# Measuring Alertness

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**A generation of research in cognitive psychology has given rise to many tasks that tap at various aspects of attention. It is now widely agreed that attention is not a single thing and that its measurement needs a strategy to study each of its various aspects. While there is no widely agreed taxonomy of attentional operations, there is an important distinction between functions of obtaining and maintaining the alert state (alerting network), orienting to sensory events (orienting network), and regulating thoughts and behaviors (executive network). Neuroimaging has confirmed that these functions involve separate but overlapping areas of brain activity. Neurochemical and genetic studies have also provided some distinctions between brain networks involved in attention. Alertness as a function of one important attentional network is emphasized and methods to activate phasic and tonic alerting are reviewed and individual or group differences in the efficiency of network operations are discussed.**

*Key words:* **attention network; alertness; orienting; executive attention; anterior cingulate gyrus**

## Background

Functional neuroimaging has allowed many cognitive tasks to be analyzed in terms of the brain areas they activate.[1,2] Studies of attention have been among the most often examined in this way. Although there is no generally agreed taxonomy of attentional operations, data from different domains[2] have supported the presence of three brain networks that contribute to the cognitive concept of attention. These networks carry out such functions as alerting, orienting, and executive control.[3,4] Alerting is defined as achieving and maintaining a state of high sensitivity to incoming stimuli; orienting is the selection of information from sensory input; and executive control is defined as involving the mechanisms for resolving conflict among thoughts, feelings, and responses. The three brain networks (see Table 1) have been shown to differ in their functional anatomy,[1] the circuitry of their component operations,[5,6] and the neurochemical modulators that influence their efficiency.[7] In this chapter we will emphasize the alerting system, but consider as well its relation to the ability to acquire sensory information and the influence of the executive network upon it.

## Alerting

The concept of arousal goes back to the classic work of Moruzzi and Magoun[8] on the role of the brain-stem reticular system in maintaining alertness. As more became known of the neuromodulatory systems of the brain stem and thalamus, it was necessary to qualify the general concept of arousal into more differentiated components. Within cognitive psychology a major emphasis is on producing and maintaining optimal vigilance and performance during tasks. It is this sense of alertness that is discussed in this chapter.

### *Warning Signals*

One approach to the study of alerting is to use a warning signal prior to a target event. If a speeded response to the target is required, reaction time improves following a warning. The improvement in reaction time is accompanied by vast changes in the physiological state of the organism.

The changes during the time between warning and target reflect a suppression of ongoing activity thought to prepare the system for a rapid response. In the central nervous system there is a negative shift in the scalp-recorded EEG, called the contingent negative variation (CNV),[9] that often begins with the warning signal and may remain present until the target presentation. This negative change, which appears to arise in the anterior cingulate and adjacent structures,[10] may overlap the event-related response to the warning stimulus. If the target interval is predictable, the person may not show the CNV until just prior to when the target occurs. The CNV persists as a negative standing wave, in the case of a visual signal, in the parietal lobe of the hemisphere opposite the location of the target. Because of the hemispheric specificity of the standing wave, it is obvious that this EEG signal can also reflect knowledge

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**TABLE 1. The three networks that are sources of attentional influence**

| Function | Structures | Modulator |
|---|---|---|
| Orient | Superior parietal<br>Temporal parietal junction<br>Frontal eye fields<br>Superior colliculus | Acetylcholine |
| Alert | Locus coruleus<br>Right frontal<br>Parietal cortex | Norepinephrine |
| Executive attention | Anterior cingulate<br>Lateral ventral<br>Prefrontal<br>Basal ganglia | Dopamine |

of where the target will occur, and in this sense overlaps with orienting to the target location.[11] The origin of the CNV in the anterior cingulate also suggests its overlap with the executive network. Indeed, it has been reported that the baseline activity in the cingulate is suppressed or reduced during the warning interval.[12]

A warning signal is accompanied by activity in the locus coeruleus that is the source of the neuromodulator norepinepherine (NE).[13] Warning-signal effects can be blocked by drugs that, like guanfacine and clonodine, have the effect of reducing NE release.[7] Drugs that increase NE release can also enhance the warning-signal effect. The NE pathway includes major nodes in the frontal lobes and in the visual system in parietal areas that are in dorsal (where) part of the visual pathways. To examine the specificity of these effects to the warning signal Marrocco[7] and his associates have used a cued detection task to separate information about where a target will occur (orienting) from when it will occur (alerting). To accomplish this they present one of four cue conditions prior to a target for a rapid response. By subtracting reaction times in a double-cue condition where the participant is informed when a target will occur, but not where, from reaction times in the no-cue condition, they get a specific measure of the warning influence of the cue. When reaction times for a spatial-cue condition indicating where a target will occur are subtracted from reaction times in the double-cue condition the resulting difference indicates the advantage from orienting correctly to the target location. Drug studies with humans and monkeys show that NE release influences the alerting subtraction, but not orienting, while drugs influencing the neuromodulator acetylcholine (Ach) have their effect on the orienting subtraction, but not alerting. Studies show that individual differences in alerting and orienting are uncorrelated[14] and that orienting improves to the same degree with a cue regardless of the level of alertness, which suggests a great deal of independence between these two functions.[15] However, the independence is by no means complete, and they most often work together when, as in most real-world situations, a single event provides information both on the when and where of a target.

There is little or no NE influence directly on the primary visual system or the ventral (what) portion of the visual pathways.[16] In agreement with this physiology, the effect of the warning signals is not to speed encoding of the following target, but rather to increase the speed of attention or response to the input signal.[17]

### *Tonic and Phasic Alertness Functions*

To study individual differences in these networks we have developed both an adult[14] and a child version[18] of the attention network test (ANT). This task examines the efficiency of the three brain networks we have discussed above.[14] The ANT procedure and the reaction-time (RT) subtractions used to measure the efficiency of each network are shown in FIGURE 1 for both adult and child versions. Subtracting RTs obtained in the double-cue condition from the RT in the no-cue condition gives a measure of alerting due to a warning signal. Subtracting RTs to targets at the cued location (spatial cue) from trials using a central cue gives a measure of orienting. Subtracting congruent from incongruent target trials provides a measure of conflict. The data provide three numbers that represent the skill of each individual in the alerting, orienting, and executive networks.

The ANT has some useful properties as a measure of attentional efficiency. It does not use language stimuli, so it can be used with children, speakers of any language and patients unable to read, or special populations. In about 20 minutes, the test provides a measure of the efficiency of the alerting, orienting, and conflict networks with reasonable reliability, in addition to overall RT and error rates. Measuring the three network scores in the same test also allows assessment of possible patterns of interactions between them. We do not exclude the possibility that certain psychopathologies or brain-injured patients would have a dysfunction in the way the attentional networks interact.

In a sample of 40 normal adults, we found the network scores to be reliable over two successive presentations. In addition, we found no correlation among the three network scores. An analysis of the reaction times found in this task shows large main effects for cueing and for the type of target, but only two small but significant interactions.[14] They both involve very

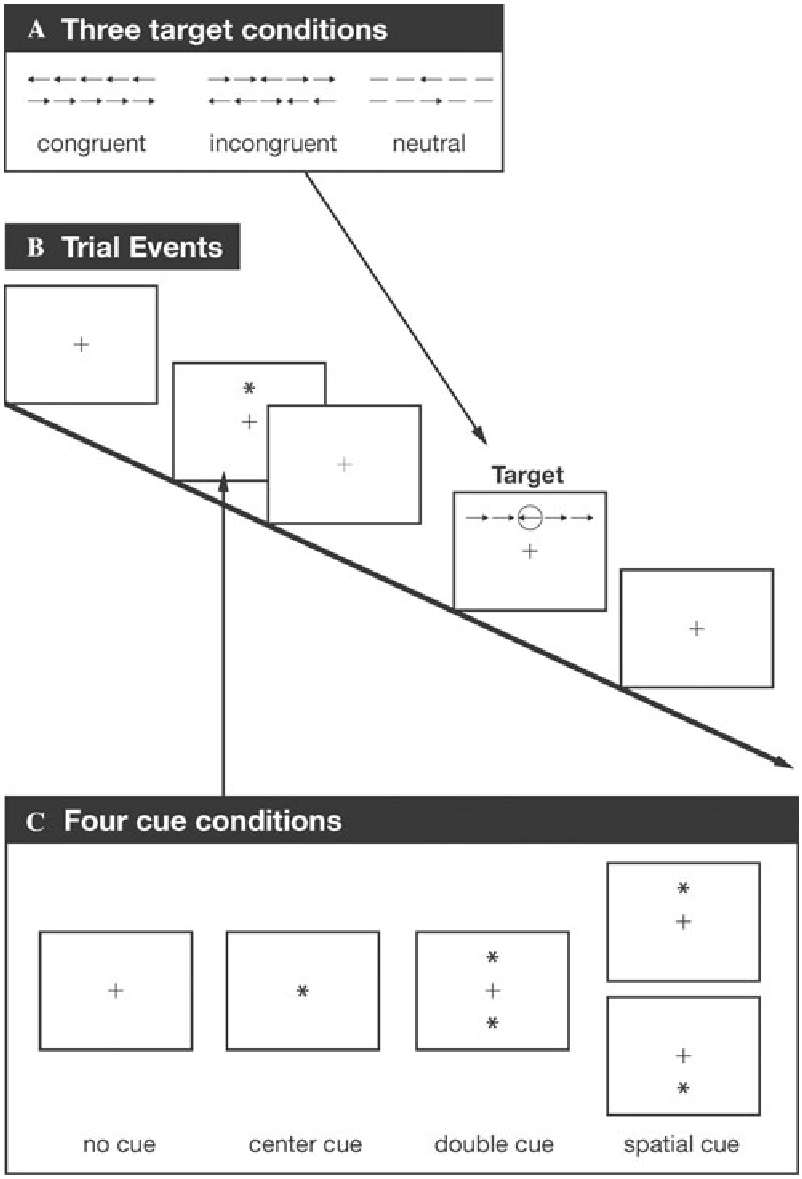


**FIGURE 1.** Representation of the sequence of events in each trial of the attention network test (ANT) task. The Attention Network Scores are obtained using the following subtractions: ALERTING = RT no cue—RT double cue; ORIENTING = RT central cue—RT spatial cue; CONFLICT = RT incongruent—RT congruent.

small reductions in conflict when either no warning cue is provided or when the cue is at the location of the target. The latter interaction is to be expected, because the effective eccentricity of flankers is increased when attention is specifically on the central arrow. The first finding appears to arise because, with no warning, the subject is generally slow and some conflict resolution may occur during the longer overall RT. This effect also appears to be responsible for a small but significant negative correlation between alerting and conflict when we examine a larger sample of more than 200 people who have taken the ANT.[19]

Although we use subtraction of RTs in the ANT as a measure of the efficiency of the networks, interpretation of the efficiency of the various networks between groups needs to be made with the full range of RT and accuracy data in mind. In general, larger differences between incongruent and congruent RTs mean more difficulty in resolving conflict. This is straight forward if error differences are in the same direction, but interpretation is complex if one group shows larger RT differences while the other group shows larger error differences. In this case, different conflict scores could reflect different strategies of approaching the task instead of differences in the ability to resolve conflict. A more conservative individual (or group) who opts for being accurate will mainly produce slow responses in an incongruent situation, in which the probability of committing an error is higher. This approach results in an increased conflict RT score.

Larger alerting numbers generally arise when one group has difficulty in maintaining alertness without a cue. This is clearly the case in right-parietal strokes (see pathology section), and children also show more difficulty when no cue warns them of a trial. When no cue occurs, the person must rely on their own internal alertness, and thus this RT may reflect the more tonic aspects of alertness. In some cases, larger alerting effects might arise because one group uses a cue more efficiently, perhaps by increased effort. In that case, larger RT differences between no cue and double cue may not indicate less efficient performance. Taking RT and errors rates for each condition into account helps us to interpret the scores and examine possible differences in strategies between groups.

A number of other situations have been frequently used to study tonic alertness. These include changes over the course of the day (circadian rhythm). Reaction times are usually longer in the early morning and decline over the course of the day, only to rise again during the night, and peaking in the early morning.[17] These measures reflect other diurnal changes such as body temperament and cortisol secretion. A long established approach to tonic alertness is to use a long and usually rather boring task to measure sustained vigilance. Some of these tasks have grown out of the job of radar operators looking for near-threshold changes over long periods of time. Vigilance tasks have been shown to rely heavily on mechanisms of the right cerebral cortex.[3] Both lesion and imaging data confirm that tonic alertness is heavily lateralized to the right. This seems also to be true of the no-cue condition of the ANT. Some have argued that this relates to lateralization of the NE system in humans.

An extensive imaging study of tonic and phasic aspects of alerting[20] shows that a largely common right hemisphere and thalamic set of areas are involved in both. Another imaging study suggested that the warning signal effects rely more strongly on left cerebral hemisphere mechanisms.[1,21] This could represent the common finding on hemispheric differences in which right lateralized processes often involve slower effects (tonic), while left hemisphere mechanisms are more likely to be involved with higher temporal (phasic) or spatial frequencies. Another possibility is that the left hemisphere effects might be more related to orienting of attention. The exact reasons for differences in laterality found with tonic and phasic studies are still unknown, but they are important in interpretation of data such as in the ANT.

### *Genetics*

The association of neuromodulators with different attentional networks has given rise to an effort to relate various receptors and transporters to individual differences in network efficiency. The most active area has used the association between dopamine and the executive network as measured by the time to resolve conflict in tasks like the Stroop and the ANT (see Ref. 22 for a review). A somewhat similar strategy has been used to relate several cholinergic genes to aspects of orienting.[23]

The association of NE with alerting could lead to a similar strategy; however, no studies have directly pursued this strategy. A number of alleles of dopamine genes have been related to attention deficit hyperactivity disorder (ADHD). However, one genetic variation that seems to involve alerting (see pathology section) is the Alpha 2 A receptor gene ADRA2A, which has been associated in some populations with ADHD,[24–26] as well as with some learning disabilities,[25] both of which might reflect alertness problems.

## Development

In previous work we found that children work best when there is a story, so in the child version of the ANT five colorful fish replaced the arrows that typically appear in the flanker task.[18] We invited the children to help us make the middle fish happy by pressing a button corresponding to the direction in which it is swimming. Visual feedback (the middle fish smiles and some bubbles come out of its mouth) and auditory feedback (a "woohoo!" sound) is provided when the response has been successful. In each trial, the flanker fish are swimming in the same (congruent) or opposite (incongruent) direction as the center fish. As in the adult version, different types of cues are presented before the fish so the efficiency of the three attentional networks can be assayed using the same subtractions explained before.

Using the child ANT, we have assayed the developmental course of the attentional networks.[18] As in the adult data, the child study also revealed independence

**TABLE 2. Attentional networks scores and overall performance data in function of age as measured by the child attention network test**

| | | | Attentional networks subtractions | | | |
|---|---|---|---|---|---|---|
| Age | Overall RT | Overall accuracy | Alerting | Orienting | Conflict | Conflict accuracy |
| 6 | 931 | 15.8 | 79 | 58 | 115 | 15.6 |
| 7 | 833 | 5.7 | 100 | 62 | 63 | 0.7 |
| 8 | 806 | 4.9 | 73 | 63 | 71 | −0.3 |
| 9 | 734 | 2.7 | 79 | 42 | 67 | 1.6 |
| 10 | 640 | 2.2 | 41 | 46 | 69 | 2.1 |
| Adults | 483 | 1.2 | 30 | 32 | 61 | 1.6 |

between the three networks scores. TABLE 2 shows the networks scores of five groups of children between 6 and 10 years of age and a group of adults as measured by the child ANT. Overall performance measures (RT and accuracy) are fundamental to interpreting the network scores, especially when comparing populations with differences in overall reaction time and accuracy.

Developmental studies such as the one summarized in TABLE 2 involve large differences in overall RT and accuracy. Despite this common decline in RT, each network shows a different developmental course. There is a significant improvement in conflict resolution when 7 year olds are compared to younger children, but a remarkable stability in both RT and accuracy conflict scores from age 7 to adulthood. The orienting score was similar to adult levels at the youngest age studied. The alerting scores show some improvement in late childhood and continued development between 10 year olds and adults. There is also some evidence that older adults lose the ability to maintain the alert state, and thus their alerting is closer to that of children.[27]

The long developmental process involved in the alerting score reflects the difficulty children have in maintaining the alert state. This factor both inflates their scores in the no-cue condition and also leads to a sharp upswing in RT as the number of trials required increases. We do not know if these two features of the child data are correlated on an individual basis, as they should be if they are both due to the same underlying tonic alertness function.

Hebb pointed out many years ago that the physiology of alerting rested on the midbrain and thalamic systems, while the precise encoding of a stimulus involved cortical sensory systems (e.g., ventral visual pathway). Adult studies separating warning signals from information provided by a stimulus to carry out a task provide strong support for this view (Kanske and Rueda, unpublished studies University of Oregon). The targets were two fish stimuli that could be introduced separately or together. The participants responded based on either a simple or complex task relating the two target events. A visual warning signal could be presented prior to presenting the targets simultaneously (pure warning); the warning could be presented first, followed by one fish at a time (pure encoding of the first fish), or the first fish could serve as both a warning and provide specific information to encode. The results show that the improvement in RT from pure encoding and pure warning can be added together to get the amount of improvement when a single stimulus produced both functions. This supports the idea that alerting and encoding are separate and largely independent functions.

## Pathology

Although the ANT itself is relatively new, there are already substantial results using this and related tasks to study ADHD. In early work using a spatial orienting task, which is similar to the orienting portion of the ANT, the most compelling deficit of ADHD children appeared to be difficulty in maintaining the alert state in the absence of a warning signal.[28] Building upon this finding, a recent theoretical approach to ADHD[29] has suggested the importance of early problems in the development of the norepinepherine pathways important for tonic and phasic alerting. According to this view, later development of frontal areas allows more voluntary control over alerting and can improve symptoms of ADHD.

Imaging data using the ANT[30] has shown that children with ADHD compared to controls show a behavioral deficit in the executive network, but neural differences in all of the three attentional networks. In another recent study[31] using the ANT with a large number of ADHD children and appropriate controls, behavioral deficits were found in both the alerting and executive networks. Thus, it appears that ADHD may involve both an alerting and an executive attention deficit.[31] More attention needs to be given to common nodes between the alerting and executive networks.

### *Stroke*

Parietal lesions often show neglect of the side of the space opposite the lesion. Patients with right and left parietal lesions have been studied extensively by use of a cued detection task similar to the orienting part of the ANT,[32] although in the ANT task the target appears above and below fixation and not on the left and right sides. Lesions of the right and left parietal lobe, most often from stroke, produce a deficit in orienting attention to the side of the space opposite the lesion. In addition, right but not left parietal patients have shown a deficit in maintaining the alert state.[32] These findings have fit well with neuroimaging results that have shown a role for the superior parietal lobe in voluntary shifts of attention toward the opposite side of the space and of the temporal parietal junction in shifting between targets.[33]

According to one view, establishing improved alertness is a key to all forms of cognitive rehabilitation following brain injury.[20] There have been a number of efforts to study rehabilitation of patients with neglect based upon training of alertness. One study[34] used central cues to compensate for patients who have had parietal damage, and peripheral cues to aid those with frontal damage. This study has shown that building upon the remaining function provides greater success than attempting to rehabilitate the lost function. Another study[35] attempted to compensate for right-parietal damage by use of subsidiary cues that maintain the alert state in these patients. This study provided some support for the loss of alertness specific to right-parietal patients. A study with seven neglect patients and three weeks of alertness training showed promising behavioral and imaging results immediately after training, but they were not maintained after a delay.[36]

The ability to measure the key functions of attention is central to the use of neuroimaging to examine recovery of brain function and to the development of rehabilitation programs. While no single measure is appropriate for all situations, this chapter has provided some background in the logic of selecting an appropriate behavioral measurement of alertness as one example of isolating an attentional component.

### Competing Interest

The author declares no competing interest.

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