Brain Literacy for Educators and Psychologists

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TABLE 5.4 Constructing the Wetware for a Reading Brain

Function[a]	Possible Brain Structure(s)[b]
Arousal unit	Reticular activating system (RAS) and its connections to cortex
Attentional system	Common structures RAS and striatum
Posterior component (sensory information)	Dorsal lateral posterior parietal cortex
Anterior component (motor coding and work with executive system)	Frontal cortex
Conflict management component	Anterior cingulate
	Orbital frontal cortex (inhibition—suppression of irrelevant stimuli)
Aural language system[c]	
Discourse knowledge	Distributed networks in cortex, especially frontal
Syntactic knowledge	Distributed networks in left cortex; left frontal operculum; bilateral planum
Word knowledge codes	
Phonological	Bilateral temporal sulcus; left superior temporal gyrus; middle temporal gyrus; angular gyrus; lateral frontal region; inferior temporal/occipital junction
Semantic	Posterior inferior temporal gyrus; angular gyrus; border between posterior middle and inferior temporal gyrus
Morpho-syntactic	Anterior superior temporal gyrus; left temporal areas; left frontal areas
Oral Language System	
Oral motor planning	Frontal cortex
Name codes[c]	Inferior temporal cortex; BA 37; superior temporal gyrus; left frontal operculum; left and midline cerebellum; left thalamus
Prosody	Right cortex
Visual System	
Sensory input	See Table 3.2 for primary projection pathway
Extraction of visual features (nonlinguistic)	V1 striatal cortex
Letter strings (prelinguistic processing of smaller elements in linear arrays)	Extrastriatal cortex
Ventral *what* pathway (identity of small elements in linear array)	Occipital to temporal cortex
Dorsal *where* pathway (spatial relationships of small elements in linear array)	Occipital to parietal cortex
Executive/Government System	Prefrontal cortex (especially left dorsal prefrontal cortex, LDPFC)
Cross-talk between existing systems in constructing new systems	

(continues)

TABLE 5.4 (*continued*)

Regulation of attentional components	
Selective focus	
Task Maintenance	
Transition among subgoals/goals	
Creation of goals and plans	
Coordination of multiple jobs as plans are executed	
Updating and monitoring	
Conscious reflection: metacognition and metalinguistic awareness	
Control processes for working memory	
Orthographic Word Forms (Codes)[d] (elements in linear visual array that can be recoded into sound units)	Left fusiform gyrus, left lingual gyrus; left middle temporal gyrus; inferior temporal/occipital junction
Sublexical code connections[e]:	Posterior left fusiform gyrus
Letter(s) → Phoneme	
Letters → Rime	
Letters → Syllable	
Lexical code connections[f]	Anterior left fusiform gyrus and/or lingual gyrus
Letters → Expressive Phonological (Name) Code	
Letters → Receptive Phonological Word Form	
Reading Lexicon[d]	BA 37
Multiway interconnections among Orthographic, Phonological, and Semantic/ Morphological codes	
Two-way connections:	
Phonological-Semantic	Left middle temporal gyrus; left fusiform gyrus; right cerebellum
Orthographic-Phonological	
(assembled phonology)	Extrastriatal cortex; left inferior temporal gyrus; supramarginal gyrus; superior temporal gyrus; left inferior frontal areas (premotor part of Broca's Area)
(addressed phonology)	BA 37; left posterior inferior temporal area; left frontal operculum; fusiform gyrus
Cross-Talk between Reading Lexicon and the Visual System[d]:	
Eye movements—fixation pauses	Fovea of retina in eye
Simultaneous (sustained processing; identifying elements)	Parvocellular system
Shifting (transient processing; tracking element position)	Magnocellular system, including V5 visual motion center in occipital cortex
Eye Movement—Saccades	Three cranial nerves; vestibular nuclei; frontal cortex, cerebellum

(continues)

TABLE 5.4 (*continued*)

and the Aural/Oral Language Systems[d]	
and the Cognitive System[d]	
Oral Reading and Silent Reading Systems	Shared components — extrastriate cortex and premotor areas
Unique to oral reading	Superior temporal-inferior parietal route with articulatory regions and auditory regions for monitoring oral output
Unique to silent reading	Inferior temporal pathway with direct access to lexicon for abstract phonological word form not tied to the incoming speech signal
Memory	
Episodic memory for novel words	Prefrontal association areas
Making novel words memorable	Hippocampus[g]
Long-term storage	
Implicit (unconscious) network — automatically activated (primed) orthographic and phonological word forms (codes)	Cortical (especially middle temporal areas)
Explicit (conscious) semantic retrieval	Temporal cortex; left hippocampus
Working Memory	
Phonological STM storage	Left inferior parietal cortex; left supramarginal gyrus
Articulatory loop	Broca's area; supplementary motor area; premotor area; parts of insula; right cerebellum
Central executive	prefrontal cortex
Cognition — reasoning	Lateral frontal network
Emotions and motivation	Limbic structures — amygdala, septum; hypothalamus — and their cortical connections
Learning Circuits	
Controlled processing (during learning)	Left lateral posterior frontal; anterior cingulate; right cerebellum activates but insula deactivates; limbic structures like amygdala
Automatic processing (after practice)	Bilateral sylvian insula activates; cerebellum deactivates; striatum

[a] See section at the end of Chapter 5 for description of function.

[b] Based on research reviewed in Chapters 3, 4, and 5; however, research findings are not always consistent and future research may modify and extend current understanding of structure-function relationships.

[c] Based on research evidence for processing aural language; refers to knowledge that is stored in long-term memory at different levels of language.

[d] Unique to the newly constructed reading system.

[e] Not all letters in a word — only those that correspond to a sound unit smaller than a whole word.

[f] All letters in a word that correspond to a phonological unit for a whole word.

[g] Hippocampus likely plays a role in making stimuli memorable, but is unlikely to play a role as a storage site.

and problems in switching from one task to another may have attention deficit disorder and should be referred to a psychologist or physician for evaluation.

The reading brain also needs to communicate with the established Language by Ear and Language by Mouth systems. Learning to read is like learning a second language that draws in some ways on knowledge about language gained in learning the first language. In the process of learning aural language children learn about (a) discourse structures (e.g., narrative schema for stories), (b) syntax for ordering classes of words that are used in written sentences as well as spoken utterances, (c) semantic knowledge for meaning of individual words (vocabulary), and (d) the prosody or musical melody of the syntax of the spoken language. All these levels of language in heard language are also used in reading written language. Early in learning to read, children borrow the naming function of the oral language system to name letters and name words. Later on, when reading text orally, children draw on knowledge of prosody from the spoken language; that is, the music or melody of the sound envelopes in which spoken words are packaged. During oral reading, like in oral language, children must plan their oral-motor productions as well as execute them.

The reading brain also needs a sensory system for extracting features of the incoming stimuli from the environment, in this case, visual features in the written words, and secondary and tertiary association systems for translating those features into language and conceptual representations. Early in processing, a general feature extractor, which the visual system uses for many purposes, can extract these features. Then a specialized processor that is dedicated exclusively to visual stimuli composed of small elements in a linear array provides additional coding. It extracts identity and position information about the elements. Next, a processor dedicated only to written words translates the information about identity and position of elements into language representations by connecting the visual elements with units of phonology (sound codes of the language).

The reading brain also needs a system for linking the orthographic codes to all the other codes for language. One link occurs in the orthographic word form lexicon where letter strings get linked to phonology at different unit sizes. A second link occurs in the reading lexicon that makes connections among all the multiple codes for representing word size units in language. As discussed earlier in the chapter, a unique property of the human memory system is that it stores the same item in multiple ways — in the case of language this multiple storage system involves codes for the orthographic word form, phonology (articulatory gestures, auditory features, name codes, abstract phonological word forms), semantics (vocabulary meaning), and morphology (structure of word meaning, including affixes that modify word meaning). Once the reading lexicon is accessed from the orthographic word form, the functional reading system gains entry to the aural/oral language systems at the level of syntax and discourse. This third link between the reading lexicon and the aural/oral reading system enables reading comprehension.

Constructing the Reading Brain requires considerable assistance from an executive system for governing the multiple components that sometimes work in harmony

TABLE 7.1 Constructing the Wetware for a Computing Brain

Function[a]	Possible brain Structure(s)[b]
Arousal unit	Reticular activating system (RAS) and its cortical connections
Quantitative Knowledge[d]	
Number concept (quantity)	
Counting (1–1 correspondence)	
Number line/analog representation of number	Right superior parietal lobe; inferior parietal cortex bilaterally; parietal lobes bilaterally; right superior temporal gyrus; middle temporal gyrus bilaterally; right superior frontal gyrus; right inferior frontal gyrus; left frontal parietal network; occipital cortex bilaterally; supplementary motor area; left precentral gyrus; Broca's area; left premotor; left prefrontal cortex
Place value	Unknown
Part-whole relationships	Unknown
Multivariate relationships	Unknown
Arithmetic Module[d]	
Math facts	Lenticular nucleus; left language and subcortical areas
Computational algorithms	Left inferior frontal and parietal areas
addition	Right orbital frontal; right insula; left frontal parietal network; left inferior frontal area
subtraction	Left dorsolateral prefrontal; inferior parietal bilaterally; left premotor; Broca's area
multiplication	Inferior parietal gyri bilaterally; parietal bilaterally; left fusiform and lingual gyri; right cuneus; left lenticular nucleus; BA 8; BA 44; left middle and frontal gyri; left frontal parietal network; occipital cortex bilaterally; supplementary motor area; left precentral gyrus
Visual-Spatial System[d]	
Sensory input	See Table 3.2 for primary projection pathway
Extraction of visual features (nonlinguistic)	V1 striatal cortex/striatal cortex
Visual Notation System[d] for representing number in numerals	Right fusiform gyrus; bilateral occipital-temporal areas; left fusiform and precentral gyri; right precentral and inferior parietal regions
Ventral *what* pathway for objects (identity of small elements in linear array)	Occipital to temporal cortex
Dorsal *where* pathway for objects (spatial relationships of small elements in linear array)	Occipital to parietal cortex
Geometrical[d] (visual-spatial)	Unknown

(*continues*)

TABLE 7.1 (*continued*)

Grapho-Motor Component[d]	See Table 6.2
Linguistic Representations of Mathematical Problems — draws on Aural Language System[c]	See Table 5.4
Math Lexicon[d]	
Quantitative vocabulary	Left inferior parietal lobule; right precentral/inferior parietal regions
Visual-spatial vocabulary	Unknown
Arithmetic operations vocabulary	Unknown
Other vocabulary knowledge	Unknown
Executive/Government System	Prefrontal cortex (especially left dorsal; prefrontal cortex, LDPFC)
Cross-talk between existing systems in constructing new system	
Cross-talk with reading brain in solving word problems	See Table 5.4
Working with attentional system (focus, maintenance, transitions)	
Creating goals and plans	
Coordinating multiple operations	
Control processes for working memory	
Metacognition (reflection) about math	
Memory	
Working memory	
Phonological STM	See Tables 5.3, 5.4
Visual-Spatial STM	See Table 5.3
Central Executive(s)	Prefrontal cortex
Long-Term Storage	See Table 5.3
Implicit (Unconscious) Network — automatically activated (primed) math facts	Unknown
Explicit (Conscious) Semantic Retrieval	Temporal cortex; left hippocampus
Attentional System	See Table 5.4
Cognition	
General Reasoning	Lateral frontal network
Quantitative	Unknown
Visual-Spatial	Unknown
Verbal	Unknown

(*continues*)

TABLE 7.1 (*continued*)

Emotions and Motivation	Limbic structures — amygdala, septum; hypothalamus — and their cortical connections
Learning Circuits	See Table 5.4
Controlled processing — Learning facts and algorithms	Unknown
Automatic processing — Automatic retrieval of facts and algorithm application	Right cerebellum; right orbital; insula

[a] See section at end of Chapter 7 for description of function.
[b] Based on existing research reviewed in Chapters 3, 4, and 5. however, research evidence is not always consistent and future research may modify or extend current understanding of structure-function relationships.
[c] Based on research evidence for processing aural language; refers to knowledge that is stored in long term memory at different levels of language.
[d] Unique to the newly constructed math computing system.

visual notation system, and a specialized math lexicon. This lexicon of single words and phrases is specialized for quantitative concepts (e.g., greater than or less than), visual-spatial concepts (e.g., above, between, diagonal, circumference), and arithmetic operations (e.g., How much altogether? How much more? How many will each have?).

As with reading and writing, the Computing Brain must be awake and sufficiently aroused to process incoming information from the environment and conduct ongoing processing within the internal mental environment. Separate representations for arithmetic facts (e.g., sums of 1-digit numbers, removal of 1-digit numbers, repeated sums of 1-digit numbers, and repeated removal of 1-digit numbers) and algorithms for operating on these facts are stored in separate, but possibly partially overlapping circuits, in long-term memory. Quantitative knowledge is represented in continuous, analog fashion along a number line. Visual symbols for representing this quantitative knowledge and grapho-motor procedures for writing these visual symbols are also stored in long-term memory. Procedures for representing and manipulating part-whole relationships are established. More than one internal number line may be created for purposes of accessing multiple dimensions in problem solving. Computing Brains show individual differences in how quickly and easily they establish these internal representations of number lines and part-whole relationships.

The Computing Brain keeps the executive/government system very busy. To begin with, the Computing Brain recruits the Reading Brain during written math word problem solving and the Writing Brain during written computation. During problem solving, the Computing Brain recruits the executive system to create goals and plans, coordinate multiple operations, monitor ongoing processes, and exert executive control over the working memory system. The executive system also