Woodcock-Johnson® III Normative Update

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Specification of the Cognitive Processes Involved in Performance on the Woodcock-Johnson III

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This bulletin integrates information on the Woodcock-Johnson III *(WJ III®), Cattell-Horn-Carroll (CHC) theory, and selected research in cognitive psychology—the branch of psychology that is based on the scientific study of human cognitive processes. Support for a specification of the cognitive processes involved in performance on the WJ III is described in terms of an integration of CHC theory with selected classic and contemporary cognitive and neuroscience research.*

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Specification of the Cognitive Processes Involved in Performance on the Woodcock-Johnson III

The *Woodcock-Johnson® III* (WJ III®) (Woodcock, McGrew, & Mather, 2001a) is a broad-based battery of cognitive, oral language, and achievement tests that can be interpreted with reference to the Cattell-Horn-Carroll theory of cognitive abilities (CHC theory) (McGrew, 2005; McGrew & Woodcock, 2001). The *Woodcock-Johnson III Tests of Cognitive Abilities* (WJ III COG) (Woodcock, McGrew, & Mather, 2001c) and the *Woodcock-Johnson III Diagnostic Supplement to the Tests of Cognitive Abilities* (Diagnostic Supplement) (Woodcock, McGrew, Mather, & Schrank, 2003) together include 31 cognitive tests. The *Woodcock-Johnson III Tests of Achievement* (WJ III ACH) (Woodcock, McGrew, & Mather, 2001b) includes 22 oral language and achievement tests. Each of the WJ III tests measures one or more narrow, or specific, cognitive abilities as informed by the independent research efforts of Horn (1965, 1985, 1988, 1989, 1991), Horn and Stankov (1982), Cattell (1941, 1943, 1950, 1971), Carroll (1987, 1993, 1998), and Woodcock (1998). In addition, each test can be considered a single measure of a broad cognitive ability and a more specific narrow ability as defined by CHC theory.

The *Woodcock-Johnson III Normative Update Technical Manual* (WJ III NU Technical Manual) (McGrew, Schrank, & Woodcock, in press) includes a discussion of the CHC abilities, particularly the narrow abilities, with reference to a number of experimental studies and related models of human information processing derived from cognitive and neuroscience research. This bulletin serves as a prepublication form of that discussion. Because many of the WJ III tests are similar (and in some cases identical) to tasks used in both classic and contemporary cognitive and neuroscience research studies, the similarities between the WJ III tests and information-processing research tasks provide a basis for making inferences about the cognitive processes required in the WJ III tests. That is, the narrow ability identified for each test is supported by a description of the cognitive process(es) identified by research as using the same or similar tasks.

Processes Across CHC Abilities in the WJ III COG and Diagnostic Supplement

The 20 WJ III COG and 11 Diagnostic Supplement tests were developed to provide a representative sampling of the complex set of abilities defined by CHC theory. Table 1 describes the constructs measured by the WJ III COG and Diagnostic Supplement tests with respect to stimuli, task requirements, inferred cognitive processes, and response modalities. Because each test in the WJ III COG and the Diagnostic Supplement measures one or more of the narrow abilities defined by CHC theory, the stimuli and the task and response requirements of each test are outlined.

Table 1.
WJ III COG Construct and Content Coverage

Test	Primary Broad CHC Factors *Narrow CHC Abilities*	Stimuli	Test Requirements	Cognitive Process(es)	Response
Test 1: Verbal Comprehension	Comprehension-Knowledge (*Gc*) *Lexical knowledge* *Language development*	Visual (pictures); Auditory (words)	Identifying objects; knowledge of antonyms and synonyms; completing verbal analogies	Object recognition and reidentification; semantic activation, access, and matching; verbal analogical reasoning	Oral (word)
Test 2: Visual-Auditory Learning	Long-Term Retrieval (*Glr*) *Associative memory*	Visual (rebuses) -auditory (words) in the learning condition; Visual (rebuses) in the recognition condition	Learning and recalling pictographic representations of words	Paired-associative encoding via directed spotlight attention; storage and retrieval	Oral (sentences)
Test 3: Spatial Relations	Visual-Spatial Thinking (*Gv*) *Visualization* *Spatial relations*	Visual (drawings)	Identifying the subset of pieces needed to form a complete shape	Visual feature detection; manipulation of visual images in space; matching	Oral (letters) or motoric (pointing)
Test 4: Sound Blending	Auditory Processing (*Ga*) *Phonetic coding*	Auditory (phonemes)	Synthesizing language sounds (phonemes)	Synthesis of acoustic, phonological elements in immediate awareness; matching the sequence of elements to stored lexical entries; lexical activation and access	Oral (word)
Test 5: Concept Formation	Fluid Reasoning (*Gf*) *Induction*	Visual (drawings)	Identifying, categorizing, and determining rules	Rule-based categorization; rule switching; induction/inference	Oral (words)
Test 6: Visual Matching	Processing Speed (*Gs*) *Perceptual speed*	Visual (numbers)	Rapidly locating and circling identical numbers from a defined set of numbers	Speeded visual perception and matching	Motoric (circling)
Test 7: Numbers Reversed	Short-Term Memory (*Gsm*) *Working memory*	Auditory (numbers)	Holding a span of numbers in immediate awareness while reversing the sequence	Span of apprehension and recoding in working memory	Oral (numbers)
Test 8: Incomplete Words	Auditory Processing (*Ga*) *Phonetic coding*	Auditory (words)	Identifying words with missing phonemes	Analysis of a sequence of acoustic, phonological elements in immediate awareness; activation of a stored representation of the word from an incomplete set of phonological features	Oral (word)
Test 9: Auditory Working Memory	Short-Term Memory (*Gsm*) *Working memory*	Auditory (words, numbers)	Holding a mixed set of numbers and words in immediate awareness while reordering into two sequences	Recoding of acoustic, verbalizable stimuli held in immediate awareness	Oral (words, numbers)
Test 10: Visual-Auditory Learning–Delayed	Long-Term Retrieval (*Glr*) *Associative memory*	Visual (rebuses) in the recognition condition; Visual-auditory in the relearning condition	Recalling and relearning pictographic representations of words from 30 minutes to 8 days later	Retrieval and reidentification; associative encoding (for relearning)	Oral (sentences)
Test 11: General Information	Comprehension-Knowledge (*Gc*) *General (verbal) information*	Auditory (questions)	Identifying where objects are found and what people typically do with an object	Semantic activation and access to declarative generic knowledge	Oral (sentences)
Test 12: Retrieval Fluency	Long-Term Retrieval (*Glr*) *Ideational fluency* *Naming facility*	Auditory (directions only)	Naming as many examples as possible from a given category	Recognition, fluent retrieval, and oral production of examples of a semantic category	Oral (words)
Test 13: Picture Recognition	Visual-Spatial Thinking (*Gv*) *Visual memory*	Visual (pictures)	Identifying a subset of previously presented pictures within a field of distracting pictures	Formation of iconic memories and matching of visual stimuli to stored representations	Oral (words) or motoric (pointing)
Test 14: Auditory Attention	Auditory Processing (*Ga*) *Speech-sound discrimination* *Resistance to auditory stimulus distortion*	Auditory (words)	Identifying auditorily presented words amid increasingly intense background noise	Selective auditory attention	Motoric (pointing)
Test 15: Analysis-Synthesis	Fluid Reasoning (*Gf*) *General sequential reasoning* *Quantitative reasoning*	Visual (drawings)	Analyzing puzzles (using symbolic formulations) to determine missing components	Algorithmic reasoning; deduction	Oral (words)

Table 1. *(cont.)*
WJ III COG Construct and Content Coverage

Test	Primary Broad CHC Factors *Narrow CHC Abilities*	Stimuli	Test Requirements	Cognitive Process(es)	Response
Test 16: Decision Speed	Processing Speed (*Gs*) *Semantic processing speed*	Visual (pictures)	Locating and circling two pictures most similar conceptually in a row	Object recognition and speeded symbolic/semantic comparisons	Motoric (circling)
Test 17: Memory for Words	Short-Term Memory (*Gsm*) *Auditory memory span*	Auditory (words)	Repeating a list of unrelated words in correct sequence	Formation of echoic memories and verbalizable span of echoic store	Oral (words)
Test 18: Rapid Picture Naming	Processing Speed (*Gs*) *Naming facility*	Visual (pictures)	Recognizing objects, then articulating their names rapidly	Speed/fluency of retrieval and oral production of recognized objects	Oral (words)
Test 19: Planning	Visual-Spatial Thinking (*Gv*) and Fluid Reasoning (*Gf*) *Spatial scanning* *General sequential reasoning*	Visual (drawings)	Tracing a pattern without removing the pencil from the paper or retracing any lines	Means-end analysis	Motoric (tracing)
Test 20: Pair Cancellation	Processing Speed (*Gs*) *Attention and concentration*	Visual (pictures)	Identifying and circling instances of a repeated pattern rapidly	Controlled, focal attention; vigilance	Motoric (circling)
Test 21: Memory for Names	Long-Term Retrieval (*Glr*) *Associative memory*	Auditory-visual (names-pictures)	Learning and recalling names	Associative encoding via directed spotlight attention, storage, and retrieval	Motoric (pointing)
Test 22: Visual Closure	Visual-Spatial Thinking (*Gv*) *Closure speed*	Visual (pictures)	Identifying an object from an incomplete or masked visual representation	Object identification from a limited set of component geons	Oral (word)
Test 23: Sound Patterns–Voice	Auditory Processing (*Ga*) *Sound discrimination*	Auditory (sounds)	Recognizing similarity or difference within a pair of voicelike sound patterns	Prelexical, perceptual analysis of auditory waveform patterns	Oral (word)
Test 24: Number Series	Fluid Reasoning (*Gf*) *Mathematics knowledge* *Quantitative reasoning*	Visual (numeric)	Determining a numerical sequence	Representation and manipulation of points on a mental number line; identifying and applying an underlying rule/principle to complete a numerical sequence	Oral (number)
Test 25: Number Matrices	Fluid Reasoning (*Gf*) *Quantitative reasoning*	Visual (numeric)	Determining a two-dimensional numerical pattern	Access to verbal-visual numeric codes; transcoding verbal and/or visual representations of numeric information into analogical representations; determining the relationship between/among numbers on the first part of the structure and mapping (projecting) the structure to complete the analogy	Oral (number)
Test 26: Cross Out	Processing Speed (*Gs*) *Perceptual speed*	Visual (pictures)	Rapidly locating and marking identical pictures from a defined set of pictures	Speeded visual matching	Motoric (marking)
Test 27: Memory for Sentences	Short-Term Memory (*Gsm*) *Auditory memory span* *Listening ability*	Auditory (sentences)	Repeating words or phrases and sentences in correct sequence	Formation of echoic memories aided by a semantic, meaning-based code	Oral (words, sentences)
Test 28: Block Rotation	Visual-Spatial Thinking (*Gv*) *Visualization* *Spatial relations*	Visual (pictures)	Matching two (from an array) of three-dimensional visual patterns to one that has been changed in spatial orientation	Visual matching using visual-spatial manipulation	Oral (letter names) or motoric (pointing)
Test 29: Sound Patterns–Music	Auditory Processing (*Ga*) *Sound discrimination* *Musical discrimination and judgment*	Auditory (sounds)	Recognizing similarity or difference within a pair of musical patterns	Prelexical, perceptual analysis of auditory waveform patterns	Oral (word)
Test 30: Memory for Names–Delayed	Long-Term Retrieval (*Glr*) *Associative memory*	Auditory-visual (names-pictures)	Recalling names learned 30 minutes to 8 days earlier	Reidentification	Motoric (pointing)
Test 31: Bilingual Verbal Comprehension–English/Spanish	Comprehension-Knowledge (*Gc*) *Lexical knowledge* *Language development*	Visual (pictures); Auditory (words)	Identifying objects, knowledge of antonyms and synonyms, completing verbal analogies when presented in Spanish	Object reidentification; semantic activation, access, and matching; verbal analogical reasoning	Oral (word)

Comprehension-Knowledge (*Gc*)

Cognitive psychologists often define the abilities that fall within the broad CHC domain of Comprehension-Knowledge (*Gc*) as *declarative memory* or "memories for facts and events that are recollected consciously" (Squire & Knowlton, 2000). Markowitsch (1992, 2000) described this as "the knowledge system":

> The knowledge system refers to context-free facts, procedural memory to various (perceptual, motor, cognitive) skills, and priming to enhanced probability of reidentifying of previously perceived stimuli (or for conceptual priming, stimuli from a previously encountered set or category). (p. 782)

Another definition of comprehension-knowledge (*Gc*) is *semantic memory* (Tulvig, 1972, 1983), "whose function is to mediate the acquisition and use of individuals' general knowledge of the world" (Tulvig, 2000, p. 728).

In accordance with CHC theory, the Verbal Comprehension test measures the narrow abilities of lexical knowledge (i.e., vocabulary knowledge) and language development (i.e., general development of spoken-language skills that do not require reading ability). Ashcraft (2002) described the narrow ability of lexical knowledge as a mental lexicon, or store of information about words. The cognitive processing involved in lexical knowledge may be best illustrated in the Synonyms and Antonyms tasks, wherein an auditory form of a stimulus word is connected to a concept via semantic access, which then activates or primes its meaning in the lexicon and consequently activates closely associated words (Caplan, 1992; Gazzaniga, Ivry, & Mangun, 1998). Although both narrow abilities (lexical knowledge and language development) are measured in the Picture Vocabulary test, this test is primarily a language development task, because the stimulus material involves no printed words (i.e., lexical retrieval cannot be accessed via reading). In Picture Vocabulary, stored vocabulary words that represent the pictured stimulus items are typically recovered (or reidentified) for current use directly from object recognition to lexical access and retrieval. The Verbal Analogies test is comprised of cognitively complex tasks that require induction of the structure for the first part of each analogy and then mapping (or projecting) that structure onto the second part (Gentner & Markman, 1997).

In contrast, the General Information test measures the CHC narrow ability of general (verbal) information. Hintzman (1978) called this type of knowledge *generic memory*—information that can be readily accessed without any integrative mental processing.

Long-Term Retrieval (*Glr*)

The CHC broad ability of Long-Term Retrieval (*Glr*) involves the processes of acquiring, storing, and retrieving information. This broad ability encompasses three major memory processes: encoding, storage, and retrieval (Schacter & Tulvig, 1994; Tulvig, 1985, 2000). Another important process involved in this ability is memory consolidation, which is a biological process. For example,

> the presentation of the to-be-remembered material is an event about which "information" is "encoded" into the memory "store." Usually, the material consists of discrete items (words, pictures, objects, faces, and simple sentences), and the

> presentation of each is a "miniature event" about which information is encoded into the store. During the retention interval, this information is maintained in the store as an "engram," and it may be "consolidated" or "recoded." Consolidation is thought of as a biologically determined autonomous process that runs its course independently of the interpolated activity, whereas recoding is an active psychological process that is shaped by the particulars of the interpolated activity. At the time of the test, the information "available" in the engram is "retrieved," or rendered "accessible." Retrieval means use of stored information, and because stored information can be used in many different ways, the term retrieval is very broad and usually needs to be specified more precisely. (Tulvig, 2000, p. 729)

The narrow *Glr* abilities defined by CHC theory help specify the nature of the type of acquisition or retrieval process. For example, Visual-Auditory Learning and Visual-Auditory Memory–Delayed measure associative memory or paired-associate learning. Kosslyn and Thompson (2000) defined *associative memory* as a subprocess that combines information from two types of properties and compares the information with stored representations. For example, in Visual-Auditory Learning, the initial task requires associating the visual rebus symbol with a verbal label. The controlled-learning format of this test uses "directed spotlight" attention (Gazzaniga et al., 1998), the mental attention-focusing process that prepares the subject to encode the stimulus (see Figure 1). The retrieval phase requires the subject to match a rebus presentation with its stored representation; this process is called *identification*. When the rebus is identified, the subject has access to the name associated with the stored representation. If the stimulus is not efficiently matched to a stored representation in the object-properties-encoding subsystem, the subject may suggest a hypothesis based on the closest match in storage by means of an "information lookup" subprocess. The information lookup subprocess has been shown to play a critical role in working memory (Kosslyn, Thompson, & Alpert, 1995). The feedback procedure used in Visual-Auditory Learning provides a correction to any faulty hypothesis.

Each of these drawings is a word. As soon as I tell you what a drawing says, you say it back to me.

Do not discuss any symbol, say its name more than once, or allow subject to review or practice words.

Point to first symbol on subject's page and say: **cowboy**. Pause for subject to repeat word once. (If necessary, remind subject to say word.) Move immediately to next symbol.

Point to second symbol and say: **dog**. Pause for subject to repeat word.

Point to next symbol and say: **horse**. Pause for subject to repeat word.

Point to last symbol and say: **and**. Pause for subject to repeat word.

Figure 1.
An example of the directed spotlight attention procedure in WJ III COG Test 2: Visual-Auditory Learning.

Memory for Names also measures associative memory. Memory for Names–Delayed is different from Memory for Names, however, because it does not include any "directed spotlight" attention-encoding procedure. Additionally, performance on Memory for Names–Delayed is influenced by the buildup of interference (i.e., forgetting caused by intervening stimulation or mental processing) (Gazzaniga et al., 1998).

Long-term retrieval is an important cognitive ability because it is a route to *automaticity* (Gazzaniga et al., 1998). That is, the processes of rehearsal and encoding create meaning-based codes that are subsequently used to relate new information or task requirements to previously acquired knowledge. For example, the Retrieval Fluency test requires fluent retrieval and oral production of examples of a semantic category. This task does not include the encoding and storage processes, but rather measures the rate or automaticity of retrieval. In CHC theory, the cognitive abilities measured by Retrieval Fluency are ideational fluency and naming facility.

Visual-Spatial Thinking (*Gv*)

All visual-spatial thinking tasks involve visual perception (i.e., the process of extracting features from visual stimuli). In information-processing terms, images share representations with visual percepts that have a spatial format (Farah, 2000). The Spatial Relations test measures the ability to use visualization (the ability to apprehend spatial forms or shapes, often by rotating or manipulating them in the imagination). Through the process of visual-feature detection (Biederman, 1987, 1990), puzzle pieces are matched to components of the target shape held in immediate awareness. The Block Rotation test also measures visualization. The task involves visual matching using visual-spatial manipulation, a component of working memory (Posner, 1978).

Picture Recognition requires the subject to form and remember—in a few seconds—mental images (representations of visual stimuli) that cannot easily be encoded verbally. These images are called *icons* (Averbach & Sperling, 1961; Neisser, 1967). As such, Picture Recognition is a measure of visual, or iconic, memory. In this task, recognition occurs when a visual input matches a stored visual memory (Kosslyn & Thompson, 2000). In contrast, Visual Closure measures the narrow ability of closure speed (recognition of a visual stimulus that has been obscured in some way). Visual Closure requires the ability to identify the stimulus object on the basis of limited depicted information. Biederman (1990) explained that objects are visually identified by feature detection of component geons (representations of visual forms that have relatively invariant features).

Auditory Processing (*Ga*)

All auditory processing tasks require aspects of auditory perception (i.e., the process of extracting features from auditory stimuli). Sound Blending measures the narrow ability of phonetic coding (i.e., phonological awareness, or the ability to code phonetic information in immediate awareness). Sound Blending involves acoustic-phonetic processing, which is the ability to analyze acoustic waveforms in terms of phonological elements, blend or synthesize the waveform elements, match the blended sequence to stored lexical entries, and unambiguously identify the component phonemes in the waveform as a complete word through the lexical activation process (Caplan, 1992). In Incomplete Words, a stored representation of a word must be activated from an incomplete set of phonological features that are extracted from the acoustic signal (Frauenfelder & Tyler, 1987). Both

Sound Blending and Incomplete Words can be considered measures of *phonetic processing* (Norris & Wise, 2000), or the extraction of specifically linguistic features such as placement and manner of articulation of consonants.

Auditory Attention measures the CHC narrow abilities of speech-sound discrimination (i.e., perception of speech sounds) and resistance to auditory stimulus distortion (i.e., the ability to process and discriminate speech sounds presented under distorted conditions). Auditory Attention requires selective auditory attention—the ability to attend to and perceive a weak speech signal in a noisy environment (Gazzaniga et al., 1998).

Both Sound Patterns–Voice and Sound Patterns–Music measure the narrow ability of sound discrimination (defined as the ability to discriminate tones or tone patterns based on pitch, intensity, duration, and temporal relations). Ashcraft (2002) described the processing requirements of tasks similar to those in the Sound Patterns tests as the perceptual analysis of auditory input. These two tests can also be described as measures of prelexical, acoustic auditory processing (Norris & Wise, 2000).

Fluid Reasoning (*Gf*)

Reasoning is considered a complex, hierarchical cognitive function that can rely on many other cognitive processes (Kosslyn & Smith, 2000), depending on the nature and requirements of the task. Reasoning also often relies on emergent properties; that is, those functions that cannot be predicted based on simple interactions between other functions. Nevertheless, certain narrow abilities have been identified by CHC theory based on different types of reasoning processes. The Concept Formation test measures the narrow ability of induction, or inference (Osherson, Smith, Wilkie, Lopez, & Shafir, 1990). The task requires rule application and frequent switching from one rule to another (Smith & Jonides, 2000). Analysis-Synthesis primarily measures the narrow ability of general sequential, or deductive, reasoning (defined as the ability to draw correct conclusions from stated conditions or premises, often from a series of sequential steps). Because of its use of specific solution keys that, if followed correctly, furnish the correct answer to each test item, Analysis-Synthesis can be also described as a measure of algorithmic reasoning (Gazzaniga et al., 1998). In CHC theory, algorithmic reasoning is an aspect of quantitative reasoning.

Dehaene (1997, 2000) provided evidence for the existence of a specific domain of knowledge that is based on an analogical representation of numbers in which numerical quantities are internally represented and manipulated as points on a mental "number line":

> The human brain contains an analogical representation of numerical quantities, which can be likened to a mental "number line." This representation is independent of, and common to, the multiple input and output notation systems we use to communicate numbers, such as words or Arabic digits. It is subject to distance and magnitude effects. (Dehaene, 2000, p. 995)

The mental representations that constitute this ability form the basis for the ability to learn symbols for numbers and perform simple calculations (Dehaene, 2000). The Number Series test measures the ability to identify and apply an analog or rule to complete a numerical sequence. In CHC theory, the internal representation of points on the number line is an aspect of mathematics knowledge, and the ability to manipulate the points on the number line is an aspect of quantitative reasoning.

Number Matrices measures the narrow ability of quantitative reasoning, but it also requires a foundation in mathematics knowledge (i.e., access to the category-specific verbal and visual code; for example, knowledge of the number line). In Number Matrices, the verbal and/or visual codes are transcoded into analogical representations between sets of numbers. The solution to each item is obtained by mapping the relationship implied from the first part of the item, thereby completing the analogy.

Tasks similar to those required for the Planning test measure means-end analysis, a form of general sequential reasoning (Newell & Simon, 1972). *Means-end analysis* is a problem-solving strategy that involves a search process over a problem space. However, Farah (2000) demonstrated that tasks requiring mental imagery (similar to Planning) draw on processes used in like-modality presentation. Therefore, Planning draws on spatial scanning (i.e., speed in visually surveying a complicated spatial field) because the task is visual in nature.

Processing Speed (*Gs*)

Efficiency of cognitive processing is based partly on the speed of mental activity. In the WJ III, several speeded psychometric tasks (described below) provide different measures of processing speed (*Gs*).

Visual Matching and Cross Out each measure the narrow ability of perceptual speed (i.e., speeded clerical ability, in which a perceived configuration is compared with a remembered one). Perceptual speed involves making comparisons based on rapid visual searches.

Decision Speed measures the speed of semantic processing (i.e., the speed of mental manipulation of stimulus content) and requires making symbolic comparisons of concepts (Kosslyn & Pomerantz, 1977). In contrast to decision making based on physical comparisons, the semantic or acquired knowledge (rather than perceptual information) needed for the Decision Speed test influences the decision-making process (Gazzaniga et al., 1998).

Rapid Picture Naming measures the narrow ability of naming facility (i.e., the speed of producing names for or attributes of objects). This test measures the speed or fluency of recognition, retrieval, and oral production of names of pictured objects (Gazzaniga et al., 1998).

Pair Cancellation measures controlled, sustained focal attention on a cue and target (LaBerge, 2000). This sustained attention, also called *vigilance,* is an aspect of executive control (Posner & DiGirolamo, 2000). Attention is the mental process of concentration on a stimulus or other mental event—an important aspect of all focused cognitive activity (Ashcraft, 2002). In CHC theory, this narrow ability is specified as attention and concentration.

Short-Term Memory (*Gsm*)

Immediate memory capacity or short-term memory (*Gsm*) sets limits on more complex information processing (Gazzaniga et al., 1998). Short-term memory is primarily auditory in nature and relies on the process of acoustic-articulary coding. Working memory, by contrast, can involve additional processes, such as visualization, semantic access and

retrieval, and even information related to physical movement. Short-term memory is an important ability, because access to the knowledge system relies on the efficiency of short-term memory (Ashcraft, 2002).

The Numbers Reversed and Auditory Working Memory tests require the ability to temporarily store and recode orally presented information (Gazzaniga et al., 1998); this ability is a subprocess of working memory. Memory for Words and Memory for Sentences measure auditory memory span (i.e., attention to temporally ordered, verbalized acoustic stimuli; registration of the stimuli sequence in immediate memory; and repetition of the sequence). Memory for Words measures the formation of echoic memories and the span of verbal echoic store (Neisser, 1967). Memory for Sentences measures the same ability; however, performance on this task can be aided by using a semantic, meaning-based code (Wickens, 1972).

Processes Across CHC Abilities in the WJ III ACH

The 22 WJ III ACH tests were developed to sample the major aspects of oral language and academic achievement. To meet this objective, the tests sample achievement in reading, mathematics, written language, oral language, and curricular knowledge. The specification of item content in these tests was based on providing a broad sampling of achievement rather than an in-depth assessment in a relatively narrow area. For example, Test 19: Academic Knowledge includes questions in science, social studies, and humanities that cover several levels of difficulty and a wide range of content in each subject area.

Table 2 describes the constructs measured by the WJ III ACH tests. For each test, the narrow abilities identified by CHC theory are identified. Each test's stimuli, task requirements, inferred cognitive processes, and response modalities are outlined.

Reading-Writing (*Grw*)

Reading-Writing (*Grw*) is a broad cognitive ability that is based on the use of one or more shared psychological processes (Woodcock, 1998). For example, both reading and writing involve mapping written forms of language onto phonological representations. In addition, learning to read and write typically is phonologically mediated, at least in part, based on the normal sequence of language development. For example, almost all children learn to use spoken language before written language, and research suggests that they map written language onto oral language (Caplan, 1992). Although learning to read and write is initially facilitated by phonological subword transformation processes, these processes may be discarded when the target skill has become more efficient and automatized (Baron & Strawson, 1976; Coltheart, 1978; Gough & Cosky, 1977). Consequently, Humphreys and Evett (1985) identified two routes to reading—a phonologically mediated process and a whole-word recognition process. Writing tasks typically involve some of the same cognitive processes. "The visual word form system holds the permanent orthographic description of the word, its meaning is located in semantic memory, and a rule-governed procedure exists for mapping phonological information onto graphemic segments" (Caplan, p. 203).

Table 2.
WJ III ACH Construct and Content Coverage

Test	Curricular Area *Narrow CHC Abilities*	Stimuli	Test Requirements	Cognitive Process(es)	Response
Test 1: Letter-Word Identification	Reading *Reading decoding*	Visual (text)	Identifying printed letters and words	Feature detection and analysis (for letters) and recognition of visual word forms from a phonological lexicon; access of pronunciations associated with visual word forms	Oral (letter name, word)
Test 2: Reading Fluency	Reading *Reading speed* *Semantic processing speed*	Visual (text)	Reading printed statements rapidly and responding with true or false (yes or no)	Speeded semantic decision making requiring reading ability and generic knowledge	Motoric (circling)
Test 3: Story Recall	Oral Expression *Meaningful memory* *Listening ability*	Auditory (text)	Listening to and recalling details of stories	Construction of propositional representations and recoding	Oral (passage)
Test 4: Understanding Directions	Listening Comprehension *Working memory* *Listening ability*	Auditory (text)	Listening to a sequence of instructions and then following the directions	Construction of a mental structure in immediate awareness and modification of the structure via mapping	Motoric (pointing)
Test 5: Calculation	Mathematics *Math achievement*	Visual (numeric)	Performing various mathematical calculations	Access to and application of knowledge of numbers and calculation procedures; verbal associations between numbers represented as strings of words	Motoric (writing)
Test 6: Math Fluency	Mathematics *Math achievement* *Numerical facility*	Visual (numeric)	Adding, subtracting, and multiplying rapidly	Speeded access to and application of digit-symbol arithmetic procedures	Motoric (writing)
Test 7: Spelling	Spelling *Spelling ability*	Auditory (words)	Spelling orally presented words	Access to and application of knowledge of orthography of word forms by mapping whole-word phonology onto whole-word orthography, by translating phonological segments into graphemic units, or by activating spellings of words from the semantic lexicon	Motoric (writing)
Test 8: Writing Fluency	Writing *Writing ability* *Writing speed*	Visual (words with picture)	Formulating and writing simple sentences rapidly	Speeded formation of constituent sentence structures requiring fluent access to semantic and syntactic knowledge	Motoric (writing)
Test 9: Passage Comprehension	Reading *Reading comprehension* *Cloze ability*	Visual (text)	Identify a missing keyword that makes sense in the context of a written passage	Construction of propositional representations; integration of syntactic and semantic properties of printed words and sentences into a representation of the whole passage	Oral (word)
Test 10: Applied Problems	Mathematics *Quantitative reasoning* *Math achievement* *Math knowledge*	Auditory (questions); Visual (numeric, text)	Performing math calculations in response to problems presented orally and visually (or by reading)	Construction of mental models via language comprehension, application of calculation and/or quantitative reasoning; formation of insight	Oral

Table 2. *(cont.)*
WJ III ACH Construct and Content Coverage

Test	Curricular Area *Narrow CHC Abilities*	Stimuli	Test Requirements	Cognitive Process(es)	Response
Test 11: Writing Samples	Writing *Writing ability*	Auditory; Visual (text)	Writing meaningful sentences for a given purpose	Retrieval of word meanings; application of psycholinguistic rules of case grammar and syntax; planning and construction of bridging inferences in immediate awareness (auditory and/or visual buffer)	Motoric (writing)
Test 12: Story Recall–Delayed	Comprehension-Knowledge (*Gc*) *Meaningful memory*	Auditory (sentence)	Recalling previously presented story elements	Reconstructive memory; content accuracy; preservation of discourse structure	Oral (passage)
Test 13: Word Attack	Reading *Reading decoding* *Phonetic coding*	Visual (word)	Reading phonically regular nonwords	Grapheme-to-phoneme translation and accessing pronunciations of pseudo words not contained in the mental lexicon	Oral (word)
Test 14: Picture Vocabulary	Oral Expression *Language development* *Lexical knowledge*	Visual (picture)	Identifying objects	Object recognition; lexical access and retrieval	Oral (word)
Test 15: Oral Comprehension	Listening Comprehension *Listening ability*	Auditory (text)	Identifying a missing keyword that makes sense in an oral passage	Construction of propositional representations through syntactic and semantic integration of orally presented passages in real time	Oral (word)
Test 16: Editing	Writing Skills *English usage*	Visual (text)	Identifying and correcting errors in written passages	Access and application of lexical and syntactic information about details of word forms and writing conventions	Oral
Test 17: Reading Vocabulary	Reading *Lexical knowledge* *Reading comprehension*	Visual (word)	Reading words and supplying appropriate meanings	Recognition of visual word forms; semantic access and activation; semantic matching and analogical reasoning	Oral (word)
Test 18: Quantitative Concepts	Mathematics *Math knowledge* *Quantitative reasoning*	Auditory (question); Visual (numeric, text)	Identifying math terms and formulae; identifying number patterns	Symbol recognition; access to and retrieval of category-specific representations; manipulation of points on a mental "number line"	Oral (word)
Test 19: Academic Knowledge	General *General information* *Science information* *Cultural information* *Geography achievement*	Auditory (question); Visual (text, picture)	Responding to questions about science, social studies, and humanities	Implicit, declarative category-specific memory	Oral (word, sentences)
Test 20: Spelling of Sounds	Spelling *Spelling ability* *Phonetic coding*	Auditory (letter, word)	Spelling letter combinations that are regular patterns in written English	Translating spoken elements of nonwords into graphemic units; phonologically mediated mapping of orthography	Motoric (writing)
Test 21: Sound Awareness	Reading *Phonetic coding* *Working memory*	Auditory (question, word)	Providing rhyming words; removing, substituting, and reversing parts of words to make new words	Access, retrieval, and application of the rules of English phonology	Oral (word)
Test 22: Punctuation and Capitalization	Writing *English usage*	Auditory (question); Visual (letters, words)	Applying punctuation and capitalization rules	Access to and application of lexical information and details of word forms	Motoric (writing)

The Letter-Word Identification test measures the CHC narrow ability of reading decoding. Letters are identified through feature analysis or feature detection (Gibson, 1965; McClelland & Rumelhart, 1981). Well-learned letters and words are accessed from the mental lexicon (i.e., the stores of acquired knowledge) by means of automatic retrieval (Ashcraft, 2002). Caplan (1992) stated, "There is good evidence that visual word forms are largely activated on the basis of their constituent letters, that is, a reader identified the letter in a word and then matches a representation of the word in memory against these letters" (p. 167). However, Coltheart (1978) pointed out that the nature of the task involved in Letter-Word Identification involves not only accessing words from the mental lexicon, but also the cognitive processes for activating and outputting representations of the sound patterns of the words, based on a phonological lexicon. As Caplan summarized, "It thus appears that most skilled oral reading and word recognition consists of identifying letters from a visual stimulus, using those letters to activate visual word forms stored in memory, and then accessing the pronunciation associated with the visual word form" (p. 167).

The Word Attack test measures both reading decoding and the narrow ability of phonetic coding, an aspect of phonemic competence (Ashcraft, 2002) that requires grapheme-to-phoneme translation of pseudo words not contained in the mental lexicon (Gazzaniga et al., 1998). Research suggests that the ability to translate nonwords such as "nat" or "ib" into sounds indicates the presence of a unique process for recognizing printed forms: assembling the pronunciation of a letter string by applying knowledge of typical correspondences between spelling units and sounds (Caplan, 1992).

Reading Vocabulary measures the narrow abilities of verbal (printed) language comprehension and lexical, or vocabulary, knowledge. These abilities are described as functions of the mental lexicon (Ashcraft, 2002), particularly the functions that involve semantic memory (Quillian, 1968). Comprehension is achieved when the visual form of the word is connected to a concept by means of the semantic access and activation processes (Caplan, 1992). However, evidence suggests that this task may also be phonologically mediated. Van Orden and colleagues demonstrated that the meanings of visually presented words can be activated via their sounds (van Orden, 1987; van Orden, Johnston, & Hale, 1988).

Reading Fluency is a speeded semantic decision task that requires reading ability. This test measures the CHC narrow ability of reading speed. However, this test also requires a store of general information to be able to confirm the accuracy of a statement that is read. This helps form a decision as to whether the statement is true (Ashcraft, 2002).

Passage Comprehension is a complex, conceptually driven processing task. This test is presented as an online comprehension task (Ashcraft, 2002; Gernsbacher, 1990) that measures the narrow ability of reading comprehension as it occurs. As the subject reads, the meaning of the passage is derived through construction of propositional representations based on concepts from stored knowledge. This aspect of the process requires the narrow ability of verbal (printed) language comprehension. Meaning is placed in immediate awareness as the passage is read. As more elements are added to the passage, they are also added to the structure held in immediate awareness via the process of *mapping,* a central feature of cognition (Ashcraft, 2002; Zhou & Black, 2000). The task is solved through *inference* (Klin, 1995), the process by which the reader determines the referents of words and ideas, draws connections between concepts (bridging) (Clark, 1977), and derives a conclusion from the passage.

Writing Samples measures the CHC narrow ability of writing ability. This test measures the ability to convey propositional meaning at the discourse level of language (Caplan, 1992). It requires retrieval of word meanings and syntactic information (i.e., knowledge of how words are combined into sentences) in the mental lexicon (Gazzaniga et al., 1998). Generation of acceptable sentences involves ideational fluency and the application of the psycholinguistic rules of grammar, particularly phrase structure. In several items, the subject must make bridging inferences in working memory to integrate the initial and final sentences into a well-formed passage. These items require planning, or tailoring the target sentence to the lexical and semantic information that is conveyed in the other portions of the sample (Ferreira, 1996).

Caplan (1992) suggests that "smooth written production of sentences depends on the temporary storage of words in a buffer that maintains information while the response is organized and executed. Many theorists consider whole-word phonology to be the most suitable code for this kind of stage device" (p. 174). This suggests an influence of auditory short-term memory span on writing performance. "If the words, having been accessed, have to be held in a buffer store for a few seconds, as is likely to be the case in writing, then acoustic, as opposed to visual, coding will, according to the evidence from studies in short-term memory, be the more durable" (Hotopf, 1983, p. 166). However, evidence also exists for a visual buffer that maintains the graphemic code in immediate awareness during spelling (Caramazza, Miceli, Villa, & Romani, 1987). Written production takes place by generating the spatial form of each letter in the correct order (Ellis, 1982). Caplan suggested that written language production is an extremely complex task whose subprocesses function dynamically and are likely monitored by a centralized mechanism that helps preserve the structure of legitimate words.

Spelling measures knowledge of the details of word forms contained in the mental lexicon (Gazzaniga et al., 1998). This test often involves mapping phonology to orthographic representations of words "either by mapping whole-word phonology into whole-word orthography (if the word is contained in the lexicon), or by translating phonemic segments into graphemic units" (Caplan, 1992, p. 214). Evidence for this form of mapping was provided by Hotopf (1980, 1983), who analyzed dictation-type spelling errors and determined that a significant proportion of the errors were related to the underlying sound of the target words. However, the orthography of entire words can also be activated entirely from their meaning (Caplan, 1992).

Writing Fluency measures the narrow abilities of writing and writing speed. This test requires speeded formulation of constituent structures, or fluency of combining words into phrases (Gazzaniga et al., 1998). Automaticity of writing performance is likely to be aided by mapping from semantics directly to orthography (Caplan, 1992) rather than by mapping phonology to orthography.

The Editing test requires knowledge of the lexical details of word forms and knowledge of writing conventions (English usage); these are functions of the mental lexicon (Ashcraft, 2002). Similarly, the Punctuation and Capitalization test requires accessing and applying lexical information and details of word forms.

Two auditory processing tests measure reading- and writing-related abilities. Sound Awareness measures phonemic competence, or retrieval and application of the rules of permissible English sound combinations (Ashcraft, 2002). In CHC theory this narrow ability is called phonetic coding. In addition, the requirement to manipulate phonemes during portions of the Sound Awareness test appears to place demands on working memory. Spelling of Sounds measures phonetic coding and spelling ability (or knowledge

of the sound patterns of word forms), which are functions of the mental lexicon (Gazzaniga et al., 1998). This task specifically targets phonologically mediated spelling (Caplan, 1992), because the correct orthographic segment(s) is based directly on the spoken elements that comprise the stimulus.

Mathematics (*Gq*)

The primary narrow CHC abilities that pertain to all of the WJ III mathematics tests are mathematics knowledge and mathematics achievement. The Calculation test requires access to and application of mathematical calculation knowledge. The Math Fluency test requires the rapid application of basic addition, subtraction, and multiplication procedures, which together comprise numerical facility. Simple addition and subtraction rules involve numbers coded as quantities on the number line; multiplication and division rules are based on a set of associations between numbers represented as strings of words (e.g., multiplication tables) (Dehaene, 1997, 2000).

Exact calculation and reasoning with numbers have been demonstrated to involve two different types of processes (Dahaene, Molko, Cohen, & Wilson, 2004). Besides mathematics knowledge, the Applied Problems and Quantitative Concepts tests also require quantitative reasoning. For example, some of the more difficult items on the Number Series subtest in Quantitative Concepts require a mental manipulation of points on the number line. Applied Problems requires the construction of mental models (Johnson-Laird, Byrne, & Schaeken, 1992) to solve problems through the application of insight or quantitative reasoning. Solutions to these problems require access to complex cognitive processes and the calculation abilities that depend on them (Ashcraft, 1995). For example, many Applied Problems items involve language comprehension (i.e., either listening ability or reading comprehension) and tasks are sometimes performed mentally using the visual working memory process.

Oral Language and Knowledge

Oral language tasks involve the integration of complex cognitive processes such as semantic memory and reasoning (Caplan, 1992). The Story Recall test requires comprehending and remembering the principal components of a story by constructing propositional representations (Anderson, 1976, 1985; Kintsch, 1974) and by recoding (Miller, 1956). *Recoding* is the cognitive process that is involved when we attempt to rephrase expressions "in our own words." These cognitive processes provide support to the specification of the CHC narrow abilities of language development, listening ability, and meaningful memory. Story Recall–Delayed requires reconstructive memory (Ashcraft, 2002) and content accuracy; it stresses memory for the meaningful, semantic content of the material. Caplan described this process as the preservation of discourse structure.

Understanding Directions requires listening and mapping a series of sequential directions onto the mental structure under construction and maintaining the sequence in immediate awareness until a new directive changes the sequence (Gernsbacher, 1990, 1991, 1997). In CHC theory, this is called working memory.

Carroll (1993) defined listening ability primarily as listening comprehension. The Oral Comprehension test is a complex, discourse-level, online listening comprehension task

that requires integration of orally presented syntactic and semantic information (Brown & Hagoort, 1999; Caplan, 1992; Gernsbacher, 1990). The task requires (a) retrieval of basic word meanings from the mental lexicon (semantic memory) to yield abstract representations, (b) assignment of words to various case roles required by the relation expressed in the sentence, and (c) formation of a propositional structure based on mapping structures within a sentence as well as across sentences in connected discourse. Unlike the Passage Comprehension task, the listener is aided in dividing the discourse into meaningful segments by prosodic information. Complex cognitive processing is required to determine the right sense or meaning of the target word in the context of the discourse (Gazzaniga et al., 1998).

Picture Vocabulary requires the cognitive processes of object recognition, lexical access, and lexical retrieval. This test is a nonreading, lexical-level language development task. Object recognition depends on an analysis of the shape and form of a visual stimulus, although nonshape cues such as color contribute to recognition (Marr, 1982). Lexical access results when representations are activated and spread to semantic attributes of words. Retrieval results when the name of the object is located in the store of lexical knowledge (Gazzaniga et al., 1998).

Summary and Implications

An objective, scientific assessment of cognitive processes can be accomplished using the quantifiable tests and standardized procedures in the WJ III. Interpretation of the WJ III is based on a multilevel approach that helps clinicians understand cognitive performance by breaking it down into component broad and narrow cognitive abilities based on CHC theory. The *WJ III Normative Update Technical Manual* (McGrew, Schrank, & Woodcock, in press) provides support for the suggestion that the different broad and narrow cognitive abilities identified by CHC theory require different cognitive processes.

The WJ III allows professionals to assess and contrast performance among a number of CHC-defined cognitive abilities and then make inferences about relative strengths and weaknesses in an individual's use of underlying cognitive processes. Understanding an individual's strengths and weaknesses in cognitive processing may provide a key to a complete and useful understanding of any learning difficulties. The interpretive information available in the WJ III may help clinicians develop individualized interventions or provide suggestions for educational accommodations.

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