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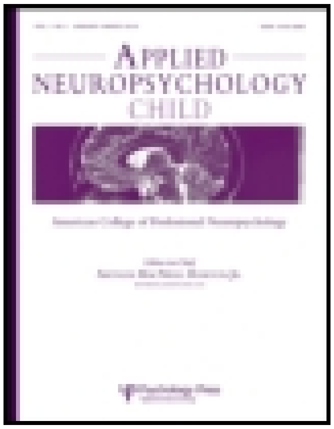

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Attention: An Evolving Construct

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Attention: An Evolving Construct

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We review the implications of large-scale brain systems on the construct of attention by first focusing on significant theories and discoveries during the previous 150 years and then considering how the comparatively recent discovery of large-scale brain systems may render previous conceptualizations of attention outdated. Seven functional brain networks are briefly reviewed and the implications of emerging principles of brain functioning for test construction and neuropsychological evaluation are considered. To remain a relevant discipline moving into the 21st century, the field of neuropsychology needs to apply the principles that have been discovered about brain networks to better inform our understanding of attention as well as our ever-refining evaluation of this construct.

Key words: *attention, automaticity, brain networks, large-scale brain systems, neuropsychology*

Attention is a vast and muddled construct that continues to evolve as we learn more about the neural circuitry of the brain. The measurement of attention overlaps with other neuropsychological domains, such as executive functions and the various types of memory. As noted by Lezak, Howieson, Bigler, and Tranel (2012), "Few tests measure a single cognitive construct and nowhere is this more true than for tests of attention" (p. 402). As an example, the Mirsky model of attention (Mirsky, 1996) includes measurement of the ability to encode new incoming information, a construct that shares features in common with working memory, which in turn has features in common with immediate memory. Similarly, divided attention requires inhibition of irrelevant stimuli and the ability to switch from one cognitive set to another, skills that are traditionally assigned to the executive-functioning domain. The application of neural circuitry (Alexander, DeLong, & Strick, 1986) and large-scale brain networks (Yeo et al., 2011) threatens to make the construct of attention outdated, at least as attention is presently conceptualized. The implications of large-scale brain networks make it clear that attempting to centralize attention to a few particular brain structures is an outdated paradigm.

Early researchers and theorists based their ideas about attention on available scientific evidence. Although their intentions were honorable and the results were fitting for the earlier times, new discoveries have shed light on the workings of the brain, leading to the need for reconsideration of the entire concept of attention. With the advent of neuroimaging technologies and the identification of large-scale brain networks, there is a need for new conceptualizations of the elements of attention and for new methods to assess those elements. The purpose of the following review is twofold: first, to provide a historical overview of the construct of attention; and second, to consider the ways in which the discovery of large-scale brain networks impacts the field of attention, especially as it applies to neuropsychological assessment.

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RESEARCH ON ATTENTION PRIOR TO 1910

Initial research focused on measuring reaction time, defined as the time from stimulus identification to motor response. Franciscus Donders (1869, trans. 1969) separated reaction time into three components: simple reaction, choice reaction, and go–no go concepts that are still in use today. Herman Helmholtz (1866/1911) was one of the first to study the ability to shift attention in the visual field. He used a technique involving limiting stimulus display presentation by lighting up the stimulus for very brief periods of time, resulting in an afterimage on the retina. Through this technique, Helmholtz demonstrated that attention can be focused on a stimulus without direct ocular fixation, thereby providing scientific evidence that visual analysis depends on attentional rather than ocular focus. Helmholtz's findings relate to a later concept: covert orienting of attention (Wright & Ward, 2008).

William James, often referred to as the father of American psychology, further distinguished the notion of attention by promoting the idea that attention could be externally directed toward the processing of sensory stimuli or internally directed toward the processing of stimuli that are not physically present, such as ideas (James, 1890). William Wundt later measured various aspects of speed of processing and examined the time it takes to switch attention from one stimulus to another (Wundt & Judd, 1897/1999).

RESEARCH ON ATTENTION FROM 1910 THROUGH 1947

In the era of behaviorism, the construct of attention was considered hypothetical rather than directly observable. Principles of behaviorism emphasized a focus on observable behavior. Thus, research focused on orienting to sensory events, and researchers examined the process of orienting sensory receptors to a particular stimulus at the cost of decreased orienting to ignored stimuli. The Russian scientist Ivan Pavlov (Pavlov & Anrep, 1927) coined the term "orienting response," which describes the reaction to the presentation of novel or unexpected stimuli. The orienting response is a reaction to change in the environment by the brain and body that involves physiological responses, such as decrease in heart rate, pupil dilation, and constriction of peripheral blood vessels, which occur automatically in response to stimuli such as loud noises, bright lights, and movement. While initially identified by Pavlov, the orienting response continued to be extensively studied by researchers such as Sokolov, who theorized a series of internal models that lead to awareness of environmental changes and reflexive orientation to new stimuli to update the internal models (Sokolov & Vinogradova, 1975).

Arthur Jersild was an educator who used a set-shifting paradigm to examine the ability to alternate between different tasks. The results of his study were published in an important paper called "Mental Set and Shift" (Jersild, 1927), which was an early precursor to information-processing psychology. Jersild had his students time themselves while working through pure and alternating lists. Those tasks that involved alternating lists (e.g., subtracting alternating numbers and adding three to numbers) took much longer to complete than pure lists (e.g., subtracting three from numbers). This finding later contributed to the concepts of set shifting and cognitive load.

Telford (1931) discovered that neurons were less sensitive to stimulation immediately after firing. This was termed the psychological refractory period, the discovery of which led to the development of the concept of divided attention. Research on divided attention has been applied to literally thousands of studies in a large number of areas, with a rich body of research that continues to the present day (Finley, Benjamin, & McCarley, 2014).

A few years after Telford's (1931) discovery, John Ridley Stroop presented a test of conflicting stimuli that displayed the spelling of a particular color printed in the ink of another color and found that naming the color of an incongruent word (e.g., naming the word "blue" spelled in red-colored ink) takes longer and is more likely to produce errors than naming the color of a congruent word (e.g., naming the word "red" spelled in red-colored ink). The described task evolved into the well-known Stroop Color-Word Test and led to the discovery of the Stroop effect, which has been applied to numerous subsequent research studies (Stroop, 1935). The Stroop effect pulls for semantic inference, such that when faced with a direct conflict between word color and word meaning, one is forced to pay attention to one or the other. People tend to pay more attention to the meaning of a word than to word color, resulting in slowed reaction times when required to attend to word color. Stated another way, it takes more effort and time to consciously interrupt an overlearned procedure (Stroop, 1935).

RESEARCH ON ATTENTION FROM 1948 THROUGH 1974

This time period saw an explosion of research on attention, which led to important findings about vigilance and selective attention. During World War II, researchers began to wonder how radio signal operators identified infrequently occurring signals. British psychologist Mackworth (1948) published a seminal study on the topic, entitled, "The Breakdown of Vigilance During Prolonged Visual Search." This study became one of the first examinations of vigilance, or the ability to sustain attention over long periods of time.

In the early 1950s, researchers became curious about how the brain filtered relevant from irrelevant information and wondered, for example, how air traffic controllers of that time discerned relevant information when listening to multiple pilots speaking through loudspeakers at the same time. Dichotic listening tasks in which different sets of information were spoken into each ear were used to develop theories about how filtering occurred. Broadbent's filter model (1952) proposed that a cognitive filter in the brain enabled an individual to manage two incoming stimuli at the same time. Termed the "early-selection" model, Broadbent's theory declared that attention was selected in an all-or-nothing manner and that attentional selection occurred before meaning was assigned to the incoming information.

Cherry (1953) showed that attention switched automatically to a new message during dichotic listening tasks if the information was highly meaningful (e.g., hearing one's name). Cherry's findings provided strong evidence that meaning was processed prior to any sort of cognitive filtration, thereby necessitating the development of a theory that involved categorization prior to attentional selection. The "late-selection" model proposed that information is processed semantically in both ears but words in the "unattended" ear are not accessed at a conscious level (Deutsch & Deutsch, 1963). Anne Treisman, a student of Broadbent, later revised the "early-selection" model to include an attenuation of the filter, such that stimuli that reach a threshold pass through the filter into conscious awareness. Treisman (1969) believed the threshold was determined by the word meaning, whereby important stimuli would gain access to awareness. Treisman's revision was termed the filter-attenuation model.

Other important findings that occurred during this time period included Rabbitt's (1966) finding that error correction response time was shorter during a continuous response task than the response time when the same signal was repeated immediately after a correct response. This finding was a precursor to identification of an error response system in the brain, which later became associated with frontal-cingulate communication (Carter & Krug, 2012). At the National Institutes of Health, Wurtz and Goldberg (1972) studied macaque monkeys and found that neuronal firing increased in the superior colliculus during tasks of attention. This finding led to continued focus on the identification of brain structures associated with attentional processing.

Luria (1973) theorized that there was an attention-arousal system that he located in the brain stem. Although imaging studies have since refuted this placement, Luria is nevertheless credited with outlining the tiered layers of attention, building upon each other from lower to higher functions. Luria understood that higher-level executive functions, such as the pursuit of goals, cannot occur without a foundation of sufficient arousal and adequate attentional focus.

RESEARCH ON ATTENTION FROM 1975 TO THE PRESENT

Beginning in the 1970s, several theoretical models of attention were developed to explain and organize a wide range of findings in the field of attention research. Pribram and McGuinness (1975) theorized a model involving arousal, activation, and effort. They posited that "arousal" was regulated by the amygdala, that "activation" was hypothesized to be mediated by the basal ganglia, and that "effort" was regulated by a hippocampal circuit connecting the amygdala and basal ganglia.

Mesulam (1981) developed a network model of attentional control. Directed attention was considered to be both specialized and redundant, with four areas of attentional control: The reticular component (similar to Luria's [1973] model) was thought to contribute to arousal and vigilance; the posterior parietal lobe provided a sensory map of the world; moving to higher levels of attentional control, the cingulate cortex gave motivational significance to objects of attention; and the frontal cortex provided motor action programs to explore and scan the world. The explanatory models of Pribram and McGuinness (1975) and Mesulam (1981) attempted to localize various aspects of attention to specific neuroanatomy based on knowledge available at that time. Today, we have good data indicating that attention occurs through a series of neural circuits involving feedforward and feedback loops which connect multiple brain areas.

Other researchers have attempted to understand the cognitive processes associated with the brain's ability to focus attention on a particular task and simultaneously screen out irrelevant stimuli. Signal detection theory (SDT), originally developed in the 1950s (Tanner & Swets, 1954), is designed to quantify the brain's ability to discriminate between signal and noise, with signal being defined as patterns that provide information and noise defined as patterns that distract from the information. Stated another way, the SDT attempts to account for the brain's ability to identify relevant information and to screen out irrelevant information. The theory has application to a wide variety of research topics, including memory (Gordon & Clark, 1974) and the stimulus characteristics of reinforcement schedules

(Nevin, Olson, Mandell, & Yarensky, 1975). Most recently, SDT has been applied to the examination of neural activation patterns during decision making (Reckless, Bolstad, Nakstad, Andreassen, & Jensen, 2013). Several studies have suggested a primary role for the basal ganglia, specifically the striatum, in this process (Ashby, Waldron, Lee, & Berkman, 2001; Pertovaara et al., 2004).

Mirsky developed a model of attention based on factor analysis of neuropsychological tests (Mirsky, Anthony, Duncan, Ahearn, & Kellam, 1991). To date, this is the only model of attention that provides a theoretical underpinning for the neuropsychological evaluation of attention. The Mirsky model incorporates four components, each of which links to specific test data, including encoding of information, capacity to shift attention, capacity to sustain attention, and the ability to focus on an unfamiliar task and execute the task with speed. The Mirsky model has been successfully applied in hundreds of research studies. The model was used to differentiate attention deficits resulting from traumatic brain injury and attention-deficit hyperactivity disorder (Thaler, Allen, Park, McMurray, & Mayfield, 2010). The Mirsky model has recently been updated to reflect current neuroscientific findings in the field of attention (Koziol, Joyce, & Wurglitz, 2014).

Until the mid-1980s, there was limited awareness of the role of brain circuitry on attentional processes. The focus was on identifying particular brain regions thought to be associated with specific functional outcomes. This began to change in 1986, with the publication of "Parallel Organization of Functionally Segregated Circuits Linking Basal Ganglia and Cortex" by Alexander et al. (1986). This model demonstrated that cortical and subcortical communication occurred in a feedback and feedforward circuitry.

Posner was an early proponent of attentional networks. He and his colleagues proposed a neural system that was separate from the sensory and motor networks, defining attention as "the selection of information for focal (conscious) processing" (Posner & Petersen, 1990, p. 25). The authors were ahead of their time in positing that attention was accomplished through a network of areas, with each area carrying out different functions. They proposed a model involving orienting to incoming stimuli; identifying signals for focused, conscious processing; and maintaining vigilant focus. Applying their theory, these researchers found that directing attention in advance increases processing of an event when it happens (Posner & Petersen, 1990). An example of this process, as cited by Wright and Ward (2008), occurs when a flight attendant announces that a list of gate transfers is about to be read. For persons transferring to another airplane, this announcement increases subsequent processing of the actual gate readings. Posner also studied the effect on attention when it has been drawn to a specific location and then is withdrawn, and he found that there is up to a 2-s delay before attention can return to the original object. This finding is termed inhibition of return (Posner, Cohen, & Rafal, 1982).

Researchers and theorists dating back to the 19th century (James, 1890) have agreed that attention involves a combination of automatic processing that falls beneath conscious awareness and voluntary, effortful, conscious processing. Some have suggested that hemispheric specialization is related to these concepts. Goldberg and colleagues (Goldberg & Costa, 1981; Goldberg & Podell, 1995) have provided evidence that the left hemisphere is geared for utilizing well-learned codes and that the right hemisphere is more adept at processing novel situations in which there is no obvious plan of problem-solving action. In this way of thinking, attention involves a continuous interplay within the environment between automatic and effortful processing.

Automatic processing involves the ability to make predictable responses to expected encounters within the environment based on previously learned and stored programs. Effortful processing occurs when unexpected, novel situations are encountered within the environment that do not lend themselves to known problem-solving responses. When this happens, the organism has to engage in episodes of effortful conscious control (Koziol, Budding, & Chidekel, 2010). The neural basis of automaticity has been explored, with findings indicating that the lateral prefrontal cortex (PFC) and caudate nucleus are primary areas involved in cognitive control and the learning process that moves a task from new and effortful to automatic and routine (Poldrack et al., 2005). This dual-tiered model of cognition fits well with known neuroscientific concepts associated with large-scale brain networks (Hikosaka & Isoda, 2010; Toates, 2006) and has been applied to understanding disorders of attention (Sonuga-Barke, 2003).

ATTENTION: THE IMPACT OF LARGE-SCALE BRAIN SYSTEMS

Traditional ideas about brain–behavior relationships are in the midst of revision based on technological developments of the last 15 to 20 years. Although theories about functional brain networks date back to the early 1990s (Mesulam, 1990), data illustrating the importance of brain networks were not obtained until 2000, through the advent of diffusion tensor imaging (DTI) and resting-state functional magnetic resonance imaging (fMRI). Large-scale brain systems have been identified through multiple techniques, including detailed parcellation of the cerebral cortex using structural magnetic resonance imaging, fMRI, and neurochemical mapping. In addition, techniques involving the diffusion of water, known as DTI, have yielded remarkable insights about brain networks and have allowed for identification of white-matter tract connections. As Bressler and Menon (2010) discuss, these techniques are in their infancy and many cortical brain areas have not been adequately mapped; future applications to the field of attention remain to be discovered. Through these technologies, multiple brain networks have been identified in the brain at rest and during activity. The implication of these new technologies is that cognitive functions, including the various aspects of attention, can no longer be attributed to isolated brain structures (Bressler & Menon, 2010).

Yeo et al. (2011) used resting-state fMRI to identify seven functional brain networks in 1,000 healthy young adults. Compellingly, these networks show connection patterns that are common across human participants. The data were divided into a discovery set and a replication set, each with 500 participants. Remarkably, more than 97% of the cortical area was assigned to one of these seven neural networks in each data set (Yeo et al., 2011). These patterns of functional connectivity are reflected in the seven large-scale brain systems implicated in the evaluation of attention.

The *frontoparietal network* (FPN) is a cognitive control system that includes working-memory functions. The FPN is activated when a rule or information is needed to guide behavior for completion of a cognitive task or in pursuit of a goal. This network of cognitive control recruits a number of brain regions when activated, including the dorsolateral PFC (DLPFC), the anterior cingulate cortex (ACC), the anterior PFC, inferior parietal lobe, and several subcortical structures, including the cerebellum and caudate nucleus. The FPN engages brain regions in goal-directed behavior. It provides executive control and the flexibility to respond to a constantly changing environment.

The dorsal and ventral networks are key to understanding attentional processes. The *dorsal attention network* corresponds to the "dorsal pathway" taught in most neuropsychology textbooks and is involved in the management of spatial attention and attentional shift. In traditional terms this network identifies where objects are and how to use them. The dorsal attention network is involved in executive control, especially in regards to visual attention. The most important areas of the dorsal attention network are the intraparietal sulcus and frontal eye fields.

The *ventral attention network* corresponds to the "ventral pathway" and allows for object identification and identification of what objects are used for. Anatomical areas of the ventral network include the tertiary processing area of the temporoparietal junction, the supramarginal gyrus, the frontal operculum, and the anterior insula. The network provides salience, an important feature regarding where attention should be placed. This network interrupts ongoing behavior and thus is involved in shifting attention (Castellanos & Proal, 2012; Koziol et al., 2014).

The role of the dorsal and ventral attention networks working in tandem has also been studied. Corbetta, Patel, and Shulman (2008) used fMRI to examine these two networks and found different network activations when cues were used to orient to a specific location versus when unexpected cues occurred at an unattended location. Following the onset of a cue, dorsal frontoparietal regions were activated. The authors posited that the dorsal network was central to selective attention. In the unexpected cue scenario, the dorsal and ventral networks were coactivated during reorientation to a new and unexpected stimulus (Corbetta et al., 2008). The concept of dorsal and ventral attention networks was given confirmation by resting fMRI results, which showed coherent activation in the relevant brain network areas (He, Shulman, Snyder, & Corbetta, 2007).

The *visual network* has important connections to the superior parietal lobe and intraparietal sulcus, both of which connect to the dorsal attention network. The visual network is made up of the occipital lobe and lateral temporal and superior parietal regions. The primary visual cortex receives input from visual and auditory sensory-processing centers. Closely interacting with ventral and dorsal attention networks, the visual network is involved in sustaining attention, suppressing attention to irrelevant stimuli, and interacting with these control systems to help direct attention.

Other neural networks include the limbic and sensorimotor networks. The *limbic network* interacts with other systems to provide motivational and reward influences. This network consists of the dorsal ACC and the bilateral insulae and provides a cortical signal of salient events, including errors. The *motor network* was the first functional brain network to be identified. It is composed of the primary, supplementary, and premotor cortex, along with the sensory cortex, putamen, thalamus, and cerebellum. The *default mode network* includes the anterior medial PFC, posterior cingulate, and the dorsomedial prefrontal and the medial temporal systems. This network is active when external stimuli are at a minimum. It has been shown to activate the dorsomedial PFC when an individual is engaged in internal cognitive processes involving the self, while a different part of the default mode network, the medial temporal lobe, becomes activated when a person is projecting self into the future (Buckner, Andrews-Hanna, & Schacter, 2008).

IMPLICATIONS FOR TEST CONSTRUCTION

Most neuropsychological tests are atheoretical (Kent, 2013) and not based on neuroanatomical substrates (see Koziol & Budding, 2009, for review). Atheoretical test construction has confused the assessment of attention due to an arbitrary division of auditory and visual modes of processing. The discovery of functional brain systems, although in its infancy, will help the field of neuropsychology to move toward a more integrated theoretical understanding of auditory and visual attention. Researchers have posited that auditory input orients and guides visual attention (Arnott & Alain, 2011; Naatanen, Kujala, & Winkler, 2011; Salmi, Rinne, Degerman, & Alho, 2007). Auditory processing has been shown to follow the same organizing principles as the visual system in regards to the ventral and dorsal attention streams. That is, the ventral auditory attention stream is involved in attaching meaning to sound, with connections through the parietal lobe and frontal eye fields, while the dorsal auditory attention stream uses sound to orient visual attention in space. Studies of dichotic listening revealed activation of the dorsal attention network during an auditory attention-shifting task, providing further evidence that auditory and visual attention are not separate (Ahveninen, Huang, Belliveau, Chang, & Hämäläinen, 2013).

Other data suggest that these sensory modes work together to call attention to pertinent stimuli in the environment. Specifically, the dorsal auditory pathway has been shown to play an important role in orienting visual attention toward spatial location. For example, there are direct auditory projections onto the medial occipital cortex (Vaidya, 2012). Furthermore, complex multimodal processing areas of the parietal lobes receive both auditory and visual input. Given these findings, it may be that auditory input has a role in the establishment of cognitive control. Studies comparing deaf and hearing individuals found that deaf individuals made more errors of commission than hearing individuals on a continuous performance test, suggesting less ability to sustain attention (Parasnis, Samar, & Berent, 2003). Furthermore, in a study of mice, deleting a specific gene involved in hearing resulted in poor impulse control and a pattern of disinhibition and hyperactivity. The gene deletion generated abnormalities in a basal ganglia region involved in cortical-subcortical loops of communication (Antoine, Hubner, Arezzo, & Hebert, 2013). This finding links inner ear dysfunction to basal ganglia damage.

Further evidence of the dual-processing roles of auditory and visual modalities comes from studies of brain regions activated during digits forward and digits backward processing tasks (Dengtang, Yifeng, & Zheng, 2004; Gerton et al., 2004; Li, Qin, Zhang, Jiang, & Yu, 2012). These studies clearly demonstrate activation of the medial occipital cortex during digit repetition. Why would this occur? Both auditory and visual processing interact with the dorsal and ventral attentional networks, and the primary visual cortex located in the occipital lobes receives projections from both auditory and visual sensory inputs (Arnott & Alain, 2011; Chabot, Mellott, Hall, Tichenoff, & Lomber, 2013; Gruters & Groh, 2012; Naatanen et al., 2011). Finally, unilateral hearing loss has been shown to effect the development of cross-modal sensory processing and the default mode network during processing of spoken language (Schmithorst, Plante, & Holland, 2014).

Taken together, these findings suggest that future theories of attention should incorporate coprocessing of auditory and visual systems (Koziol, 2014). More importantly, this example illustrates the importance of considering data in the light of our current understanding of brain networks (e.g., dorsal and ventral attention networks, visual network), which should allow the field of neuropsychology to develop new theories and test instruments that are consistent with what is known about brain function and large-scale brain systems. As many researchers and theorists focus on the implications of large-scale brain networks to understand cognition, "A new paradigm is emerging" (Bressler & Menon, 2010, p. 277). The construct of attention will continue to be impacted by discoveries about large-scale brain systems.

IMPLICATIONS FOR THE EVALUATION OF ATTENTION IN CHILDREN AND ADOLESCENTS

The field has barely begun to examine the way brain networks develop in the maturing brain and the implications of that development on the evaluation of children and adolescents. A recent study demonstrated that the orientation and executive control brain networks do not interact with each other until age 7 years (Abundis-Gutiérrez, Checa, Castellanos, & Rosario Rueda, 2014)! Functional connectivity of the default network during resting-state fMRI in children, adolescents, and adults has also been evaluated (Chai, Ofen, Gabrieli, & Whitfield-Gabrieli, 2014). The default mode network involves brain regions thought to be inactive during attentional processing. The authors found that as age increases, there are increasingly larger negative correlations between DLPFC and medial PFC in the default mode network, indicating that lack of age-appropriate differentiation of these regions during childhood may contribute to attention disorders.

Electroencephalography (EEG) studies have also begun to examine the developmental patterns of human brain rhythms. Chu, Leahy, Pathmanathan, Kramer, and Cash (2014) used scalp EEG during the sleep state to examine 384 healthy children and found a stereotypical pattern of human brain rhythm development. This pattern involved the gradual maturation of broadly distributed networks in a predictable pattern.

Research on the development of attention networks has important implications for how attention should be evaluated in children and how disruptions in attentional processes are identified (e.g., attention-deficit hyperactivity disorder [ADHD]). In a study examining resting-state fMRI data in participants with ADHD and normal controls, those with ADHD had decreased overall brain network integration and increased network segregation compared with normal controls (Lin et al., 2013).

CONCLUSIONS

Neuroscientific discoveries about large-scale brain systems are continuing at a rapid pace, with implications for the neuropsychological assessment of attention. Although it has long been understood that the parietal lobe is activated when attending to location, recent studies (Cole et al., 2013; Hwang, Hallquist, & Luna, 2013) have identified an FPN or "hub" that mediates internal versus external cognition. The FPN was shown to have high between-network connectivity with both the default mode network (internally directed thought) and the dorsal attention network (externally directed thought), suggesting a gatekeeping role for the FPN when shifts in attention are required (Spreng, Sepulcre, Turner, Stevens, & Schacter, 2013). The implications of these findings are profoundly important for neuropsychologists attempting to accurately measure the construct of attention. The FPN hub interacts with multiple networks, suggesting a dynamic rather than fixed aspect to adaptive behavior and its measurement, consistent with the aforementioned dual-tiered model of behavior (Toates, 2006). One neuropsychological implication of dynamic interaction is the importance of evaluating the integrity of procedural learning systems, which are associated with automatic processing. A roadmap for the integration of neuroscientific principles in the field of neuropsychology can be found in Koziol and Budding (2009). An illustration of how discoveries related to large-scale brain networks might be applied to the field of attention can be found in a recent update of the Mirsky model of attention (Koziol et al., 2014).

Historically, various practitioners have attempted to provide theoretical understanding of the construct of attention based on information available to them at the time. We have attempted to highlight some of the relevant attempts in an effort to illustrate the evolution of the construct of attention. Continued application of findings from large-scale brain networks to the assessment of attention needs to be applied, so that the field of neuropsychology can remain relevant into the 21st century.

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