what might cause this higher incidence of mental health problems in writers, although Kyaga references Crow's (2008) theory that psychosis has its genetic origin in the human facility for language, which would explain why writers in particular might show greater susceptibility.

In fact, the field of genetics has made several interesting contributions to this idea of a shared link, with comparative genomic studies of several species finding strong evidence for the positive selection during the evolution of modern humans of a number of genes putatively associated with both schizophrenia and creativity (Crespi, Summers & Dorus, 2007; Kozbelt et al., 2014; Lo et al., 2017). Given that the positive selection of genes that confer such profound cognitive and attentional impairments makes little sense in evolutionary terms, unless they also provide strong benefits, it has been argued that polymorphisms carrying elevated risk of schizophrenia remain in the human gene pool as the byproduct of a shared genetic link with creativity (Carson, 2011; Crespi et al., 2007; DeYoung, Grazioplene & Peterson, 2012). The hypothesis is not that creativity is enhanced by clinical schizophrenia per se, but that it may be facilitated by some of the milder aspects of schizotypal cognition found at the non-clinical end of the spectrum, such as increased divergent thinking, non-conformity, impulsivity, formation of unusual associations and reduced cognitive inhibition. It has been suggested, therefore, that the relationship between schizotypal cognition and creativity is not linear but, rather, an inverted U shape (Abraham, 2014; Martindale, 2007), as severe psychiatric disorders such as schizophrenia are likely to be more detrimental than beneficial for meaningful creative achievement.

Thus, whilst historically most research in this area has focused on deficits in clinical populations, there is now emerging interest in the cognitive advantages that this genotype may confer in healthy individuals, particularly when permeable attention is combined with high intelligence. For example, Kéri (2009), found that the highest levels of creative achievement were found in people who carried the T/T genotype (which has previously been related to psychosis risk) when coupled with high IQ. Carson et al. (2003), found a similar link between low Latent Inhibition (which has also previously been linked to schizophrenia) and high IQ in creative achievers.

Latent Inhibition is a pre-conscious gating mechanism that was first discovered in animal studies of classical conditioning. Human versions of the task date back to the late 1950s (Lubow, 1973) and measure the ability to ignore a non-reinforced stimulus, i.e. the extent to which an individual can screen irrelevant information from conscious awareness (Lubow & Gewirtz, 1995). Typically, participants are exposed to what is apparently an irrelevant stimulus while they complete a masking task. Then, they are given what appears to be a completely new task, but one which can only be solved by paying attention to the apparently irrelevant stimulus from the first phase (which continues to be present). Individuals are said to show low Latent Inhibition when in the second phase they do not automatically ignore the 'irrelevant' stimuli from the first phase, and therefore, learn the rule for the new task more quickly. Those said to show 'intact' Latent Inhibition exhibit delayed learning as they automatically discount the stimulus from the first phase as 'irrelevant,' and therefore take longer to make the connection.

Carson et al. (2003) found that creative achievers were seven times more likely to show a combination of low Latent Inhibition and high IQ than individuals with low creative achievements. This led Carson (2014) to posit a 'shared vulnerability model of creativity and psychopathology' in which certain risk factors for psychiatric disorders, such as leaky early attention and neural hyperconnectivity, are moderated by protective factors such as high IQ, cognitive flexibility and, increased working memory capacity, in order to become conducive to creative achievement. Carson's model clearly drew on Latent Inhibition research which had suggested that individuals with a combination of low Latent Inhibition were at risk from sensory overload and potential psychosis (Lubow & Gewirtz, 1995). However, although a robust construct in animal models, the evidence for Latent Inhibition in humans has been inconsistent, with a recent review concluding that Latent Inhibition tasks were essentially too flawed to support any conclusions as to the cause of retardation in learning (Byrom, Msetfi & Murphy, 2018). Further to this, although there is now convergence on the neural correlates of intelligence (Jung & Haier, 2007; Neubauer & Fink, 2009), there so far appears to have been no investigation of how the potential mechanism suggested by Carson (2014), might function, and therefore these conclusions must be treated with caution. There is, however, evidence in the opposite direction, which suggests that even non-clinical schizotypy may negatively impact working memory and intelligence among other cognitive functions (Matheson & Langdon, 2008; Noguchi et al., 2008).

However, the much-hypothesized link between the attention patterns characteristic of creativity and those of schizophrenia has received support from several neuroimaging studies. For example, in a sample of participants with intact working memory abilities and no history of psychological illness, researchers found that the more creative an individual was, the less they were able to deactivate the precuneus while carrying out a difficult working memory task (Takeuchi et al., 2011). Similar neural behaviour has also been observed in individuals with schizophrenia, as well as in their first degree relatives (Whitfield-Gabrieli et al., 2009). This is interesting because the precuneus is thought to be part of the Default Network (which will be discussed in more detail later), that typically shows greater activation during rest but deactivates during the performance of tasks that require focused attention (Cavanna & Trimble, 2006; Raichle et al., 2001). This brain region has been associated with attending to environmental stimuli (Corbetta et al., 2008), the unsystematic gathering of information (Raichle et al., 2001) and also mental representations involving the self, including personal memories (Cavanna & Trimble, 2006). Therefore, attenuated activity in this area is thought to suppress task-irrelevant stimuli that could disrupt successful task performance (Raichle et al., 2001) and, indeed this behaviour was observed in the control participants of both studies (Takeuchi et al., 2011; Whitfield-Gabrieli et al., 2009). Fink et al., (2014) investigated this further and compared groups of psychometrically high and low schizotypal individuals with controls and found that schizotypy and creativity were both positively associated with reduced deactivation of the right precuneus. Therefore, by 'failing to deactivate' their precuneus, as Takeuchi et al. (2011) describe it, more creative individuals and those on the schizotypal spectrum can be perceived as allowing more stimuli to enter their awareness and maintaining more broadly oriented attention, enabling them to generate more remote associations and original ideas.

In summary, permeable early attention is likely to be most relevant to ideation, the aspect of creativity responsible for the generation of novel ideas or making of novel connections. Although this is the element of creativity that has received most emphasis from researchers to date (as will be discussed in the next section), with many tests of creativity being constructed solely on measures of idea generation (e.g. the Torrance Tests of Creative Thinking (Torrance, 2008) and the Alternate Uses Task (Guilford, Christensen, Merrifield & Wilson, 1978)), this is only one part of the process and does not lead to meaningful creative achievement by itself (Cropley, 2006). Indeed, most recent models of creativity (cf. Sowden, Pringle & Gabora, 2015) encompass at least two processes: a process of generating ideas, and a goal-directed process of elaborating them into finished creative products. As will now be discussed, attentional control plays a vital role in both of these processes.

Late attention and creativity

Flexible attentional control and the generation of new ideas

Historically, creativity has been operationalized in research as the ability to generate new ideas on divergent thinking tests such as the Alternate Uses Task (Gamble & Kellner, 1968; Torrance, 2008; Guilford et al., 1978; Wallach & Kogan, 1965). The concept of divergent thinking originates from Guilford's theory of creative thought as something that branches off into many different directions (Guilford, 1950). In accordance with this, divergent thinking tests are laboratory tests of creative potential to which there is not one correct answer. In fact, these tests require participants to generate multiple meaningful answers to a question or problem that are as creative as possible within a short time frame.

For example, Guilford's Alternate Uses Test (Guilford et al., 1978) asks participants to generate as many different and creative uses as possible for an everyday object, such as a brick. An obvious and therefore non-creative use for a brick would be to build houses or other objects with it, while a more creative use might be something along the lines of using it as a marker or pumice stone. The responses to these tests are typically evaluated for quantity (fluency) and originality (statistical infrequency) to produce a total divergent thinking score, with more creative responders producing a larger number of original ideas. Guilford's approach has been, and still remains, the dominant one in the psychometric measurement of creativity (J. C. Kaufman et al., 2008).

However, it has been argued that the attentional profile of a creative individual, as operationalised by divergent thinking tests, is very different to that of a creative individual, as operationalised by real-world creative achievement (Zabelina et al., 2015, 2016; Zabelina &

Ganis, 2018). In contrast to the broad or leaky attention associated with creative achievement, divergent thinking performance is associated with flexible control of attention (Martindale, 1998; Zabelina & Ganis, 2018; Zabelina & Robinson, 2010). To perform well on these tasks, an individual needs the flexible attentional control to consider a task from multiple angles, generate new ideas at speed and identify what is valuable and promising, while at the same time engaging top-down control in order to focus, shut out distractions and suppress or disengage from irrelevant or less creative responses (Gilhooly, Fioratou, Anthony, & Wynn, 2007; Groborz & Necka, 2003; Nijstad, De Dreu, Rietzschel, & Baas, 2010; Nusbaum & Silvia, 2011; Zabelina & Robinson, 2010). The fact that divergent thinking tests are typically administered in timed conditions, requiring the rapid shifting from one generated idea to the next, is also thought to increase the involvement of the executive attention network at the expense of more unfocused attentional states such as day dreaming and the relaxation of mental constraints, thought to be more conducive to real-world creativity (Duncker, 1945; Mok, 2014; Plucker & Makel, 2010). Unsurprisingly therefore, highly creative individuals, as measured by high performance on divergent thinking tasks, show greater attentional flexibility and speed than low divergent thinkers (Vartanian, 2009).

Recent EEG and fMRI research has provided additional evidence of the involvement of executive attention in divergent thinking task performance, showing activation in regions such as the inferior frontal gyrus and inferior parietal cortex, regions linked to response selection, interference resolution and attentional control (Abraham, Beudt, Ott & von Cramon, 2012; Benedek, Jauk, Sommer, Arendasy & Neubauer, 2014; Chrysikou & Thompson-Schill, 2011; Fink & Benedek, 2014).

Therefore, the attentional profile associated with creativity may depend to a great extent on how creativity is operationalized (Zabelina, 2018; Zabelina & Ganis, 2018; Zabelina et al., 2015). This is an important point to make because of the extremely large body of research that has regarded measures of divergent thinking as being synonymous with creativity, and extrapolated from these findings that the attentional profile needed to perform well on these tests is the same one that is necessary for real-world creative achievement, despite there being strong indications to the contrary.

Undoubtedly, many of the aspects required for high performance on divergent thinking tests are also relevant to creative achievement such as ideation, the attentional flexibility not to get stuck on an unpromising idea and the executive control required to focus (Batey & Furnham, 2006; Gilhooly et al., 2007; Nusbaum & Silvia, 2011). However, there are clear indications that, in addition to requiring a different attentional profile to the one needed by high scorers on inventories of creative achievement, divergent thinking tests may also be measuring a different construct of creativity. For example, divergent thinking scores often do not differentiate between modestly and highly creative individuals (Batey & Furnham, 2006; Silvia et al., 2008) and a large number of studies have found no, or only a modest association between divergent thinking and real-world creativity (Barron & Harrington, 1981; Runco & Acar, 2012).

Sustained attentional control and the development of ideas

Although the 'in the moment' process of generating new ideas has received most research attention over the years, the process whereby these ideas are developed into publicly recognised creative achievements is of equal importance. Whereas ideation requires the attentional control to shift and inhibit attention flexibly, once an idea or creative product has been selected as promising, it must then be refined and developed, a process which requires a long-term and persistent form of attentional control. In the real world, as opposed to a laboratory environment, this stage of the creative process can take years (Simonton, 1999).

The ability to maintain an extended and intense attentional focus on task goals over such long periods has been argued not only to be unusual, but also to be one of the defining cognitive characteristics of highly creative individuals (Eysenck, 1993; Feist, 2006; Richards, Kinney, Benet, et al., 1988). Further evidence of sustained attention lies in the fact that most creative fields require many years of intensive study and practise in order to master what is already known in a domain before an individual can begin to formulate their own creative ideas (Simonton, 1999; Wallas, 1926). It has been argued that the extended attentional focus and maintenance of task goals underlying this process of preparation and development, are as important for creative achievement as personality factors such as grit and motivation, and may reflect a core cognitive preference for a persistent attentional focus (Zabelina & Beeman, 2013).

However, the effort of maintaining this type of persistent attentional focus can have costs as well as benefits. Although such immersive thinking has been associated with more creative ideas (Nijstad et al., 2010) it may also reduce attentional flexibility, resulting in real-world creative achievers (as opposed to high performers on divergent thinking tests) making more mistakes on tasks that require them to shift their level of attention (Zabelina & Beeman, 2013).

Shifting attentional focus and creativity

From the discussion so far, it is apparent that creativity involves the recruitment of a range of attentional processes. Neither generative and evaluative, nor associative and analytic thinking are likely to rely on one mode of attention exclusively, but rather to be supported by a range of attentional processes such as broad attention, flexible attention and sustained attention. While leaky attention may support more creative responses by promoting originality, focused top-down attentional control may support fluency and flexibility through enabling shifts between multiple information categories. In addition, sustained attention may support fluency and flexibility through persistent retrieval of information from one category (see Nijstad et al., 2010). Unsurprisingly therefore, Groborz and Necka (2003) have described creative attention as being a balancing act.

As has been extensively argued, it seems certain that creative individuals do not favour just one sort of attention, but are in fact characterised by their ability to shift flexibly between different types (Gabora, 2010; Sowden et al., 2015; Vartanian, 2009; Vartanian, Martindale & Kwiatkowsky, 2007; Zabelina & Robinson, 2010). As Gabora (2010) has argued, it would be dangerous and impractical to live one's life entirely in a state of defocused or associative attention, and therefore entering into this attentional state only makes adaptive sense if there is also a mechanism to switch to more focused and analytic modes when required. In line with this, it has been argued by several researchers that creativity involves the ability to shrink or expand the field of attention according to the task or situation (Finke, Ward & Smith, 1992; Gabora, 2002; Howard-Jones & Murray, 2003; Martindale, 1998; Martindale, Smith, Ward & Finke, 1995).

There continues to be speculation regarding exactly how this shifting is accomplished, in particular regarding the mechanism that facilitates the switching of attention between internal knowledge and external information for the purposes of idea generation, and to working memory for the purposes of synthesising, simulating and evaluating ideas. The frontal pole (Brodman area 10) is one brain area that is thought to be key to this process, together with lateral regions of the prefrontal cortex, as these regions of the brain are thought to manage the division of abstract (i.e. internal) versus concrete information processing (Badre, 2008; Koechlin, 2016; Ramnani & Owen, 2004). It also appears that the salience network, which detects and determines the relevance of environmental stimuli, plays an important role in shifting between externally and internally directed attention (Chand & Dhamala, 2016; Menon & Uddin, 2010; Uddin, 2015).

The salience network is also thought to manage the interaction between other large-scale brain networks such as the default mode network, which is associated with generative and spontaneous processing, and the central executive network, which is linked to more convergent and evaluative thinking (Beaty et al., 2014, 2016, 2018). It has been suggested that, during creative cognition, the salience network may identify promising ideas that are the result of generative processing and forward them to the executive attention system for higher order processing (Jung, Mead, Carrasco & Flores 2013). This area of research is relatively new, but the pattern now emerging seems to be that creativity requires the dynamic coupling and increased co-operation of two large-scale brain systems that normally act in opposition to one another (Beaty et al., 2014, 2016, 2018; Fox, Zhang, Snyder & Raichle, 2009). The extent to which these networks co-operate appears to be related to the task itself, and the presence or absence of task goals: for example spontaneous idea generation not involving a clear task goal appears to involve less coupling (Liu et al., 2015) while the evaluation of ideas seems to require considerably more interaction between the networks (Ellamil et al., 2012). The most recent work in this area has now identified a pattern of brain network connectivity that is not only characteristic, but also predictive of high-creative thinking ability, and which involves the simultaneous coupling and uncoupling of cortical areas within the default, salience and executive networks (Beaty et al., 2018). Therefore, according to this approach, the salience network is the mechanism that mediates the way in which the various attentional processes interact. Interestingly, the co-activation of default and executive networks is in line with the finding discussed earlier that the precuneus, the proposed hub of the default network, remains activated in more creative individuals during executive network dependent working memory tasks.

The Role of Attention in the Development of Creativity in Children

As noted at the beginning of this chapter, there has, to date, been very little research into the development of attention in highly creative children. This may, in part, be because there is still much we do not know about the developmental trajectory of attention in the general population, although neuroscience is rapidly advancing our understanding in this area.

The development of attention

Attention develops rapidly from birth (Colombo, 2001). However, early and late attention networks appear to mature at different speeds (Johnson, Posner & Rothbart, 1991). The posterior cortical and subcortical regions associated with early attention appear to mature earlier than the anterior systems involved in late attentional control (Nigg, 2000; Posner , Rothbart, Thomas-Thrapp, 1997; Posner, Rothbart, Sheese & Voelker, 2014). In line with this, full attentional control takes many years to develop, mirroring the continuing maturation of the cortical regions of the parietal and temporal lobes throughout childhood and adolescence (Amso & Scerif, 2015; Booth et al., 2003; Miller & Cohen, 2001; Plude, Enns & Brodeur, 1994; Zelazo, Müller, Frye & Marcovitch, 2003).

As a result, children find it more difficult than adults to focus, divide, switch and sustain attention even into adolescence (Curtindale, Laurie-Rose, Bennet-Murphy & Hull, 2007; Davidson, Amso, Anderson & Diamond, 2006; Enns & Akhtar, 1989; Enns & Girgus, 1985; Huizinga, Dolan & van der Molen 2006; Schul, Townsend & Stiles, 2003; Wainwright & Bryson, 2005). As their attentional gating is poorer, children also display greater interference effects in both auditory and visual modalities (Hanania & Smith, 2010; Hanauer & Brooks, 2003; MacLeod, 1991; Remington et al., 2014). Behaviourally, this manifests in younger children tending to be slower, more distractible and more error prone on attentional tasks than older children and adults (Hanauer & Brooks, 2003; Huang-Pollock, Carr & Nigg, 2002; Remington, Cartwright-Finch & Lavie, 2014).

In neural terms, the immature attentional system appears to be characterised by a greater overall volume of activation compared with adults performing similar tasks, suggesting that the maturation of these networks results in improved efficiency and focus (Durston et al., 2002; Fair et al., 2007, 2008). A good example of how much more attentional effort is required by immature cognitive control networks is Rueda, Posner, Rothbart and Davis-Stober's (2004) study of the N2, an ERP associated with executive control (Kopp et al., 1996). The researchers found that four-year-old children not only take almost double the amount of time of adults to first produce the N2, but then have to maintain it for 10 times as long before making their response. In addition, the adults displayed much more focused neural activity than the children, who showed a pattern of much broader activation (Rueda, Posner, Rothbart and Davis-Stober (2004).

With regards to perceptual capacity, it has been argued that capacity also increases with age, with younger children's attentional capacity for, and awareness of stimuli outside of their attentional focus, being exhausted at much lower levels than that of older children and adults (Remington et al., 2014). The combination of reduced perceptual capacity and weaker cognitive control in young children manifests in what can seem a somewhat paradoxical pattern of behaviour of them tending to be both more distractible when task load is low but also more focused than older children and adults when task load is high (Carmel, Fairnie & Lavie, 2012; Remington et al., 2014).

In summary, the general consensus is that overall children, particularly at young ages, are likely to show poorer sensory gating and greater distractor interference than adults, as well as to demonstrate less flexible attention and more effortful attentional control. However, there is one aspect of attention where very young children often outperform adults, which is on tests of distributed attention. As has been discussed, prior to the onset of the development of selective attention between 4 and 7 years old, infants and young children lack the attentional control needed for selective processing (Hanania & Smith, 2010). Instead of attending to information selectively, they typically show a very wide attentional focus compared to adults, and an equal level of processing of both task relevant and task irrelevant information (Posner & Rothbart, 2007; Rueda, Posner & Rothbart, 2005). Therefore, although younger children display neither the processing speed, nor the efficiency of adults, they can exhibit much more thorough processing of unattended information compared to adults who only encode a small subset. This has been illustrated by empirical work, which has found that younger children outperform older children and adults in this respect on memory, categorization and inattentional blindness tasks (Best, Yim & Sloutsky, 2013; Coch, Sanders & Neville, 2005; Deng & Sloutsky, 2016; Plebanek & Sloutsky, 2017).

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Existing research on attention, creativity and children

To date, we do not know whether the relationship between leaky early attention, attentional control and creativity is the same in healthy children as in adults, although there are suggestions in the literature that this may be the case. For example, children who noticed unexpected objects in an inattentional blindness task, produced more original ideas and solutions in divergent thinking tasks (Memmert, 2009). Further, adolescents high in openness to experience, the personality trait strongly linked to creative achievement, were quicker to perceive implicit patterns in probabilistic sequence learning tasks (S. B. Kaufman, DeYoung, Gray, Jiménez & Brown 2010). Given the indications that sensory gating appears to be genetically determined, at least in part, it seems plausible that permeable early attention is present from birth, as has been discussed earlier.

However, as attentional control is something that continues to develop even into late adolescence, it is likely to be challenging for researchers to isolate exactly what distinguishes the attention pattern of highly creative individuals during childhood. One difficulty is that the pattern of either greater distractibility or perseveration, depending on the circumstances (Enns & Girgus, 1985; Huang-Pollock et al., 2002; Remington et al., 2014), appears on the surface to be not too dissimilar to the pattern of permeable attention and greater perseveration discussed earlier in this chapter as being characteristic of creative achievers. This might suggest that variation in levels of creative achievement amongst children will be reduced relative to adults. Further, as noted at the beginning of this chapter, creative achievement in childhood is unlikely to be at the level of professional or world-renowned creators making it more difficult to identify actual high levels of creative achievement in children. Therefore, realistically, research may have to focus more on the study of creative potential, which makes the identification of creative children potentially even more problematic (Beghetto & Kaufman, 2007).

For these reasons, it is perhaps not surprising that majority of the studies to have specifically linked creativity and attention in children have focused on attentional disorders, as attention patterns that show an extreme divergence from the norm, and their impact on creativity, are likely to be more clearly discernible. As has already been discussed, there are also additional grounds for believing that there may be a link to attentional disorders, given the evidence that a certain level of neuro-diversity may be beneficial for creativity (Abraham, 2014; Martindale, 2007).

Creativity and childhood disorders of attention

The similarities between creative individuals and those with ADHD have been a particular research focus. For example, it has been argued that the previously discussed pattern of diffuse early attention and the inability to inhibit irrelevant stimuli is similar to the one found in ADHD (Auerbach, Benjamin, Faroe, Geller & Ebstein, 2001; Cramond, 1994; Pritchard, Healey & Neumann 2006). In line with this, individuals with ADHD have also been found to have leaky early attention in the form of low Latent Inhibition (White, 2007). White (2018) has argued that adults with ADHD have a very broad concept of what constitutes relevance in a given context, in line with many of the theories of how broad early attention relates to creativity discussed earlier in this chapter (e.g. Eysenck, 1993; Mednick, 1962; Mendelsohn & Griswold, 1964).

There are also other neural and genetic commonalities between the two groups. Like creative thinkers, adults with ADHD also demonstrate inefficient suppression of default network activity during cognitively demanding tasks (Beaty et al., 2016, 2018; Castellanos & Proal, 2012; Fassbender et al., 2009; Takeuchi et al., 2011; Uddin et al., 2008). Spontaneous activity in the default network is thought to cause fluctuations in focused attention during goal-directed activity, which results in a cognitive style that is more spontaneous, unstructured and more likely to promote creative and divergent thinking (Acar & Runco, 2012; Eysenck, 1993; Finke, 1996; Sonuga-Barke & Castellanos, 2007). Another shared link appears to be the prevalence in both groups of the DRD4-7R gene which is related to dopaminergic transmission (Auerbach et al., 2001; Dietrich & Kanso, 2010; Munafò, Yalcin, Willis-Owen & Flint, 2008). Commonly referred to as the 'novelty gene' the DRD4-7R has been associated with a preference for novelty, sensation-seeking and a more dispersed attention pattern in children from one years old (Auerbach et al., 2001).

There is some behavioural support for this theory, with several studies having found that children and adolescents with ADHD produce more creatively unusual and original ideas than children without ADHD (Abraham, Windmann, Seifen, Daum & Güntürkün 2006; Cramond, 1994; Fugate, Zentall & Gentry, 2013; Gonzalez-Carpio, Serrano & Nieto, 2017; Shaw & Brown, 1990, 1991). Individuals with ADHD, like other distractible individuals with mild executive function deficits, appear to be better at overcoming the constraints of existing knowledge or conceptual boundaries in order to generate more unusual and original ideas (Abraham et al., 2006; Abraham & Windmann, 2007; White, 2018). However, it should also be noted that several studies, including a recent meta-analysis, have found either no, or no conclusive evidence of enhanced creativity in children with ADHD (Aliabadi, Davari-Ashtiani, Khademi & Arabgol, 2016; Healey and (Aliabadi, Davari-Ashtiani, Khademi, & Arabgol, 2016; Healey & Rucklidge, 2005; Paek, Abdulla, & Cramond, 2016).

Further, this body of research focuses chiefly on creative ideation, in line with Simonton's (2004) conception of creativity as being characterised by a thinking style that embraces novelty and unconventionality and is not constrained by existing knowledge and norms. However, as previously discussed, ideation is just one part of creativity and, while ADHD may confer advantages in this respect, it appears to have a detrimental effect in relation to other aspects of the creative process such as persistence, and cognitive control. For example, Gonzalez-Carpio et al. (2017), found that children with ADHD displayed enhanced creativity compared with controls on measures of originality and unusualness of perspective, but not on measures relating to developing an idea or persisting with it. White and Shah (2011) found that individuals with ADHD showed a preference for the ideational phase of problem solving and had less interest in the clarification and development phase. Abraham et al. (2006) found that adolescents with ADHD had an enhanced ability for overcoming contextual constraints, but struggled to produce an invention that was functional. Furthermore, divergent thinking in its extreme form without the concomitant cognitive control needed to evaluate and develop these new ideas has been dismissed as only quasi or pseudo-creativity (Cropley, 2006), so the results of such studies should be interpreted with caution.

Despite this, there are aspects of this research that help to elucidate the way in which individual differences in attentional permeability and spontaneity, as well as in cognitive control, may strongly influence how creativity develops in healthy children from an early age. It suggests that children with broad and permeable attention and a more spontaneous processing style may show greater originality than those with attention that is narrower and more constrained, and it seems plausible that this may be a precursor to greater creativity in later life (Acar & Runco, 2012; Eysenck, 1993; Simonton, 2004). Also, given the current consensus that ADHD is the result of deficits in self-regulation and cognitive control, rather than an attention deficit *per se* (Barkley, 1997; Dramsdahl, Westerhausen, Haavik, Hugdahl & Plessen, 2011; Slobodin, Cassuto & Berger, 2015), together with the evidence of a shared genetic link, it seems plausible that the early attention processes of creative individuals and those with ADHD may not be dissimilar. However, the poorer performance of children with cognitive control deficits such as ADHD relative to normal controls on the evaluation and development of their original ideas indicates that individual differences in levels of cognitive control may have an early impact on other aspects of creative development. Therefore it has been suggested that individuals with ADHD may benefit from effective executive function training and that this is the missing piece of the puzzle that would enable them potentially to become successful creators (Barkley, 1997; Cortese et al., 2015; S. B. Kaufman, 2013; Klingberg et al., 2005).

A more nuanced view of the coexistence of creativity and attention disorders has been provided by Healey and Rucklidge (2006), who found elevated levels of some ADHD traits in 40% of their sample of healthy creative children and adolescents, over four times the number that would typically be expected in the general child population. Although none of these children met the full criteria for an ADHD diagnosis, they did show evidence of significant deficits in executive function, such as impairments in processing speed, reaction time and naming speed. This meant that their cognitive performance fell between that of creative children with ADHD, and creative children who were without ADHD symptoms and appeared to have normal executive functioning. The small sample size of this study means the results should be interpreted with caution, but a longitudinal study of similar groups of children would provide valuable information as to whether it is the mild ADHD cognitive profile or the one with intact executive function skills that is most beneficial for creative achievement in the long term. There is some evidence that ADHD symptoms in adults may be associated with recognised creative achievement (Boot et al., 2017), but a thorough analysis of the prevalence of mild ADHD symptomology among adult creative achievers is also needed.

Suggestions for future research

To date, there has been considerable research on creativity and giftedness in children, including extensive longitudinal studies, many of which have spanned decades (Holahan, Sears & Cronbach, 1995; Torrance, 1993). Clearly, creative achievement is not only determined by attention, but is a complex mix of elements that also involves motivation and personality factors, as well as opportunity. However, the majority of these individual difference factors have already been identified and explored (Lucas & Spencer, 2017; Mumford & Gustafson, 1988). In this final section of the chapter we briefly discuss some key research directions that we believe would greatly benefit our understanding of the role of attention in the development of creativity:

1) To gain a more detailed understanding of how the cognitive processing skills necessary for creativity develop, and what the potential roadblocks to the development of these skills might be.
2) The creation of a standard behavioural measure of permeable early attention that can be used with adults as well as children.
3) An investigation of whether any reduction in divergent thinking ability in children after 5 years old is the natural result of the development of selective attention and the change from a broader attentional style.

1) Understanding the developmental trajectory of attention and creativity

To date there has been little research focus on the *development* of the cognitive processing skills necessary for creativity. Permeable attention and executive control have both been strongly associated with creative achievement in adults and, as has been already discussed in this chapter, there are indications that there may be a similar link in children. However, at present, we have little idea of whether there is a trajectory in terms of the development of attentional processes from child with creative potential to creative adult.

One important question that needs answering is what the roadblocks are to the development of creativity: for instance, if it is found, as argued by Carson (2014), that permeable attention only facilitates creative achievement when coupled with strong executive control, what characterises those children who maintain the permeable attention patterns of early childhood but also go on to achieve strong executive control compared to those that do not? Further to this, we need to gain a more precise idea of the relationship between different dimensions of ADHD symptomatology in childhood (McLennan, 2016), and the corresponding creative prognosis in adulthood, rather than confining research only to clinical cases. We also need to develop a much clearer understanding of what the developmental *attentional* milestones are that need to be reached in order to ensure the maximum likelihood of a child achieving their creative potential in the fullest sense, as defined at the beginning of this chapter. In addition, this research needs to be combined with the development of new ways of measuring creative potential that can be used right across the lifespan and, as discussed earlier, that encompass more than just divergent thinking ability.

2) Measuring permeable early attention

The biggest hurdle to further research in this area is the problem of how to assess permeable attention in children. Although there is a long and established track record of testing executive function, together with creative ideation and cognitive flexibility as measured by divergent thinking tests, there is currently no standard behavioural measure of permeable attention. Previous work on this topic has used a wide variety of methods including dichotic listening tasks (Coch et al., 2005; Rawlings, 1985), Stroop tasks (Gamble & Kellner, 1968; Golden, 1975; Wang et al., 2018), P50 ERP response ratios (Zabelina et al., 2015), genotyping (Kéri, 2009) and connectome-based predictive modelling (Beaty et al., 2018). However, many of these do not lend themselves well to large-scale studies of children in relatively naturalistic settings. As discussed earlier in this chapter, a set of behavioural tasks that has been particularly linked to research on creative achievement is Latent Inhibition tasks (e.g. Carson et al., 2003; Peterson & Carson, 2000). Although there have recently been some efforts to modernise these tasks (Evans, Gray & Snowden, 2007), they remain unreliable, as has been discussed earlier in this chapter, and have no track record of working well with healthy child populations (Kaniel & Lubow, 1986; Lubow, Toren, & Kaplan, 2000). The concept of Latent

Inhibition in humans also remains problematic, with there still being no consensus on the psychological mechanisms underlying the construct (Byrom et al., 2018).

3) Does the developmental transition from distributed to selective attention have an impact on levels of creativity in children?

As has been discussed at length in this chapter, a broad attentional focus that takes in a wide range of stimuli may be beneficial for creative ideation. Children aged 5 tend still to favour a distributed attention style and the majority of children (98%) of this age and stage of cognitive development have been found to score very highly on divergent thinking tests (Land & Jarman, 1992), suggesting that creative potential may initially be very widely distributed in the general population indeed. The same study found that by the time these same children were 10 years old, this figure had declined to 30%, and to 12% by age 15, a steep decline that has often been attributed to the emphasis the education system places on convergent thinking and rote learning rather than on promoting creative thinking and originality (Delis et al., 2007; Robinson, 1999). However, it would merit investigation as to what extent this decline in divergent thinking performance may be the consequence of typical development in selective attention processes, and an associated narrowing of attentional focus, and whether the mild attentional deficits discussed in this chapter might be what differentiates the 12% of children who continue to score highly.

Conclusion

In summary, this chapter has presented evidence that the various stages of creative thinking from spontaneous idea generation to its evaluation and refinement into a creative product, require the involvement of a large number of attentional processes. These have included broad, flexible, executive and sustained attention. While leaky attention may support more creative responses by promoting originality, focused top-down attentional control appears to support fluency and flexibility through enabling shifts between multiple information categories. In addition, sustained attention is necessary to carry out the process of refining and developing an idea into a publicly recognised creative achievement.

We have also discussed the growing body of evidence supporting the theory that mild attentional deficits, observable in individuals at the lower end of the ADHD and schizotypy symptomatology spectrum, may confer advantages for creative thinking. In addition, we have considered the promising contribution of brain network approaches which have already been shown to reliably predict creative thinking ability. Given the evidence for the importance of attentional processes to creative thinking, we suggest that the development of attention has an important role to play in terms of whether a child reaches his or creative potential, and that gaining a thorough understanding of the necessary attentional milestones should now be a research priority. In conclusion, the evidence presented in this chapter indicates that the development of attention is likely as integral to the development of creativity in children as it is to all other aspects of their cognition.

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