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The Changing Face of Attentional Development

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Abstract
The field of attentional development has recently undergone a quiet revolution. Attention is no longer being studied as a static gatekeeper of consciousness and action; instead, it is being reconceptualized as a *dynamic* system that both influences and is influenced by the interactions between individuals and their environments. In this review, we first revisit the conventional understanding of attentional development, showing that a large body of research conducted using a handful of laboratory tasks failed to deliver deep theoretical insights. We then trace the revolution to show how investigators have been changing their research questions in response to this impasse. Finally, we speculate on what the future of attentional development research might look like from this emerging dynamic perspective.

Keywords
attention, development, dynamic systems

It is customary to begin a review of attention with an apology for the lack of a clear definition and a nod to William James (1890) for nevertheless encouraging researchers to study it. A practical consequence of this definitional uncertainty has been that the study of attention and its development has been dominated by a handful of tentative operational definitions, called *attentional tasks* or *paradigms*. While these paradigms have generated a large amount of research, they have so far failed to produce a sophisticated understanding of age-related changes in attention. Here, we describe an ongoing paradigm shift in the field of attentional development that is occurring in response to this stalemate (Fig. 1). By tracing the recent changes in research practice and connecting them to underlying theoretical ideas, we outline a new conceptualization of attentional development. Developmental changes in attention are now studied as both a cause and an outcome of the dynamic interactions among the environment, the developing brain, and an individual.

The Way We Were

Cognitive science during the second half of the 20th century was dominated by the metaphor of the mind as a computer. Within this view, attention was seen as the mental gatekeeper, as illustrated in Figure 1a, with its primary function being to manage and select a subset of available sensory information for the control of action. An important corollary of the gatekeeper model is the *situational invariance* assumption. This means that attention operates as an encapsulated module or a functional unit in a similar fashion across different individuals and situations (e.g., Posner, 1978). Following this idea, by adapting the chronometric tasks first developed for testing adults, attentional development researchers started to measure age-related changes in basic attentional functions. This approach promised to detect the onset of attentional abilities in childhood, to record changes in those abilities with maturation, and to document deviations from normative development in atypically developing populations. Figure 2 illustrates and summarizes seven widely used laboratory paradigms of attention.

A large body of evidence documenting developmental changes in attentional function has emerged from work using these popular tests (e.g., see Rueda, 2013, for a recent review). However, when we recently evaluated this literature (Ristic & Enns, in press), we noted that the large volume of data generated by the fine-grained laboratory tasks was not matched by a similar refinement in

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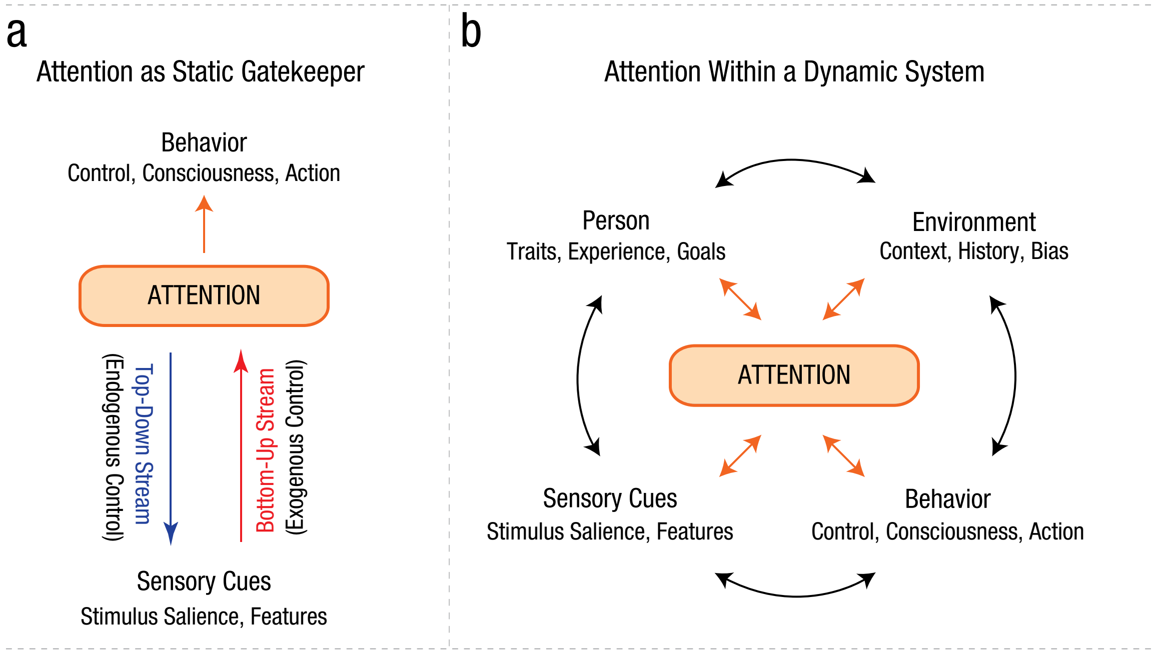

Fig. 1. The changing concept of attention. In the conventional view of attention as a static gatekeeper of consciousness and action (a), the "gate" is the brain's way of coping with the vast amount of environmental information and can be controlled in one of two modes. A *bottom-up* mode is triggered by the strongest signals coming from the sensory organs, which are delivered automatically and rapidly to the higher-order cognitive centers controlling thought and action. A *top-down* mode is directed by the higher-order cognitive centers in order to modulate the incoming sensory information. The top-down mode is therefore slower acting, effortful, and voluntary (e.g., Posner, 1978). In the emerging dynamic view (b), attention is both cause and outcome within a larger dynamic system. To study attention from this standpoint requires not only mapping the relationships among attention, sensory systems, and action control but also specifying the links between an individual's attention and his or her personal characteristics, environment, life history, and enduring behavior styles. Note that this new conceptualization contrasts with the traditional gatekeeper view in three important ways (see Ristic & Enns, in press). First, the dynamic view allows environmental and personal factors to reset attentional priorities in advance of bottom-up processing, whereas the gatekeeper view conceives top-down control as secondary and temporally sluggish. In the new view, personal goals, motivations, and biases, although residing in higher cognitive centers, can exert their influence well before new sensory information is encountered. Second, the dynamic view proposes top-down influences as central to understanding developmental change. In the gatekeeper view, by contrast, the slow maturation of the frontal lobes relative to other brain regions has been implicated as a key reason for the late onset of top-down control. Recent anatomical and neuroimaging data suggest that ventrolateral prefrontal areas, which are involved in maintaining personal and social biases, exert their influence as early as 3 months of age. Third, in the dynamic view, moment-to-moment fluctuations in attention and nonlinear interactions are expected features, because the underlying brain networks are responding flexibly to ongoing changes in the environment and to ongoing changes in individual interests, values, and goals. In contrast, the gatekeeper view treats these sources of variability as measurement error, because once priorities have been set, they are expected to run in a relatively stable, automated fashion (see the discussion of the *situational invariance* assumption in the main text).

theory. Instead, we were able to summarize the data for each task with the same conclusion: Voluntary control over attention improves during childhood. For example, studies of short-term visual memory indicated that children performed with an adult-like accuracy when the recall prompt appeared with a delay of 200 ms or less. Yet, when this interval was lengthened, older children found it easier than younger children to actively maintain information in memory in the absence of sensory help (e.g., Enns, 1987). In a related vein, children were shown to improve in perceptual filtering efficiency through the school years, as indicated by reduced flanker interference effects (e.g., Akhtar & Enns, 1989). The application of the Posner cuing task showed little age-related change in exogenous (involuntary) attention but considerable change in endogenous (voluntary) attention (e.g., Enns & Brodeur, 1989). Similarly, visual search tests showed that school-aged children performed like adults on simple feature search but that search defined by feature conjunctions resulted in larger search slopes as a function of array size for younger children (e.g., Kaye & Ruskin, 1990). Thus, gradual developmental changes were consistently associated with the increased demand for voluntary control of attention.

There are at least three reasons why this volume of research has not resulted in a more sophisticated theory.

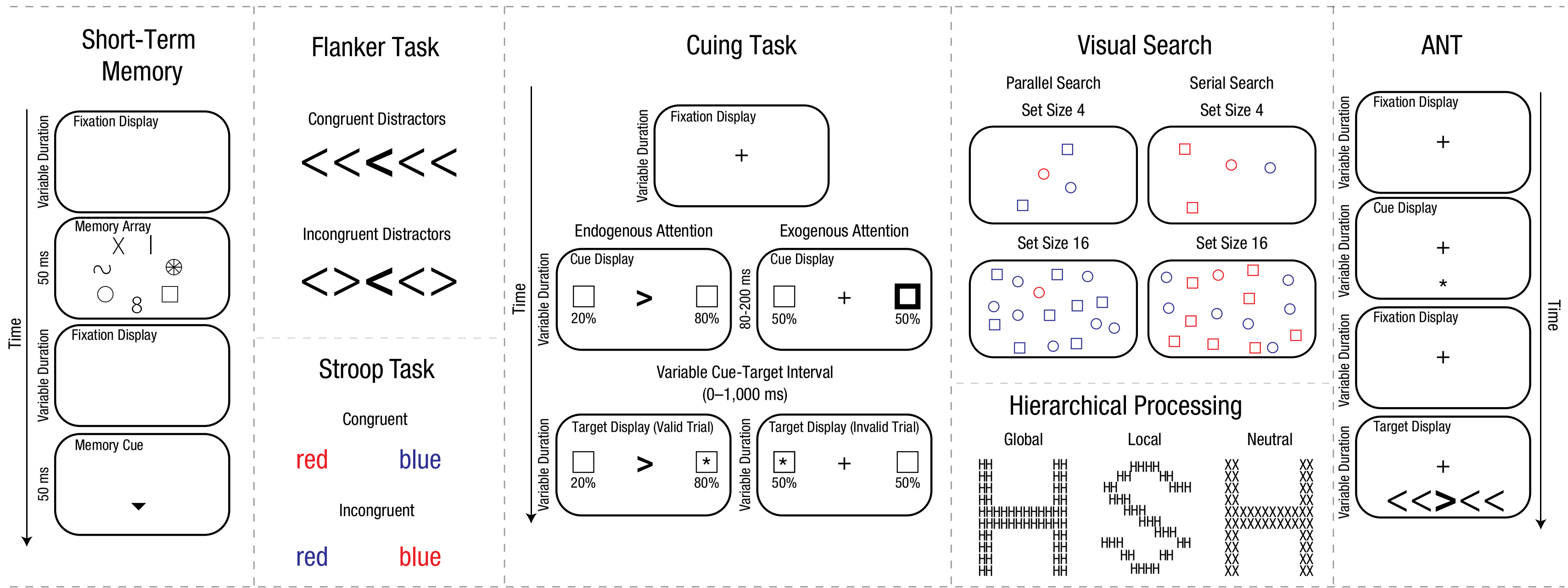

Fig. 2. Examples of seven chronometric tasks for measuring attention. Mental chronometry assumes that by comparing performance in two or more experimental conditions or age groups, the researcher can deduce the speed and quality of the attention gatekeeping function (Posner, 1978). In the short-term memory task (Sperling, 1960), participants see a brief display, and, following a variable delay, are asked to recall either all the items (whole report) or only the cued item (partial report, depicted here). The partial report is more accurate than the whole report following brief delays (iconic memory), whereas accuracy continues to decline equally for both tasks after longer delays (short-term memory). In the flanker task (Eriksen & Eriksen, 1974), participants are asked to report the direction of the central arrow (bolded here for emphasis) while trying to ignore the flanking arrows that display either congruent or incongruent directions. The decrease in performance accuracy that accompanies incongruent flanking distractors is a measure of the spatial acuity of the attentional zoom lens. In the Stroop task (Stroop, 1935), participants are asked to report the color of the word's font while ignoring its meaning. In the incongruent condition, the habitual skill of word reading interferes with the less commonly exercised task of naming the color of a word's font and results in poorer performance. In the cuing task (e.g., Posner, 1978), participants see a location cue followed by a target. For endogenous attention, the location cue is at fixation and offers predictive information about the target location (e.g., 80% reliability). For exogenous attention, the location cue is one of several potential target locations and is non-informative (e.g., 50% reliability when two locations are possible). Participants respond to the target by detecting, localizing, or identifying it. Attention is measured by the difference in response time for validly cued trials (shown in the endogenous example) versus invalidly cued trials (shown in the exogenous example). In the visual search task (Treisman & Gelade, 1980), participants are asked to report the presence or absence of a target shape (e.g., a red circle), which is defined either by a simple feature difference (e.g., red vs. blue) or by a conjunction of features (e.g., a red circle vs. red squares and blue circles). Conjunction search is influenced more by the size of the search array (e.g., 4 vs. 16 items) than feature search. The difference in response time slopes over the array size is a measure of the speed of feature binding. In the global-local task (Navon, 1977), participants are asked to identify a letter (e.g., H) that is defined at either the global or the local level. The global and local levels can be congruent (the same letter), neutral (one letter is not a target), or incongruent (two different letters). The difference in identification time for these three conditions is a measure of the ability to ignore information at one or the other level. In the Attention Network Test (ANT) procedure (Fan, McCandliss, Sommer, Raz, & Posner, 2002), participants are asked to report whether a central arrow points left or right. Prior to seeing the arrow, participants may receive no spatial cue, an alerting cue (a location cue occurring at all possible target locations), or a predictive location cue. The target arrow then appears either above or below the point of fixation and may or may not be accompanied by distracting flankers. Differences between these conditions in average response time are used to draw inferences about the functional state of three putatively independent attention faculties, namely, alerting, orienting, and executive control. Note that because paradigms' parameters (e.g., temporal duration of displays, cue predictability, stimuli, set sizes) vary across studies, the values depicted here are given as examples.

First, its developmental scope is limited. Chronometric measures that were designed for adults are outside the repertoire of infants and toddlers. Modifying these tasks in an age-appropriate manner was also not fruitful, as older participants frequently performed at ceiling in simplified procedures. Second, even when chronometric measures were applied carefully, inevitable age-related differences in baseline response times and accuracy remained. This is especially troublesome when the effect size of an attentional manipulation is correlated with this baseline speed. As a case in point, Goldberg, Maurer, and Lewis (2001) reported no difference in endogenous attention between younger and older children when the chronometric data were treated with the rigor usually afforded to adult data, including sufficient repetition of conditions and outlier screening procedures. Third, and perhaps most critically, performance on chronometric tasks did not prove to be a useful predictor of attentional functioning in clinical populations and everyday contexts (e.g., patients with attention deficit/hyperactivity disorder; Nigg, 2005).

In short, operational definitions of attention inspired by the gatekeeper view and premised on the situational invariance assumption have not delivered either a unified theory of attention or a fine-grained understanding of how attention changes during human development. Theoretical advancement in the area of attentional development has been, in a word, underwhelming.

The Times Are Changing

Yet the field of attentional development has not been standing still. The headline news is that over the past decade, researchers have quietly moved away from the view of attention as a gatekeeper and have embraced an alternative concept of attention as reflecting dynamic person-environment interactions (e.g., Belsky, Friedman, & Hsieh, 2001; Connors, Connolly, & Toplak, 2012; Fulcher, Mathews, & Hammerl, 2008; Gavrilov, Rotem, Ofek, & Geva, 2012; Harmon-Jones & Gable, 2009). This is depicted in Figure 1b. This conceptual shift is exemplified by recent publication trends. When we examined the number of studies citing the keyword *attention* (literature search performed using the Web of Knowledge database in July 2013), we recorded a 2.5-fold increase over the two decades on either side of the year 2000. Combining the keyword *children* with *attention* returned a 2.7-fold increase. Much of this increase likely reflects the general upsurge in publications. However, it is against this backdrop that we noted a striking 5.3-fold increase in articles using the keywords *attention* and *emotion*, and a 5.2-fold increase in articles using the triple conjunction of *attention, emotion*, and *children*.

One of the central themes fueling this paradigm shift is the question of how the everyday functioning of an individual influences attention. At first, researchers tackled this issue by substituting the symbols used in conventional chronometric tasks with everyday content that included images of people, faces, and social interactions, as shown in Figure 3. The results of these investigations were groundbreaking! They showed that children attend to social-emotional content in a fundamentally different way than they attend to arbitrary symbols. For example, Sørensen and Kyllingsbæk (2012) found that the oft-reported increase in short-term-memory capacity with age held only for stimuli that required considerable perceptual expertise (e.g., the alphabet). When the stimuli were pictures, age-related capacity differences were erased. Fletcher-Watson, Collis, Findlay, and Leekam (2009) also reported that children's attentional priority for the content of pictures did not differ from that of adults, such that 6-year old children detected changes to objects of central interest as efficiently as adults.

Attentional filtering ability was also reported to vary with social content. When distracting flankers were faces displaying anger and fear, children and adults alike had trouble ignoring them. This result held for 7-month-old infants (Hoehl, Palumbo, Heinisch, & Striano, 2008), preschool children (LoBue, 2009), and adults (Calvo, Avero, & Lundqvist, 2006). When flashing boxes from the Posner cuing task were replaced with images of gazing faces, infants, preschoolers, and adults followed the gaze cue in an equally spontaneous manner (Hood, Willen, & Driver, 1998; Ristic, Friesen, & Kingstone, 2002). Finally, visual search for targets defined by social-emotional content also led to results not predicted by the conventional view. Waters, Lipp, and Spence (2008) reported that when 9- to 12-year-olds and adults were presented with images of spiders and snakes embedded among images of mushrooms and flowers and vice versa, both age groups were faster at identifying fearful stimuli regardless of the number of items to search.

This strategy of substituting geometric shapes with images of everyday content revealed three important results. First, attention operated differently when experimental displays depicted social, emotional, and evolutionarily relevant content relative to when they depicted symbols. Second, the trajectory of typical development differed for social versus arbitrary stimuli, insofar as many previously documented age-related changes disappeared. Finally, existing theoretical models premised on the situational invariance assumption could not explain these context-dependent results.

Yet the tactic of substituting shapes for social content has faced its own interpretational challenges. Despite the shift to more lifelike stimuli, the results from these studies have also not translated easily to clinical and everyday settings (e.g., patients with autism; Birmingham, Ristic, & Kingstone, 2012). One reaction to this challenge has been

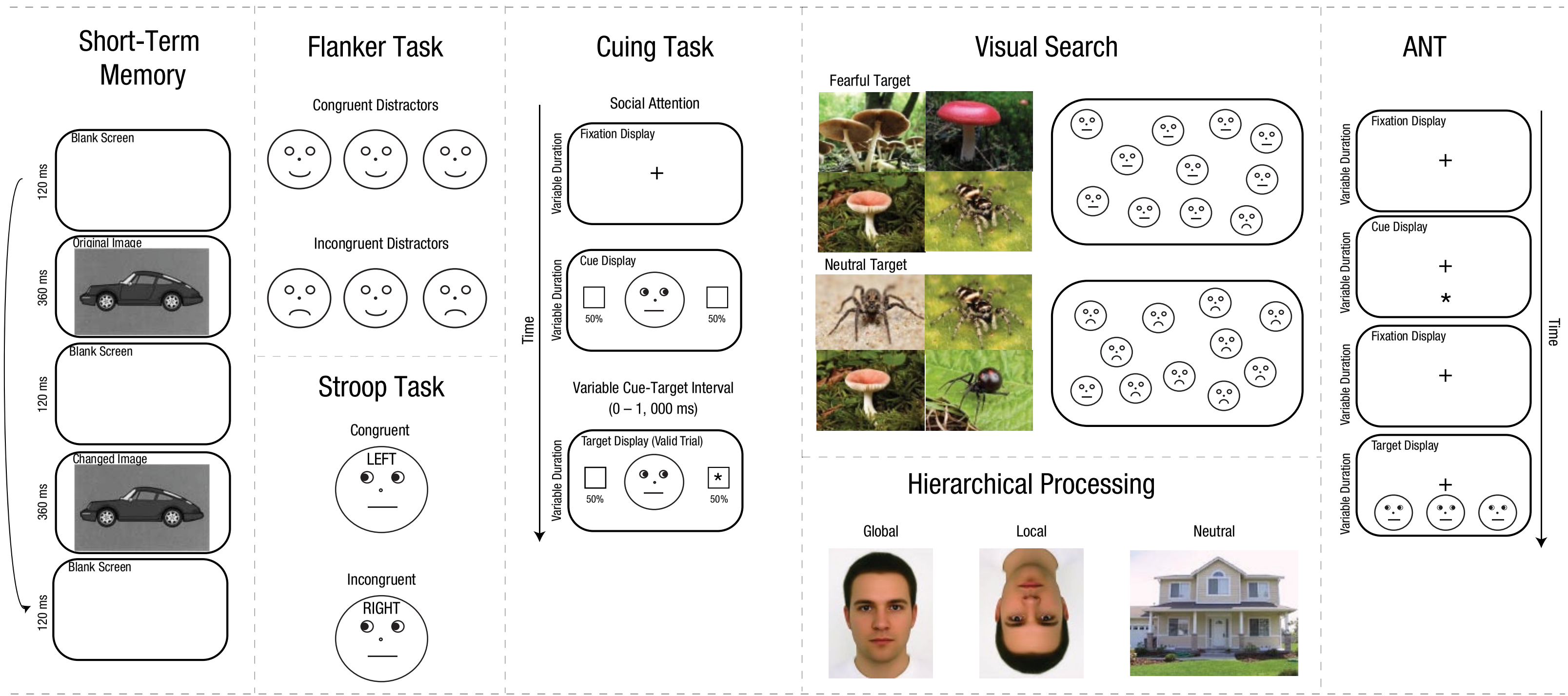

Fig. 3. Examples of modified chronometric tasks for studying attention to social-emotional content. Short-term memory for pictures is often tested using a change detection task (e.g., Fletcher-Watson, Collis, Findlay, & Leekam, 2009). Here, participants are asked to report whether they detect any change in the display (in this example, a change to a car door), which alternates between the original and a changed image separated by a brief blank screen. The flanker task modification involves using flankers that are emotionally or socially congruent or incongruent with the target (e.g., Fenske & Eastwood, 2003).The depicted modified Stroop task pits gaze direction against the semantic content of words (e.g., Langton, Watt, & Bruce, 2000). The modified cuing task uses gaze direction to cue potential target locations (e.g., Ristic, Friesen, & Kingstone, 2002). In the modified visual search task, participants report the presence of a fearful target item (e.g., a spider, a sad face) among nonfearful neutral distractors (e.g., mushrooms, a neutral face) and vice versa (e.g., Waters, Lipp, & Spence, 2008). In the modified global-local task, responses to upright faces are thought to depend on holistic processing, and responses to inverted faces and neutral stimuli (e.g., houses) are thought to require local processing. The modified Attention Network Test (ANT) procedure (e.g., Federico, Marotta, Adriani, Maccari, & Casagrande, 2013) presents a social flanker task in which the target face displays a gaze direction (left shown here) that is either congruent or incongruent (shown here) with the gaze direction displayed by the flankers. Note that because paradigms' parameters (e.g., temporal duration of displays, cue predictability, stimuli, set sizes) vary across studies, the values depicted here are given as examples.

to increase the ecological validity of experimental tasks even further. For example, while tracking the eye position of infants and toddlers viewing naturalistic social scenarios, Frank, Vul, and Saxe (2012) found that when viewing faces alone, younger children looked more at eyes, whereas older ones looked more at mouths, especially during dialog. With increasing age, there was also greater situational sensitivity. Gredebäck, Fikke, and Melinder (2010) reported that although infants spontaneously started to follow gaze at about 2 months of age, between 4 and 8 months they did so less frequently when interacting with parents relative to strangers. Thus, attention in life is sensitive to many factors. These factors include not only the content of the information but also the context in which this information is presented and the stage of development. To understand these interactions, new experimental approaches and theoretical viewpoints are needed to move us beyond the confines of the gatekeeper theory and its associated chronometric tests.

Where Do We Go From Here?

Answering the question of how attention functions in everyday life will require, at a minimum, tools for studying individual differences and situational variability. Second, researchers can no longer afford to conceptualize attention as a system that simply reacts to the sensory world. Instead, they must study attention both as a system that can influence perception and as a system that is itself influenced by personality variables, neuroplastic changes in the brain, environmental factors, and genetic predispositions. Put simply, attention must be studied as a *dynamic* system.

In keeping with this conceptual shift, Johnson et al. (2005) recently outlined how the environment may facilitate brain development through a process called *interactive specialization*. These authors proposed that age-related changes in the ability to prioritize, process, and respond to external information occur as a direct consequence of person-environment interactions. This is because brain regions involved in supporting these behaviors mature along with the strengthening of connections between the specific brain areas. For example, as social communicative functions become more sophisticated with maturation, they also become more closely linked to a fully differentiated social brain network. This perspective has important consequences for research. Unlike the conventional approach, in which behavioral functions are mapped onto developing brain *structures* that are believed to house a mental faculty, interactive specialization suggests that along with the maturation of individual brain structures, social and cognitive functions mature through an ongoing reorganization of the *connections* between those structures. This means the acquisition of new skills will alter interconnections both within and between neural regions, with the entire system undergoing continual reorganization as a function of experience. The context in which an information exchange occurs is therefore as important as the content of the signal, such that the same stimulus may convey very different messages depending on its relationship to an individual and his or her environment.

How might a dynamic attention system organize itself? There are currently several interrelated possibilities. One is that an individual's attention ability may be predisposed by genetic influences on neural architecture and traits of temperament (e.g., Plomin, 1994; Rothbart, Posner, & Kieras, 2006). For example, Rothbart defined temperament as a two-pronged concept that includes an inherent bias to react to sensory stimulation and the ability to regulate behavior. Because attentional selectivity is intimately bound to both of these functions, this view situates attention as a superordinate self-regulatory mechanism, which develops as a function of interactions between temperament traits and environmental demands. This means that attention, by definition, will vary both between individuals and within individuals as circumstances change.

Another starting position situates individual variability in attention within the brain's intrinsic organization. One example of such organization is found in the literature on mind wandering. Here, it is suggested that an individual's ability to focus on the external world may depend on a balance between the brain networks associated with on-task versus off-task processes (e.g., Raichle, 2010). Brain imaging data suggest that these two states reflect a functional rivalry between two brain networks. Resolving this competition involves allocating the finite mental resources to either internal processes (e.g., self-referential thought) or externally driven demands (e.g., task stimuli). Along with an individual's neural anatomy, temperament-driven reactivity bias, and changes in brain differentiation, the developing balance between these two networks may in turn influence each person's capacity for on-task performance. For example, individuals with a higher ratio of off-task states may exhibit poorer educational outcomes or develop maladaptive behaviors (e.g., aggression; Dodge & Frame, 1982).

Finally, an individual's attentional balance may be affected by motivational factors. Both stable biological drives (e.g., hunger) and changeable psychological motivators (e.g., need for affiliation) may drive individual fluctuations in attention. In line with this position, recent data indicate that attention is preferentially engaged by even the simplest visual features that hold personal motivational value (e.g., Anderson, Laurent, & Yantis, 2011).

Regardless of one's preferred entry point into this dynamic web, the future of attentional development research looks bright! As the field embraces individual characteristics and contextual influences, the main challenge will be to design approaches that test the dynamic age-related changes among brain interconnectivity, attentional priority setting, self-regulation, individual information-processing capacity, and personal histories. This means that it will no longer be possible to study attentional development from the perspective of a single paradigm or theoretical position. Rather, a successful approach will likely be multidisciplinary, including contributions from the neurosciences, genetics, neuroimaging, social psychology, anthropology, and the cognitive sciences. Studying attentional development as a *dynamic* system appears to hold great promise for unraveling the power of this human ability and the central role that it plays throughout the life span. Taking such a dynamic perspective will also likely benefit mainstream attention research in adults, and eventually psychological theory more broadly.

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