

Attention

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Introduction

Attention may be defined as the selective enhancement of some behavior at the expense of other behavior. Writings on attention often cite William James, *Principles of Psychology* (1890), “. . . everyone knows what attention is.” This is because we all have a commonsense notion of what attention is, and that it is ubiquitous across all types of behavior (e.g., attention to objects, joint attention with others, social attention, motor abilities). It is defined both as a specific psychological mechanism and as a characteristic of individual psychological behavior. Thus, in a developmental perspective, there may be a separate cognitive process called ‘attention’ that develops independently of other psychological mechanisms, as well as attention development specific to behavior. Attention development is often linked to the development of brain areas that are involved in attention.

Newborn attention: stimulus orienting

Attentive behavior may be observed in newborns. Newborns show a form of attention called ‘stimulus orienting,’ which involves the movement of sensors to enhance the quality of external information. For example, a rattle shaken to the side of a newborn will result in a head turn that enhances hearing and vision as both eyes and ears can be aligned with a sound by means of turning the head. Attention is limited, however, by the infant’s perceptual apparatus (poor vision, poor hearing), and by brain areas that are yet to develop. Many changes in visual and auditory behavior over the first six months involve development of the receptors themselves (e.g., eyeball size, density of retinal connections), or development in the primary sensory areas in the cortex that support perceptual activity (e.g., connections within the primary visual cortex). Thus, changes in the range of stimuli to which stimulus orienting may occur, or the number of situations in

which it does or does not occur, are not likely to be due to a change in the ability to show stimulus orienting, but to development other than stimulus orienting *per se*.

Young infant attention development: from stimulus orienting to sustained attention

The greatest change in attention during the first eighteen months is in sustained attention (also called focused attention). Sustained attention is an extended selective engagement of a behavior system that primarily enhances information processing in that system. It is similar to a state of arousal during which cognitive processing is enhanced. Many interesting cognitive and social activities of the infant occur mainly during episodes of sustained attention. For example, infants prefer to look at relatively novel objects, faces, and sounds. Novel stimuli elicit an initial stimulus orienting and then sustained attention. During sustained attention the infant ‘memorizes’ and becomes familiar with the aspects of the stimulus (J. E. Richards, 1997). The infant then will be less likely to show either stimulus orienting or sustained attention in response to the stimulus.

Infants as young as 3 months of age will engage in five- to ten-second periods of sustained attention (J. E. Richards, 2001). From 3 months of age to the middle of the second year, the duration of sustained attention increases. For example, heart rate changes that are known to accompany sustained attention will occur for longer durations in older infants than in younger infants, and the infants will show longer looks toward interesting stimuli. Stimulus orienting (present at birth) and sustained attention (developing from 3 to 18 months) are two processes that are basic in the human cognitive and behavior system. By the middle of the second year (18 months), these two basic attention processes are fully developed.

The development of sustained attention during the period of infancy is closely related to that of brain systems controlling arousal and state. Sustained

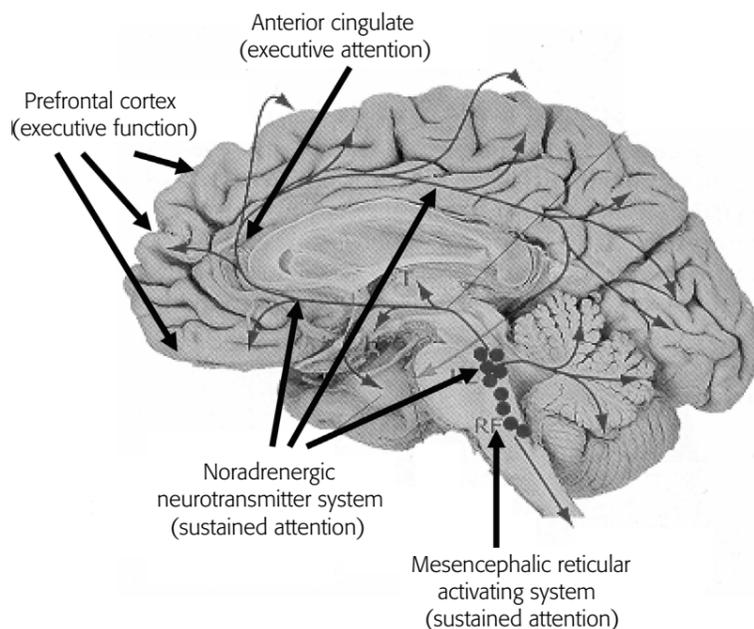


Figure 1. The areas of the brain involved in attention development. The noradrenergic neurotransmitter system and the mesencephalic reticular activating system control sustained attention and show developmental changes in infants. The prefrontal cortex and anterior cingulate gyrus control executive attention and show developmental changes from early childhood through adolescence.

attention is a manifestation of a 'global arousal' system, not unlike sleep and other behavioral states. This arousal system controls responsiveness to events in the environment and affects sensory systems. It is closely associated with the mesencephalic reticular activating system, and is mediated by the noradrenergic and cholinergic neurotransmitter systems (Robbins & Everitt, 1995). Figure 1 shows several areas of the brain that are involved in attention development, including the noradrenergic neurotransmitter system and the reticular activating system. These neurotransmitter systems have a widespread influence over cortical sensitivity and excitability. Thus, sustained attention represents the activation of this arousal system in situations calling for attention. The behavioral (decreased peripheral activity and movements, increased processing) and physiological (heart rate, scalp-recorded brain activity) indices of sustained attention are also signs that these brain systems are active. Thus, developmental changes in the neurochemical systems controlling arousal are manifested and correspond to developmental changes in sustained attention in infants.

Infant attention and visual fixation

There is a counter-intuitive relation between attention and duration of visual fixation in infants. Many

researchers define visual attention as coincident with visual fixation. That is, a dependent variable in psychological research on infant attention will often be the duration that the infant keeps the eyes directed toward a visual stimulus. However, infants can look at visual patterns and actually be in an inattentive state. This is particularly true in the first three months of life. An infant's look toward a visual pattern may be captured by the pattern even though other signs indicate the infant is inattentive (heart rate change, brain activity, psychological manipulations, no later recognition memory). For example, heart rate changes can be used to indicate that a child is in an attentive state, during which heart rate decelerates, or that an attentive state has ended with heart rate returning to baseline (J. E. Richards, 2001). Young infants will often continue to look at a visual pattern even when their heart rate shows that they are no longer aroused (i.e., sustained attention is not occurring).

Between 3 and 12 months, with the increase in sustained attention, there is concomitant decline in looking duration to simple visual patterns. Figure 2 (top panel) shows the changes in visual fixation duration to relatively simple stimuli that have been found in a number of studies of infants. There is an initial increase in look duration from birth to 2 months followed by a decline through 6 months of age. This change has been interpreted as indicating an increase in processing speed over this age range. The decline in looking duration to simple patterns may indicate increases in sustained attention, leading to more efficient cognitive processing, and a decline in the amount of time necessary to process simple visual patterns. Alternatively, across this same period there is an increase in looking duration to complex and varied visual patterns, or complex auditory-visual patterns.

Figure 2 (bottom panel) shows the average look duration to the television program *Sesame Street* or to simple computer-generated black-and-white geometric forms. There is an increase in look duration from 6 months to 2 years for the *Sesame Street* program, but no change in the amount of time spent looking at the simple forms. The increase in looking time to complex visual patterns indicates that infants will engage in selective enhanced processing if sufficient complexity exists in the stimulus.

Individual differences in the development of attention

There are individual differences in attentive behavior in infants that may be stable through early childhood. At a specific age, say 6 months, one can find that some infants engage in more attentive behavior than other infants.

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For example, changes in behavior (fast processing time, body movements, recognition memory) or physiological indices (heart rate change, brain activity) indicate that the degree of attentiveness differs among infants, and that this difference exists across several types of stimulus situations. One can measure similar behaviors at two different ages (e.g., 6 and 12 months), and find that individuals showing high levels of attentiveness at the first age are also those showing attentiveness at the second age. This relationship between multiple behaviors at a single age (intra-age stability) and that between behaviors across age (inter-age stability) are typically measured with a correlation coefficient. Correlations between early and later behavior in months 6 to 12 typically range from .2 to as high as .8.

A remarkable finding is that some aspects of early infant behavior are correlated with measures of intellectual outcome in early childhood (e.g., 5 years), and perhaps through the adolescent years. For example, it has been shown repeatedly that the amount of attention to a novel visual stimulus in 6-month-old infants is negatively correlated with measures of intelligence (e.g., Stanford-Binet IQ) in 11-year-old children (Rose, Feldman, Futterweit, & Jankowski, 1997). The interpretation of this finding is that infants with faster processing speed, and presumably higher levels of attention, look at a simple stimulus for a shorter period of time, and have higher intellectual abilities in early childhood. Thus, individual differences in infant attention occur that are very stable across short periods of time, and that remain relatively stable through the childhood years.

Development of executive attention

The period from 18 months through mid-adolescence is accompanied by an extended development of executive attention and executive functioning. Executive function is a description of psychological activities that control behavior, allocate cognitive resources, evaluate behavior progress, and direct activity with goals and plans. One aspect of executive function is the ability to allocate attention in a way that is consistent with self-established goals and plans. For example, if young children decide to play with a set of toys and construct a small setting from the toys, they must attend to the relevant characteristics of the toys (e.g., building connections, framework for a scene, characters in the setting). At the same time, characteristics of the toys that are irrelevant to the planned setting must be ignored, such as toys that do not belong in the setting, particular attributes of the toys, or how many toys or people are available. Similarly, other activities in the environment that might be of interest to the child must be ignored, or it will disrupt the playful behavior. The executive functioning that

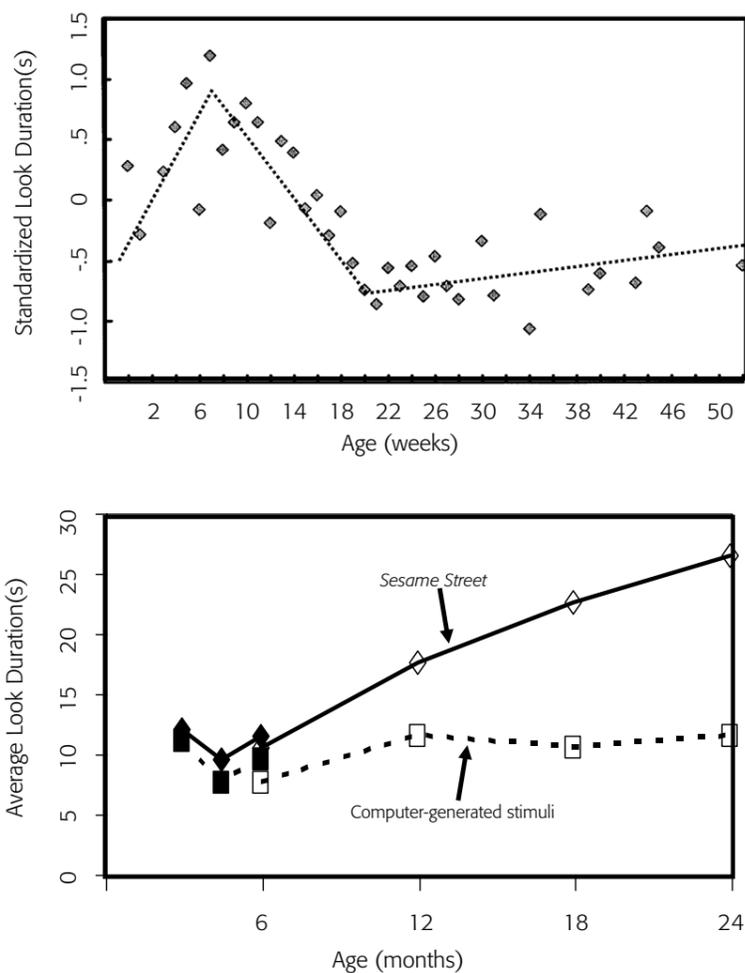


Figure 2. Changes in fixation duration reflecting attention development in infants. The top panel shows a systematic decline in fixation to simple stimuli reflecting an increase in processing speed and decline in the amount of time necessary to process simple visual patterns (compiled by John Colombo). The bottom panel shows an increase in fixation duration to *Sesame Street* and no change to simple geometric patterns, reflecting increases in sustained attention for stimuli of sufficient complexity (solid symbols for a study from 3 to 6 months; empty symbols for a study from 6 to 24 months).

guides such playful behavior selectively enhances attention to the particular aspects of the environment that are consistent with this behavior, and inhibits attention to things that are inconsistent with it.

As with sustained attention, executive attention and executive functioning are closely related to brain activity, in particular to the prefrontal cortex. Figure 1 shows several areas of the brain that are involved in the development of attention, including the prefrontal cortex. This area of the brain controls the ability to engage in goal-directed behavior, to inhibit intrusive behavior, and coordinate multiple actions to be consistent with goals and plans. Specific areas in the prefrontal

cortex may be related to executive attention. Some studies have shown that the anterior cingulate region of the prefrontal cortex (Fig. 1) is involved in shifting attention from one object to another in situations demanding internal control of attention. Presumably, development in the areas of the brain controlling executive functions is partially responsible for the extended period of development of executive function and executive attention measured in behavior (i.e., 18 months through adolescence).

Mental effort and development of attention

There are apparent changes during childhood in the amount of attention used on a task due to the close link between attention and mental effort. When mental effort is necessary to solve a task or is required for a psychological process, one observes attention being used in the task. Both basic processes (e.g., stimulus orienting, sustained attention) and more complex processes (viz., executive attention) will be engaged in proportion to how effortful a task may be. There are dramatic developmental changes in several cognitive functions that employ mental effort. For example, the amount of working memory increases throughout childhood as does speed of information processing, which lead to a decrease in the effort and time to complete a mental task. Along with the decrease in mental effort during childhood, there is a decrease in the amount and duration of attention to the task. Similarly, with increased working memory and increased skills, some tasks may be engaged in for increased periods of time as the child grows older. This would be accompanied by an increase in the amount and duration of attention devoted to the task. These apparent increases or decreases in attention are not developmental changes in attention itself. Rather, they reflect the close association of attention with other behaviors and changes intrinsic to other behavioral or cognitive processes.

ADHD and childhood attention

One type of attention difficulty seen in young children, particularly as they enter school, is Attention Deficit Hyperactivity Disorder (ADHD). ADHD affects from 5 to 10 percent of school-aged children. It is characterized by inattentiveness, hyperactivity, poor impulse control, and behavior management problems. These children often come to the attention of health-care professionals when entering school because they do poorly in situations demanding sustained behavior control. ADHD is usually separated into three sub-types: ADHD-

Inattentive (ADHD-I), ADHD-Hyperactive (ADHD-H), and ADHD-Combined (ADHD-C). The children who are diagnosed as ADHD-I have problems in attention control, sustained attention, and show a great deal of inattentiveness. The children diagnosed as ADHD-H show poor impulse control and exhibit high levels of activity. The ADHD-C children show signs of both inattentiveness and hyperactivity. The treatment for ADHD is generally pharmacological (e.g., the methylphenidate Ritalin).

The types of ADHD may be related to the distinction between sustained attention and executive attention. A popular hypothesis about the cause of ADHD-H subtype is a poorly functioning executive function system. Supporting this, ADHD-H children have been shown to do poorly on tasks requiring plans, the inhibition of reflexive or automatic behavior, and impulse control. Several studies link deficits in the prefrontal cortex to ADHD-H children. Alternatively, children with the diagnosis of ADHD-I perform nearly as normal children on executive function tasks. However, they show deficits on tasks requiring sustained attention, such as in the continuous performance task, covert shifting of attention, and selective attention (Aman, Roberts, & Pennington, 1998). The ADHD sub-types may be due to differences in the brain regions controlling sustained attention and executive attention.

Individual differences in sustained attention in the early part of infancy may be related to ADHD-I outcomes, particularly in infants showing extremely low amounts of sustained attention. Deficits in parts of the brain that allow the sustaining of attention over extended time periods may be damaged or impaired leading to consistently poor performance for these infants and children. Alternatively, ADHD-H is not predicted by individual differences in attention observed prior to 2 or 3 years of age. This is likely due to the fact that the areas of the frontal cortex controlling executive attention are not yet sufficiently developed. Individual differences in impulse control depend on prefrontal brain development.

Conclusions

Attention is the selective enhancement of some behavior at the expense of other behavior. Developmental changes occur in infants in stimulus orienting and sustained attention. Stimulus orienting involves the general orientation of sensory systems and receptors to important environmental events, and sustained attention involves the enhanced and selective processing of information for specific psychological behaviors. Thus, by the end of infancy these two basic functions of attention are fully developed. Development of attention in early and

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middle childhood involves the development of executive attention, which is the ability to carry out tasks with planfulness, allocate attention to self-established goals and plans, and monitor one's progress in complex tasks. Changes in sustained attention and executive attention are closely linked to brain development. One of the most recognized childhood disorders, ADHD, is closely related to problems in the executive attention system, and may be caused by a deficit in the brain areas involved in the development of executive function and executive attention.

Questions

1. The development of sustained attention is hypothesized to be closely related to changes in brain systems mediating arousal (e.g., noradrenergic and cholinergic neurotransmitter systems). Are there direct measures of these neurotransmitter systems, such as MRI or fMRI, that could be tested in human infants and young children? Would these changes show the same developmental time course as sustained attention?
2. Executive attention and executive function are controlled by the prefrontal cortex. Children with Attention Deficit Hyperactivity Disorder (ADHD) have been hypothesized to have a disorder in the prefrontal cortex and thus show deficits in tasks of executive functioning. Would it be possible to get direct measures of the deficits in the prefrontal cortex in individuals with ADHD? Since pharmacological treatment (e.g., Ritalin) is an effective treatment for the behavioral disorders seen in ADHD, could it be shown that such drug treatment improves brain functioning in those children who show improvement in the behavior deficits?
3. There is a paradoxical relationship between improvement in sustained attention and look duration (i.e., with increases in the development of sustained attention, information processing becomes more efficient and look duration decreases). Can stimuli be found for which an increase in sustained attention leads to an increase in look duration? What aspects might characterize such stimuli?

See also:

Magnetic resonance imaging; Experimental methods; The status of the human newborn; Cognitive development in infancy; Perceptual development; Development of learning and memory; Brain and behavioral development (II): cortical; Executive functions; Intelligence; Sleep and wakefulness; Behavior and learning disorders; Cognitive neuroscience

Further reading

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