Neuropsychological assessment of attention and executive functioning

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This chapter describes the cognitive neuroscience and neuropsychological assessment of attention and executive functioning. Each cognitive construct is defined within a theoretical framework. Additional information highlights the neuroanatomical and neurochemical underpinnings of specific aspects of attention and executive functioning. Adequate assessment of attention and executive functioning requires at least a basic knowledge of these features in order to choose the neuropsychological test measures best suited for a particular patient or clinical population.

Attention

Attention is one of the oldest issues in cognitive neuropsychology; its role in assessment is equally as historic and remains integral to the successful evaluation of a presenting patient. Attention is the process of selecting for active processing specific aspects of the physical environment (e.g. objects) or ideas stored in memory (Raz, 2004). Originally, attention was thought of as a unitary concept akin to a filter (Broadbent, 1958) or a spotlight (Shalev & Algom, 2000). More recent theories suggest that attention is a system of disparate networks including alerting, orienting and selection (Fan *et al.*, 2002).

Alerting involves particular changes in the internal state of an individual in preparation for perceiving a stimulus otherwise thought of as vigilance. Alerting is critical for optimal performance in tasks involving higher cognitive functions. With the use of neuroimaging technologies, alerting has been associated with the frontal and parietal regions of the right hemisphere. Lesions within these regions will reduce the ability to maintain the alert state. For example, right frontal lesion patients show an impaired ability to voluntarily sustain attention during continuous performance tests, displaying a larger number of errors over time when compared to left frontal lesion patients (Raz, 2004). It has long been established that right parietal lobe lesions, particularly those secondary to stroke, disrupt one's ability to remain alert and orient to stimuli in left hemispace, producing a profound and sometimes permanent neglect (Heilman & Van Den Abell, 1980). Alerting is thought to involve the cortical distribution of the brain's norepinephrine system arising in the locus coeruleus of the midbrain (Coull *et al.*, 2001).

Orienting involves the selection of information from sensory input which can be triggered by the stimulus or shifted as a result of voluntary control. Thus, orienting can be reflexive as when a sudden target event directs attention to its location, or it can be more voluntary as when a person searches the visual field looking for a particular target. Even though orienting typically involves head and/or eye movements toward the target or overt orienting, it can also be covert. Orienting has been associated with areas of the parietal and frontal lobes, particularly the superior parietal lobe and frontal eye fields. Lesions within these regions will negatively impair the ability to determine a point of reference to sensory objects. Basal forebrain cholinergic systems play an important role in orienting (Beane & Marrocco, 2004).

Selection involves choosing among multiple conflicting actions or responses. Selection is critical for optimal performance in tasks involving decision making, error detection, or over-riding a habitual response. Neuroimaging data consistently reveals the anterior cingulate cortex as a central node in this attentional network (Posner & Rothbart, 1998). Additional brain areas involved in selection include the lateral prefrontal cortex and basal ganglia. Focal brain lesions to the anterior cingulate reduce and can often annihilate specific aspects of self-regulation and voluntary control making the inhibition of a pre-potent response difficult if not impossible. Selection is thought to involve the dopaminergic system given that both the anterior cingulate and lateral prefrontal cortex serve as target areas to this neurotransmitter system (Deth *et al.*, 2004).

These largely orthogonal attentional networks interact in many practical contexts to compute different aspects of cognitive and emotional tasks; however, they also retain a certain degree of functional and anatomical independence. Variations in the operational efficiency of these various attentional networks serve as a basis for differences in such complex cognitive neuropsychological processes as self-regulation and emotional control as well as more basic mechanisms of volition and sustained effort. Thus, evaluating each aspect of attention that is, alerting, orienting and selection, is advised if one is to gain a complete picture of the attentional functioning of the presenting patient.

Assessment measures of attention

We now highlight measures of attention that assess aspects of the alerting, orienting or selection networks. Please consult the references associated with each test measure for a more in-depth discussion of administration, scoring and interpretation procedures.

- *Digit Span–Forward* (DSp-F; Wechsler, 1981) DSp-F is a measure of immediate attention and rote recall. It requires participants to listen to increasingly longer lists of digits and recite them in the exact order presented. Scores range from 0–14 and each point reflects successful completion of one trial of a particular list length.

There are visual variants of the traditional digit span task which involve learning increasingly longer lengths of 3-dimensional spatial positions as represented by raised blocks on a stimulus board (Milner, 1971) or 2-dimensional visual locations as represented by coloured circles on a visual display (Wechsler, 1945).

- *Trail Making Test – Part A* (TMT-A; Army, 1944) TMT-A is a test of speeded attention, mental tracking and visual search. Participants are required to connect a series of circles containing numbers randomly arranged in a spatial array. Both time-to-completion in seconds as well as error rate give an indication of an individual's level of attention.
- *Visual Search and Cancellation Tasks* (Diller *et al.*, 1974) Many forms of these measures exist but the underlying instructions remain the same: to 'cancel' or indicate by either crossing out or circling a particular target stimulus embedded in a larger array of distracter items. Traditional cancellations tasks include identifying the letter 'A' within a complex visual array of various letters and finding a variant of a star within a complex visual array of abstract designs. The number of items omitted is an indication of vigilance and the proportion of items omitted in each quadrant of the test page can suggest the presence of a possible neglect.
- *Stroop Colour Word Interference Test* (Stroop, 1935) In the classic Stroop task experienced readers are asked to name the ink colour of a displayed word. Responding to the ink colour of an incompatible colour word (e.g. the word 'RED' displayed in blue ink), subjects are usually slower and less accurate than identifying the ink colour of a control item (e.g. "XXX" or "LOT" inked in red). This difference in performance is called the Stroop Interference Effect (SIE).
- *Global Local Test* (Robertson *et al.*, 1988) Assesses attentional preference and the ability to reorient attention (i.e. from the global, or overall gestalt of a figure, to the local, or more detailed level of analysis). Thus, individuals are presented with a large number or letter (e.g. a 2) made up of smaller numbers or letters (e.g. strategically positioned 1's) at a rapid rate of visual presentation and asked to indicate what number or letter they perceive. Alternatively, individuals may be asked to indicate what object (e.g. number), is represented at either the global or the local level. Reaction time data indicates which level of analysis, global or local, is more taxing with slower reaction times suggesting greater difficulty. Error rates can also be informative.
- *Flanker Tasks* (Eriksen & Eriksen, 1974) Subjects respond to the direction of a central arrow when flanking arrows could either point in the same, that is congruent, or opposite, that is incongruent, direction.
- *Attention Network Test* (ANT; Fan *et al.*, 2002) The ANT, a variation of the Flanker task, requires subjects to determine whether a central arrow points rightward or leftward while the surrounding arrows may be either congruent or incongruent. Targets are arrows above or below fixation, pointing to the left or right and they are flanked on both sides by congruent or incongruent arrows. Targets are preceded by informative or uninformative spatial cues. The ANT provides three numbers that indicate the efficiency of the networks that perform the alert, orient and conflict resolution functions of attention and can be performed by adults, children, patients and even non-human animals.
- *Lateralized Attention Network Test* (LANT; Barnea *et al.*, in press) A variation of the ANT, the LANT was developed to measure the sensitivity and reliability of the three networks of attention in each hemisphere and demonstrate their validity in relation to standardized clinical measures of attention. The promise of the LANT centres on its potential to critically assess training protocols for modulating the relative attentional engagement of the two hemispheres. Furthermore, the LANT can be used, together with EEG, on self-regulation protocols to rehabilitate normal human attention.

Executive functioning

The role of executive functioning has long been to coordinate other neurocognitive systems through activities such as working memory, planning and monitoring (Stuss & Alexander, 2000). A number of authors have presented conceptual definitions of different aspects of executive functioning including models of working memory (Baddeley, 1992) and the organization of complex behaviours (Luria, 1980). Based on a review of such definitions, executive functioning appears to encompass a network of cognitive operation involving mental coordination of behaviour including planning, monitoring and mental tracking; self-regulation of behaviour including mental flexibility and the capacity to shift mental set; and complex purposive action involving self-initiated and goal-directed behaviour (Lamar *et al.*, 2002). In breaking down executive functioning into a network of cognitive operations, one is better able to determine the neuroanatomical underpinnings of this complex construct and to conduct a more complete neuropsychological evaluation.

There is a long history of non-human lesion studies as well as an increasing amount of in vivo human neuroimaging studies describing the neural substrates involved in various aspects of executive functioning (see Fuster, 1997 for review). The dorsolateral prefrontal cortex, Brodman's area (BA) 46 (Figure 1), is associated with the successful mental coordination and manipulation of information. The dopaminergic system is most affiliated with this aspect of executive functioning although other neurotransmitter systems may modulate performance on select measures of working memory and mental manipulation (Ellis & Nathan, 2001). The orbitofrontal cortex is associated with the acquisition of appropriate behaviours and the inhibition of inappropriate ones with medial orbitofrontal cortex (BA 25) associated with error detection and positive reward and lateral orbitofrontal cortex (BA 11) responsible for the inhibition of a prepotent response (see Elliott *et al.*, 2000 for review). Investigations repeatedly suggest that decreases in serotonin negatively impact various measures of orbitofrontal functioning, particularly decision making (Rogers *et al.*, 2003).

Neuroimaging studies corroborate the notion that there are separable components of executive functioning which may not reside within prefrontal cortex but are nonetheless integral to and supervised by this region. For example, specific areas within the

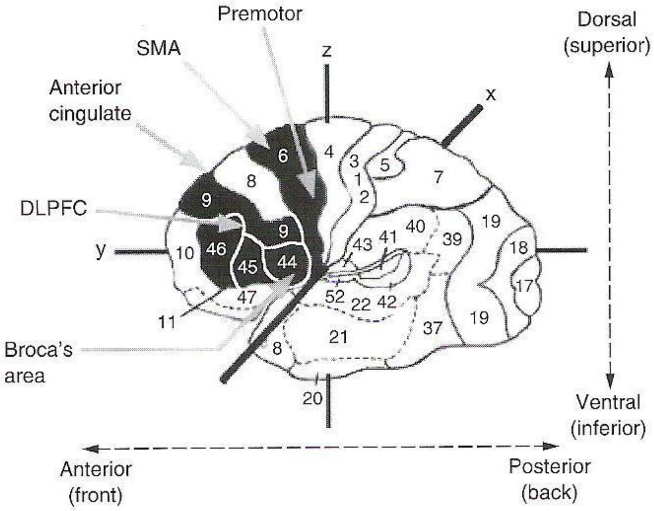

Fig 1 Brain with Brodman's areas and prefrontal highlights.

parietal lobe (BA 40; BA 7) have been associated with storage and mental coordination whose purpose is to maintain information online; while Broca's area (BA 44) appears responsible for the rehearsal of information that resides in short-term memory (see Smith & Jonides, 1998 for review). Thus, a thorough assessment of executive functioning should be a part of any neuropsychological evaluation when assessing individuals with frank frontal lobe lesions as well as individuals without obvious damage to prefrontal cortex.

Due to the complexity of the behaviours in question and the multifaceted nature of most tests of executive functioning, it is difficult to say with certainty what any particular executive function task assesses. The variability present in the literature to describe any single measure of executive functioning (Lezak, 1982) illustrates the trouble in measuring a single aspect of executive ability or developing a consensus regarding the specific abilities tapped by any particular executive function task. Therefore, it is advised to rely on several measures to gain a global picture of executive functioning.

Assessment measures of executive functioning

We now highlight measures of executive functioning that primarily assess some aspects of mental coordination, self-regulation or complex purposive action. Please consult the references affiliated with each measure for a more in-depth discussion of administration, scoring and interpretation.

- *WAIS-R Digit Span Backward* (DSp-B; Wechsler, 1981) DSp-B is a measure of mental tracking as well as brief storage and mental manipulation. It requires participants to listen to increasingly longer lists of digits presented for immediate recall in the reverse order from what was originally presented. In addition to the attentional requirements also evident in DSp-F, DSp-B requires mental manipulation for successful completion. Scores range from 0–14 and each point reflects successful completion of one trial of a particular list length. Visual variants of DSp-B are described within the section 'Assessment measures of attention' with the caveat that these measures require recall in the reverse order from the initial visual presentation.
- *WAIS-R Similarities subtest* (Wechsler, 1981). Similarities is a measure of concept formation and reasoning which relies on continuous monitoring of output. It requires participants to find associations between word pairs of increasing complexity. Points are given based on the nature of the response and calculated using standardized procedures.
- *Trail Making Test Part B* (TMT-B; Army, 1944) The TMT-B is a test of speeded attention, mental tracking and visual search, as well as sequencing and mental flexibility. In addition to the attentional demands evident in TMT-A, TMT-B requires the additional processes of mental flexibility and set shifting as participants alternate between connecting a series of circles containing numbers and letters randomly arranged in a spatial array. Variables indicating an individual's performance include time-to-completion and errors. Some researchers subtract the scores of TMT-B from TMT-A to further isolate executive functioning from attention.
- *Alpha Span* (Asp; Craik, 1990) ASp involves short-term memory and mental tracking. It requires participants to listen to increasingly longer lists of common words presented for immediate recall in alphabetical order. Participants receive two trials of each list length, and the task is terminated after the failure of both trials. ASp scores range from 0–14, and each point reflects successful completion of one trial of a particular list length.
- *Porteus Maze Test* (Porteus, 1959) The Porteus Maze test involves the planning aspect of executive functioning. It requires participants to navigate through increasingly difficult 2-dimensional mazes. A mental age score is calculated according to standard procedures.
- *Rivermead Behavioural Memory Prospective Memory Tasks* (Wilson, Cockburn & Baddeley, 1985) Prospective memory involves planning, monitoring and purposive action. Items require participants to remember to execute different activities in the future (e.g. remembering to: ask about the next appointment when an alarm clock goes off). All tasks are introduced within 15 minutes of the beginning of the test session and interspersed throughout the course of a complete neuropsychological evaluation. Two, one, or zero points are given for each activity depending on the level of cueing needed at the time of recall. Higher scores indicate better performance.
- *Verbal Fluency* (Spreen & Benton, 1969) Although measures of verbal fluency primarily tap language functions, they also assess spontaneous flexibility through the generation of responses within a particular set of constraints and the capacity to shift mental set. Fluency tests require participants to generate as many words as possible in one minute for a given letter (F, A, S) or category (animals, fruits, vegetables), excluding proper nouns and variations of the same word. Separate scores for letter and category fluency reflect total output across all three trials (see also 'Communication assessment').
- *Wisconsin Card Sorting Test* (WCST; Grant & Berg, 1948) The WCST assesses many aspects of executive functioning including mental flexibility and concept formation. Individuals are given individual cards containing one of four forms (triangles, stars, crosses, or circles) in one of four colours (red, yellow, green or blue) presented one of four times per card. They are required

to match each card to one of four target cards based on a series of rules. These rules are not explicitly stated but must be deduced based on examiner feedback. Only when 10 cards have been placed correctly under a specific rule does the rule change. Thus, sorting to colour would require 10 successful matches based on colour before the rules changed to either form or number. A total of 6 rule changes are possible and a variety of scores including the number of categories achieved and perseverative errors may be calculated.

- *The Graphical Sequence Test* (Bilder & Goldberg, 1987); *The Graphical Sequence Test – Dementia Version* (Lamar *et al.*, 1997) These measures, designed to elicit perseverative behaviour across a wide variety of clinical populations, consist of a series of consecutive verbal commands to write or draw simple geometric shapes, e.g. circles and squares, or common figures, e.g. flowers and houses. The total number of errors provides a measure of overall executive dysfunction and various error types represent increasingly lower levels of executive dysfunction.
- *The Self-Ordered Pointing Task* (SOPT; Petrides & Milner, 1982) This task assesses planning and self-monitoring through sequential selection of visual or verbal stimuli. The SOPT consists of a set number of stimuli per page with the number of pages dependent upon the number of stimuli (e.g. 12-items/12 pages). Each page contains all the same stimuli; however, the position of each stimulus on any given page varies so that no stimulus is in the same location twice. For each page, participants are instructed to select a different stimulus from those selected on previous pages in the trial. A trial is complete when all pages in the series have been presented. A total of three trials are administered. The number of items selected more than once is summed across all trial blocks with higher scores indicative of greater executive dysfunction.
- *Intra/Extra-Dimensional Shift Task* (CANTAB, Cambridge, UK). This task assesses participants' ability to attend to specific attributes of compound stimuli and to shift mental set based on feedback. Dimensions for visually presented stimuli consist of colour-filled shapes and white lines. Participants are required to choose the correct stimulus from a set of stimuli. Initial responses are to simple or unidimensional stimuli but as the task progresses, stimuli become more complex, consisting of both colour and line dimensions. Correct responses are based on criterion learned as the task progresses and become increasingly difficult to determine; that is, moving from simple, intra-dimensional shifts (e.g. colour rules only) to more difficult, extra-dimensional shifts, i.e. colour and line rule combinations). A variety of shift scores may be determined based on the total correct at each stage of difficulty.

Assessment batteries of executive functioning

- *Delis-Kaplan Executive Function System* (D-KEFS; Delis *et al.*, 2001) This battery consists of nine sub-tests that tap such areas of executive functioning as mental flexibility, planning, concept formation, the ability to attain and maintain mental set and self-regulation. Thus, the D-KEFS evaluates the majority of executive function aspects outlined throughout this chapter. Comprehensive normative data assists in the evaluation of all age ranges and the qualitative scoring system allows for an error analysis that may help explain subtle nuances of behaviour not addressed by more traditional measures of executive functioning.
- *The Executive Control Battery* (ECB; Goldberg *et al.*, 2000) The ECB takes an error production approach to assessing executive functioning through a series of subtests designed to elicit perseverations, inertia, stereotyped behaviour and mimicry. In addition to the Graphical Sequences Test, a version of the Go/No-Go task assesses self-regulation by either rewarding the selection of a prepotent response or the inhibition of it, respectively. Two remaining sub-tests require the repetition or mirroring of various motor programmes and sequences to evaluate more basic aspects of executive control involving the premotor cortex.

Conclusion

We have attempted to highlight the various component parts or networks that constitute attention and executive functioning. Furthermore, we have outlined the neuroanatomy and neurochemistry involved in each of these cognitive constructs and the neuropsychological test measures that may be used to investigate performance. In order to pick the most appropriate measures of attention and executive functioning for a particular evaluation, one should always consider the referral question, the presenting symptomatology and/or diagnosis of the client. Given this information, one can then attempt to predict the expected functional and/or structural areas of involvement. These predictions will make choosing the appropriate neuropsychological test measures easier. However, if little or no information exists, it is advised to select a few neuropsychological test measures that assess various aspects of attention and executive functioning to adequately cover these cognitive abilities (see also 'Neuropsychological assessment: general principles').

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Neuropsychological assessment of learning and memory

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With over 100 different theorized types of memory in existence (Tulving, 2002) it is no wonder that the assessment of learning and memory can be quite complex. However, despite our current knowledge, memory is often conceptualized as a unitary concept, especially by non-psychologist health professionals. Memory is actually a multidimensional construct with dissociable sub-systems,