Cambridge Brain Sciences Tests Overview

CAMBRIDGE BRAIN SCIENCES

A. An introduction to Cambridge Brain Sciences

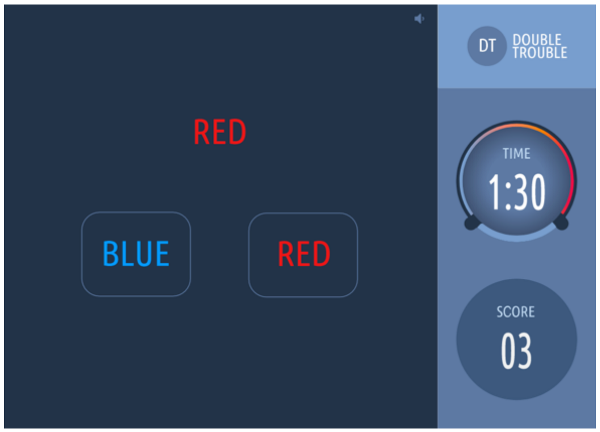
The Cambridge Brain Sciences (CBS) tests were developed in the laboratory of Dr. Adrian Owen, Canada Excellence Research Chair in Cognitive Neuroscience and Imaging (owenlab.org), over the course of his 25-year career. The tests assess aspects of cognition including reasoning, memory, attention and verbal ability. Over 300 scientific studies have been run to date using the CBS tests, yielding numerous publications in leading academic journals.

The tests have been validated in studies of patients, brain imaging studies of healthy volunteers and in several large-scale public studies involving tens of thousands of volunteers. They have proven to be efficient and sensitive measures of baseline cognitive capacity. For example, in one study, the results of the 30-minute Cambridge Brain Sciences battery were comparable to those of a standard 2-3 hour (paper and pencil) neuropsychological battery (WAIS-R) (Levine et al., 2013). In another recent study of mental capacity in the elderly, the CBS test battery outperformed a standard test of cognitive abilities (the MoCA) (Brenkel et al., 2017). Finally, performance on the CBS battery is highly predictive of reasoning and problem solving abilities, as indexed by “classic” tests such as Raven’s Matrices and the Cattell Culture Fair test (Hampshire et al., 2012).

CBS maintains a global normative database of more than 75,000 participants (built off of a larger database of 7 million+ completed tests) that allows for detailed comparisons of individuals to specific populations. Importantly, all of the tests, which users report to be fun and engaging, are administered online and require no expert technical support to administer. Test results are stored securely in the cloud and can be easily downloaded for offline analyses.

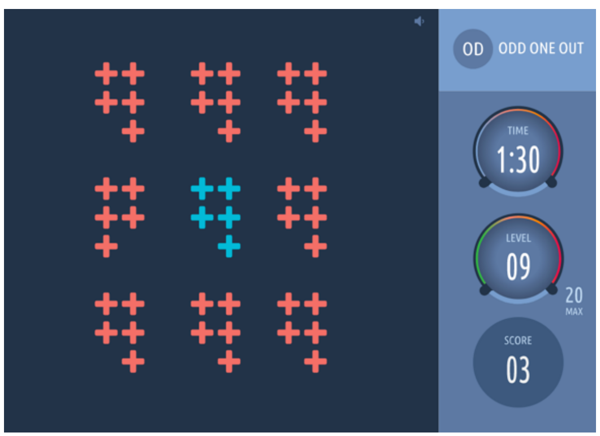
B. Description of the Cambridge Brain Sciences tests

The Cambridge Brain Sciences cognitive tasks are based on classical paradigms from the cognitive psychology literature.



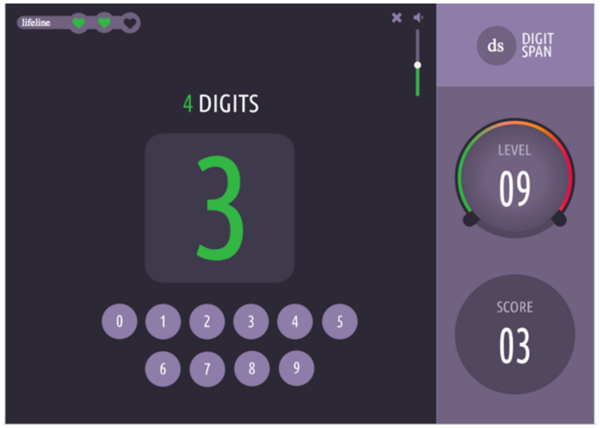
Double Trouble Task

A variant on the Stroop test (Stroop, 1935). Three coloured words are displayed on the screen: one at the top and two at the bottom. Participants must indicate which of two coloured words at the bottom of the screen (ignoring the colour of those words) correctly describes the colour that the word at the top of the screen is written in. The colour word mappings may be congruent, incongruent, or doubly incongruent, depending on whether or not the colour of the top word matches the colour that it is written in. Participants have 90 seconds to solve as many problems as possible. Primary outcome measure is the number of correctly answered problems, minus incorrect ones.



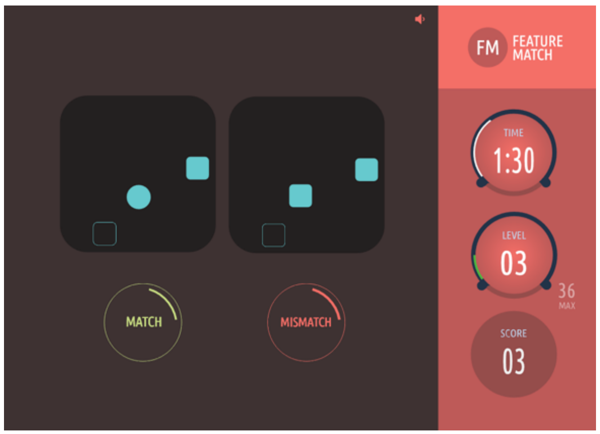
Odd One Out Task

Based on a sub-set of problems from the Cattell Culture Fair Intelligence Test (Cattell, 1949). Nine patterns will appear on the screen. The features that make up the patterns are colour, shape, and number and are related to each other according to a set of rules. Participants must deduce the rules that relate the object features and select the pattern that do not correspond to those rules. Difficulty is increased or decreased depending on whether the participant got the previous trial correct. Participants have 3 minutes to solve as many problems as possible. Primary outcome measure is the number of correctly answered problems, minus the number of incorrectly answered problems.



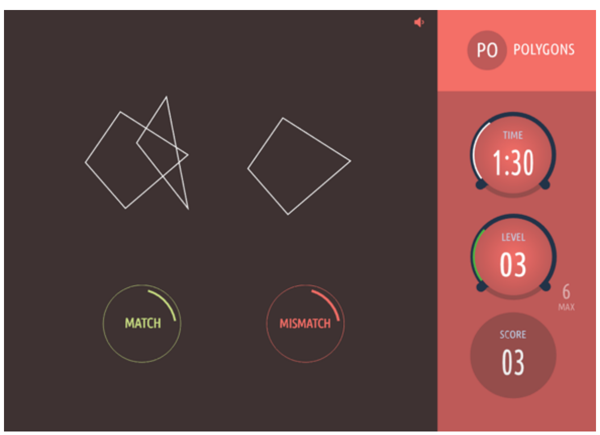
Digit Span Task

A variant on the verbal working memory component of the WAIS-R intelligent test (Weschler, 1981). A sequence of numbers will appear on the screen one after another. Once the sequence is complete, participants must repeat the sequence. Difficulty is increased or decreased by one number depending on whether the participant got the previous trial correct. After three errors, the task ends. Primary outcome measure is the maximum level (i.e. the problem with the highest number of digits) that the player successfully completed.



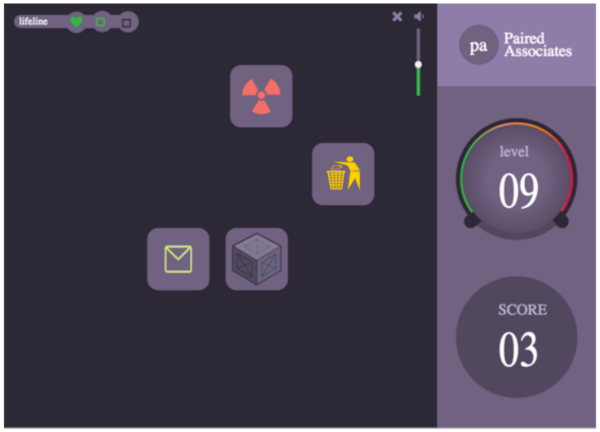
Feature Match Task

Based on the classical feature search tasks that have been used to measure attentional processing (Treisman & Gelade, 1980). Two grids are displayed on the screen, each containing an array of abstract shapes. In half of the trials the grids differ by just one shape. Participants must indicate whether or not the grid's contents are identical. Difficulty is increased or decreased by one shape depending on whether the participant got the previous trial correct. Participants have 90 seconds to solve as many problems as possible. Primary outcome measure is overall score - the sum of the difficulties of all successfully answered problems, minus the sum of the difficulties of all incorrectly answered problems.



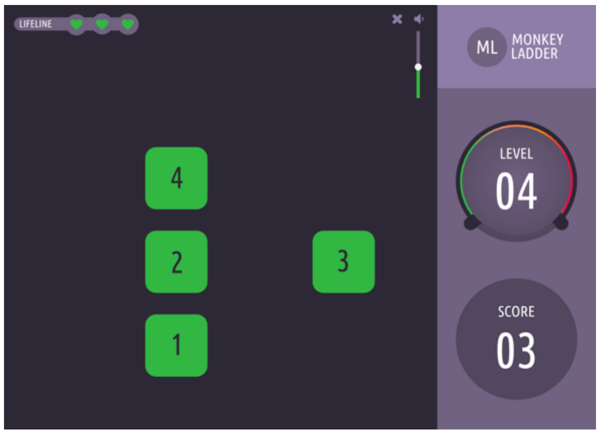
Polygons Task

Based on the Interlocking Pentagons Task, which is often used in the assessment of age-related disorders (Folstein et al., 1975). A pair of overlapping polygons is displayed on one side of the screen. Participants must indicate whether a polygon displayed on the other side of the screen is identical to one of the interlocking polygons. Difficulty is increased by making the differences between the polygons more subtle or decreased by making the differences between the polygons more pronounced. Participants have 90 seconds to solve as many problems as possible. Primary outcome measure is overall score - the sum of the difficulties of all successfully answered problems, minus the sum of the difficulties of all incorrectly answered problems.



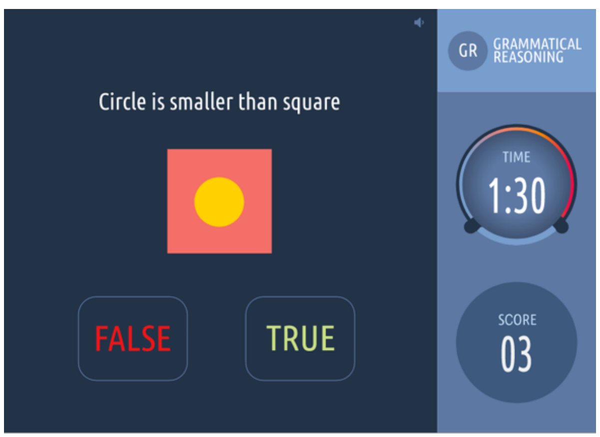
Paired Associates Task

A variant on a paradigm that is commonly used to assess memory impairments in aging clinical populations (Gould et al., 2005). Boxes are displayed at random locations on the screen. The boxes are opened one after another to reveal an enclosed object. Subsequently, the objects are displayed in random order in the centre of the screen and participants must determine which box contains the object that is presented. Difficulty is increased or decreased by one box depending on whether the participant got the previous trial correct. After three errors, the task will end. Outcome measures are (i) maximum level completed (e.g. the problem with the most boxes that the user successfully completed) and (ii) average score: the sum of the number of boxes in all successfully solved problems, divided by the number of successfully completed problems.



Monkey Ladder Task

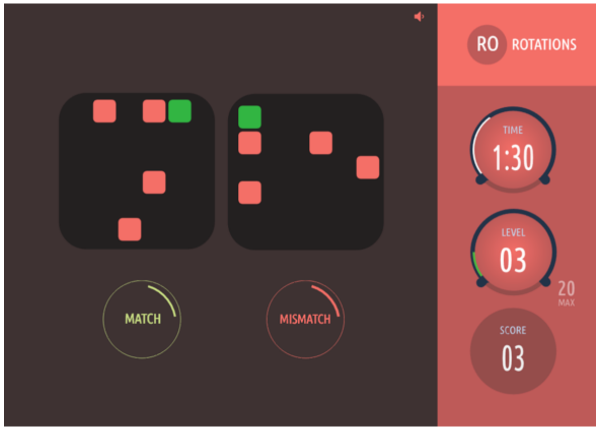
A variant on a task from the non-human primate literature (Inoue & Matsuzawa, 2007). Sets of numbered squares are displayed on the screen at random locations. After a variable interval of time, the numbers disappear leaving just the blank squares and participants must respond by clicking the squares in ascending numerical sequence. Difficulty is increased or decreased by one numbered box depending on whether the participant got the previous trial correct. After three errors, the task ends. Outcome measures are (i) maximum level completed (e.g. the problem with the highest number of boxes that the user successfully completed) and (ii) average score: the sum of the number of boxes in all successfully solved problems, divided by the number of successfully completed problems.



Grammatical Reasoning Task

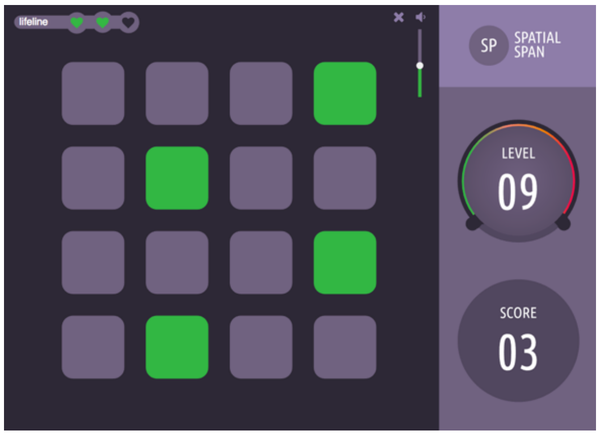
Based on Alan Baddeley's three minute grammatical reasoning test (Baddeley, 1968). Short sentences describing the relationship of two shapes along with an image of the shapes are displayed on the screen. Participants must indicate whether the sentence correctly describes the pair of objects displayed on the screen. Participants have 90 seconds to solve as many problems as possible. Primary outcome measure is the number of problems solved correctly, minus the number of problems answered incorrectly.

Rotations Task



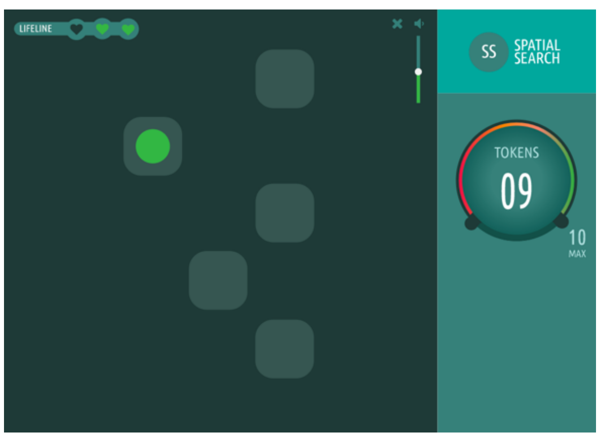
Often used for measuring the ability to manipulate objects spatially in mind (Silverman et al., 2000). Two grids of coloured squared are displayed to either side of the screen with one of the grids rotated by a multiple of 90 degrees. When rotated, the grids are either identical or differ by the position of just one square. Participants must indicate whether or not the grids are identical. Participants have 90 seconds to solve as many problems as possible. Primary outcome measure is overall score - the sum of the difficulties of all successfully answered problems, minus the sum of the difficulties of all incorrectly answered problems.

Spatial Span Task

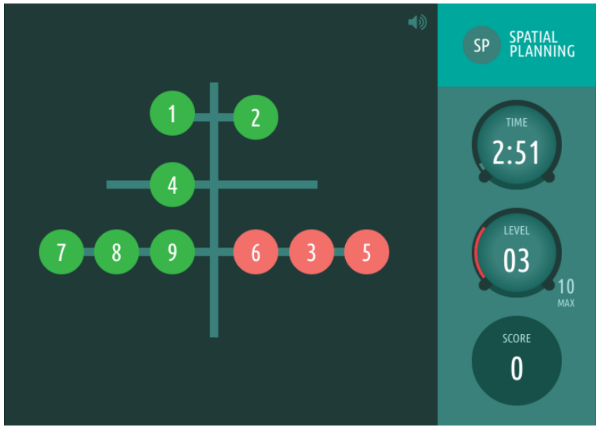


A variant on the Corsi Block Tapping Task (Corsi, 1972), used for measuring spatial short-term memory capacity. 16 squares are displayed in a 4 x 4 grid. A sub-set of the squares will flash in a random sequence at a rate of 1 flash every 900 ms. Subsequently, participants must repeat the sequence by clicking on the squares in the same order in which they flashed. Difficulty is increased or decreased by one box depending on whether the participant got the previous trial correct. After three errors, the task will end. Outcome measures are (i) maximum level completed (e.g. the problem with the highest number of targets that the user successfully completed) and (ii) average score: the sum of the number of targets in all successfully solved problems, divided by the number of successfully completed problems.

Token Search Task



Based on a test that is used to measure strategy during search behaviours (Collins et al., 1998). Boxes are displayed in random locations. Participants must find a hidden “token” by clicking on the boxes one at a time. When the token is found, it is hidden within another box. The token will not appear within the same box twice, thus, participants must search the boxes until the token has been found once in each box. If they search the same empty box twice, or search a box in which the token has previously been found, this is an error and the trial ends. Difficulty is increased or decreased by one box depending on whether the participant got the previous trial correct. After three errors, the task will end. Outcome measure is the maximum level completed (e.g. the problem with the most tokens that the user successfully completed).



Spatial Planning Task

A direct descendant of the “Tower of London” task, Spatial Planning is a classic neuropsychological test of planning (Shallice, 1982). When the test begins, numbered beads are positioned on a tree-shaped frame. Participants must reposition the beads so they are configured in ascending numerical order, in as few moves as possible. Problems become progressively harder, and participants have three minutes to solve as many as possible. The primary outcome measure is the overall score, calculated by subtracting the number of moves made from twice the minimum number of moves required.

C. Origin of the Tests

The tests on the Cambridge Brain Sciences platform have a long history, beginning with Dr. Owen's early studies in patients with focal lesions in the early 1990s, which pioneered the use of computerized cognitive testing in neuropsychology (e.g. Owen et al., 1990; 1991; 1992; 1993a; 1993b; 1995a; 1995b; 1996a; 1997). These studies have been followed by more than 600 publications using these original tests in Parkinson's disease, Alzheimer's disease, Huntington's disease, Depression, Schizophrenia, Autism, Obsessive-Compulsive Disorder and ADHD, among many others over a 25-year period. With the advent of functional neuroimaging, the tests were adapted for the scanning environment and used in numerous positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) studies of both healthy participants and patients (e.g. Owen et al., 1996b; 1996c; 1996d; 1996e; 1997; 1998; 1999). Most recently, they have been adapted to capitalize on the numerous advantages that internet-based testing can offer and have been used in several large-scale population-based studies involving tens of thousands of participants (Owen et al., 2010; Hampshire & Owen, 2012). While some of the tests have changed in appearance over time, these adaptations have been made to take advantage of newly available technologies, or to increase the speed and accuracy with which the core performance indices can be assessed. With every iteration, we have striven to maintain the core essence of the tests—their neuroscientific validity. That is, their relevance to specific regions (or networks of regions), within the brain, and the cognitive processes that are known to be underpinned by those regions. In all, more than one million users have taken the tests.

Rather than going through the history of each test, here are three specific examples representative of how the tests were chosen and developed.

The test called Token Search was first used to demonstrate that patients with frontal-lobe damage are specifically impaired at tasks that require them to organize the contents of working memory (Owen et al., 1990). Indeed, the so-called “strategy measure” from that test, which has been widely used in numerous different patient populations, was devised by Dr. Owen, and published in his PhD thesis in 1992. In 1996, the test was used for the first time to double dissociate the mnemonic and executive sequelae of temporal and frontal- lobe damage in humans (Owen et al., Brain, 1996a). In the same year, in a paper that remains one of the most highly cited articles ever to appear in the journal Cerebral Cortex, the test was used in a PET scanning study to refute the then prevailing view of lateral frontal-lobe organization and is still widely cited in that context (Owen et al., 1996b). In 2010, the Cambridge Brain Sciences Spatial Search test was used to evaluate the effects of six weeks of commercial brain training in 11,400 participants. The results were published in the journal Nature (Owen et al, 2010).

The Cambridge Brain Sciences test called Spatial Span is actually a web-based version of a classic neuropsychological task developed by Corsi and Milner in the early 1970s. Our version was first used in 1992 to chart the progress of cognitive decline in Parkinson’s disease and to dissociate the type of deficits seen in those patients from those seen in patients with early Alzheimer’s disease (Owen et al, 1992). The task was used in numerous functional neuroimaging studies through the 1990s and early 2000s, most notably perhaps in a paper from Dr. Owen’s lab that appeared in the journal Neuron showing that encoding strategies dissociate prefrontal activity from working memory demand (Bor et al., 2003). A companion Digit Span task, also developed for the Cambridge Brain Sciences platform, has been used for studies that have appeared in Cerebral Cortex (Bor & Owen, 2007), The European Journal of Neuroscience (Bor et al., 2004) and Nature (Owen et al., 2010), among others. In 2012, the Cambridge Brain Sciences Spatial Span and Digit Span tasks were used in an online study of 44,600 participants to refute the concept of IQ. The paper appeared in the journal Neuron (Hampshire et al., 2012).

The Cambridge Brain Sciences test called Spatial Planning, is a direct descendant of, and operationally similar to, “The Tower of London Task,” a classic neuropsychological test of planning developed by Tim Shallice in the 1980s. The original test was first computerized in the late 1980s and has been used since in dozens of behavioural and functional neuroimaging studies of healthy participants and patients (e.g. Owen et al., 1990; 1992; 1996c). It has been particularly useful in unpicking the role of COMT val158 met genotype in planning in patients with Parkinson’s disease (Williams-Gray et al., Journal of Neuroscience, 2007). Most recently the task was used in an fMRI study to evaluate the (impaired) cognitive performance of retired NFL players (Hampshire et al., 2013). Historically, a significant problem with versions of the task based on the “Tower of London” format is that with relatively few degrees of freedom participants very quickly become very proficient at the task rendering it less useful for assessing planning per se. For the same reason, the number of unique problems that can be generated is inherently limited. The version of the task that appears on the Cambridge Brain Sciences platform solves these two issues (an almost infinite number of unique problems can be generated on the fly), yet retains the key cognitive planning requirements of all of its predecessors.

D. Validity and Reliability

The tests' validity has been demonstrated through numerous studies using them, published in top journals (see above, and a selection of key studies below). Reliability has also been demonstrated in the large database of test scores.

Table: Test-Retest Reliability and Learning Effects

Task	N	Retest reliability (Pearson's correlation)	Learning effects % improvement
Spatial Span	647	0.62	0.46
Visuospatial Working Memory	804	0.57	1.62
Self Ordered Search	1113	0.66	4.99
Paired Associates	1131	0.45	-0.38
Spatial Planning	1150	0.87	3.75
Spatial Rotation	1122	0.7	5.43
Feature Match	1132	0.57	4.09
Interlocking Polygons	905	0.6	7.91
Deductive Reasoning	1138	0.73	1.55
Digit Span	1022	0.64	1.33
Verbal Reasoning	1148	0.89	2.24
Color-Word Remapping	1151	0.92	4.9
average		*0.69*	*3.16*

The reliability measures were calculated from a population sample collected on the CambridgeBrainSciences.com website. Data were standardized so that for a given task, there was unit deviation and zero mean. Correlations were then calculated between the first and second instances in which participants chose to undertake a task.

Table: An examination of the factor structure of the full test battery

Table 2. Task-Component Loadings from the PCA of Internet Data with Orthogonal Rotation

	1 (STM)	2 (Reasoning)	3 (Verbal)
Spatial span	0.69	0.22	
Visuospatial working memory	0.69	0.21	
Self-ordered search	0.62	0.16	0.16
Paired associates	0.58		0.25
Spatial planning	0.41	0.45	
Spatial rotation	0.14	0.66	
Feature match	0.15	0.57	0.22
Interlocking polygons		0.54	0.3
Deductive reasoning	0.19	0.52	−0.14
Digit span	0.26	−0.2	0.71
Verbal reasoning		0.33	0.66
Color-word remapping	0.22	0.35	0.51

The table on the left is from "Fractionating Human Intelligence" (Hampshire, Highfield, Parkin, & Owen, 2012), which also used imaging to examine brain networks activated by each test.

This study, and other key studies used in the development of the Cambridge Brain Sciences tests, are listed in the following section.

E. Methods references (by author)

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F. Origin of the tests references (by year)

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G. Other recent studies using the Cambridge Brain Sciences test battery

2017

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