Neurocognitive and classroom-based validation of computer-generated, visual-syntactic text formatting for college and high school reading.

Randall C. Walker, MD – Walker Reading Technologies, Inc.
Charles A. Vogel, PhD – Denver University
Charles R. Fletcher, PhD – University of Minnesota

Synopsis of a Peer-Reviewed Paper Accepted for Presentation
at the Annual Meeting of the
American Educational Research Association
April 12-16, 2004

Accepted by - Division C - Section 1 - Literacy and Language Arts
American Educational Research Association
Paper Discussion (Roundtable)
Examining the Many Factors that Mediate Readers' Understanding of Text

Correspondence to:
Randall C. Walker, MD
WRT
Two Appletree Square
Suite 132
Bloomington, MN 55425
rwalker@liveink.com

Neurocognitive and classroom-based validation of computer-generated, visual-syntactic text formatting for college and high school reading.

Objectives.

This paper will:

- review the neurocognitive framework for a computer-generated, visual-syntactic text formatting method;
- describe two research approaches used to validate this formatting method;
- compare the results of these approaches;
- and discuss the results' implications for reading science, literacy and content-area learning.

Perspectives and theoretical framework.

Over the past 30 years, NAEP reading proficiency scores for the 4th, 8th, and 12th grade have remained unchanged, despite over $200 billion in federal programs. [1] Moreover, growth in proficiency flattens out beyond the 4th grade, and the gap between actual and targeted proficiency widens with each passing year. This widening proficiency gap through the higher grades cannot be attributed entirely to inadequate word-decoding skills: an intermediate step between word-decoding and higher-order comprehension is another possible factor. Converging educational and neurocognitive evidence over the past 30 years indicates that this intermediate step may be syntactic processing, and reveals new strategies in text formatting to improve reading proficiency.

Observational studies show that better readers, (children and adult), first gravitate toward the point in a sentence where the subject phrase separates from the subsequent predicate phrase. [2] Longitudinal studies indicate that one's syntactic awareness in the

5th grade is predictive of the reading proficiency that one will attain in adulthood.[3] Studies of reading in a non-native language demonstrate that reading difficulty increases in proportion to the difference between the syntactic rules of the non-native versus native language.[4]

Neurophysiologic and fMRI brain investigations have discovered that syntactic processing is performed in discrete cortical areas [5] [6] [7], and *dynamically collaborates* with lexical and other cognitive processes that are performed in separate regions. [8] [9]

Prosody (the pauses, cadences, and varying patterns of pitch with which words and phrases are spoken) contains syntactic cues that directly and immediately assist in listeners' comprehension. [10] [11] When prosodic-syntactic cues are experimentally stripped away from speech, listeners' comprehension drops [12]; when language is written down, many of these same syntactic cues are similarly stripped away. [13]

Readers' eye-movements frequently "regress" to previously viewed words, in order to revise tentative syntactic interpretations that were discovered to be incorrect. [14] Regressions illustrate how conventional "block" formatting fails to harness, and, instead, impedes natural capacities for visual pattern recognition. [15] [16] Such block text surrounds each fixation field (typically 9 to 15 characters across) with a homogenous array of visually similar elements (a "sea of words") that compete for the "attentional spotlight" of visual processing. [17] [18] This competition for attentional resources impels the visual system, when viewing block text, to adopt visual "searching" procedures (which retain no memory of the visual data in a fixation field); by contrast, when examining objects and natural scenes, the visual system employs image-building, "scanning" procedures (which retain and integrate visual data from multiple fixations). [19]

For the past 50 years, various phrase-cueing methods have been proposed to improve reading; however, results have often been irregular and irreproducible, and have depended on the type of reader and reading material. [20] [21] [22] These mixed results, and the considerable effort and cost of preparing phrase-cued material, have prevented broad implementation of phrase-cueing.

A possible cause for the limited effectiveness of prior phrase-cueing methods (including earlier computer-based methods that simply used function words to chop text into concatenated segments) may be their inability to represent the complex, multidimensional syntactic relationships that exist in over half of the sentences found in contemporary documents.[23] This multidimensional, “recursive”, structure in syntax -- in which clauses are embedded or “nested” within other clauses -- is now recognized as the factor that enables the human language faculty to represent an infinite number of sentence meanings. [24]

The Rand report on Reading Comprehension [25] and the report of the National Reading Panel [26] identify fluency and phrasing as bridging-steps between mere word-decoding and higher-order comprehension. The Rand report also identifies “repeated oral-reading exercises” as one of the few methods proven to increase reading fluency and reading comprehension, (even for content that was not read repeatedly with the exercise). These exercises help the reader create an "acoustic diagram" of the sentence's syntactic structure, serving, in effect, as an <u>implicit</u> method to make students aware of syntactic variety. [27] [28]

Description of the visual-syntactic formatting method.

Multidimensional visual-syntactic text formatting is a cueing method that exploits the visual system's capacity for pattern recognition, by explicitly, (but, as in prosody, transparently), depicting the recursive structure of syntax. To make the implementation of the method feasible and consistent, the text analysis algorithms are computer-executable. In contrast to earlier programs that simply used function words to chop or "chunk" the text into concatenated segments, the new visual-syntactic algorithms recursively identify multiple levels of syntactic hierarchies between phrases and clauses in the sentence, and then use this hierarchical information to vary the relative horizontal displacement of each segment. The current software parsing engine performs over 2 million calculations to transform a 30-word, 9th grade level sentence.

Because the spatial lengths of syntactic units can vary widely, the algorithms include visual criteria to recursively parse the text into ever shorter segments until the length of each segment fits into one or two visual fixation eyespans; the accompanying generative indentation of such successively parsed segments depicts their syntactic ancestry, with spatial cues that can be perceived in the periphery of each fixation.[29 30] With such an integrated multidimensionality between syntactic and visual structure, visual processing of the displayed text can now employ an image-building "scanning" strategy, (rather than a memory-less "searching" strategy), and engage the visual system's capacity for pattern recognition to guide eye-movements, direct the attentional spotlight, and assist in interpretation of the text.

Validation of the Method.

Neurocognitive research. The initial validation research examined 48 college students in a university-based neurocognitive laboratory. In a "within subjects" design, participants read six 500-word, expository passages: 3 passages in the standard, word-wrap format, and 3 passages in the cascading phrase format. Both formats used monochrome 15-point font and single inter-line spacing; the standard, "word-wrapped", format was ~70 characters wide, with left-only justification. The order of passages and their format were randomized across participants. Each participant was tested individually, reading from a 17-inch computer display, and advancing text with a "slide show" (not scrolling) method. The testing software allowed readers to move back and forth within a single passage, but prevented re-reading a passage after leaving it; in this way, overall reading time per passage was also measured. Immediately after the reading session, participants completed survey questions and took a written test with four investigator-prepared, retention/comprehension questions for each of the 6 passages, (which were later graded in a blinded manner following stringent criteria). A testing session lasted about 1.5 hours.

Results. *Retention/Comprehension Performance.* Scores on the retention/comprehension tests were 40% higher with the visual-syntactic format ($p<0.05$, one-way ANOVA). Reading efficiency (retention-comprehension score ÷ passage reading time) was also significantly higher (30%) with the visual-syntactic format ($p<0.05$). These effects were seen across the entire range of reading ability levels.

Eyestrain and Format Preference. Forty-one percent reported eyestrain symptoms while reading the conventional format; by contrast, only 11% reported eyestrain symptoms with the visual-syntactic format, (X^2 p<0.01). Sixty percent preferred the visual-syntactic format to conventional format; notably, among the 40% of participants who preferred the conventional format, comprehension scores nevertheless were significantly higher with the visual-syntactic format.

Classroom-based research. The new format was then evaluated in a yearlong (7 month) classroom-based study, involving 100 high school students. Randomization occurred at the class section level. Both the control and intervention groups spent 50 minutes a week (averaging 20 minutes in each 90-minute, every-other-day class) reading the same passages from the textbook assigned for the course (9th grade World History). Because of the possibility that any computer-based reading might result in a significant decline in learning compared to paper textbooks, control sections read from standard, paper textbooks. Each participant in the intervention group read from an individually assigned 15-inch computer monitor in a computer lab.

Results. *Immediate retention/comprehension.* Students who read textbook passages in the visual-syntactic format had significantly higher scores on publisher-provided quizzes administered after each reading session, averaging 75.6% correct, compared to 62.5% correct for the students reading conventional text (p<0.001, ANOVA). Notably, this effect was greater in the quizzes taken at end of the academic year, (83% vs. 62%), than at the beginning of the year (71.5% vs. 63%).

Intermediate and long-term retention. Similar results were found with periodic, publisher-provided unit exams that were given approximately every 6 weeks during the 7-month study. The final exam contained questions from quizzes given throughout the academic year, representing a measure of long-term retention and learning. Compared to pretests given at the beginning of the year, the visual-syntactic group scored an additional 77.5% correct on the final exam (95% Confidence Interval [CI] 73.8 to 81.1), whereas the control group scored an additional 63% correct (95% CI 60.2 to 66.2), a highly significant difference ($p<0.001$, ANOVA).

Impact on Long-term Reading Proficiency in any text format. Before and after the yearlong intervention, students took the *Terra Nova*® (McGraw-Hill) nationally standardized reading test. At the end of the 7-month intervention, the control group's national percentile ranking on the test was 57.5 -- not significantly different from its baseline of 59. By contrast, the visual-syntactic group's national percentile ranking increased significantly, from a baseline of 57 to 66.5 -- a 9.5 percentile point increase (95% CI 6.3 to 12.8, $p<.001$). The school district's analysis of these students' annual, state-mandated reading tests showed gains that were similar in magnitude and significance to the *Terra Nova* results.

Significant benefits from visual-syntactic formatting were seen across all levels of baseline reading aptitude, and among non-native English readers.

A post hoc *Levene Test for Homogeneity of Variance* was not significant across all groups and measures, indicating that the differences found were the result of the intervention, rather than innate differences between the study groups.

As was found for college readers, the high school students also indicated a preference for visual-syntactic formatting over conventional text, by a 3 to 1 ratio. Further research with visual-syntactic formatting, spanning grades 6 through 12, will occur during the 2003-2004 academic year.

Conclusion.

Combining advances in the neurocognitive sciences of vision and language to develop new educational and literacy interventions requires unique validation strategies. Novel interventions entail the risk of reducing student learning during a curriculum-based study. In this research, such a risk was minimized by first conducting a laboratory-based experiment; the controlled conditions of this initial experiment also allowed for measurement of reading time (and calculation of reading efficiency), and comparison of eyestrain symptoms. Conversely, the classroom-based study, while corroborating the laboratory research results, was also able to measure cumulative, long-term effects on learning and reading proficiency -- measurements that were not feasible in the single-session, laboratory-based studies.

The mechanism by which visual-syntactic formatting increases reading proficiency (in any text format) may be through increasing syntactic awareness -- with an explicit and, (compared to diagramming), relatively transparent syntactic edifice that can be perceived in conjunction with the reading of the text itself. The method can also present a larger variety of sentences than is feasible in formal syntax instruction or repeated oral reading exercises.

Visual-syntactic formatting can be used as a research tool to illuminate the cognitive interactions between fluency, prosody, syntactic awareness, and comprehension. The new formatting method also creates new categories of neurocognitive interactions, such as those between visual pattern recognition, syntactic processing, and the dynamics of building higher-order representations during the reading process.

Visual-syntactic formatting immediately helps college students read more efficiently, and reduces the eyestrain that frequently develops with prolonged electronic reading. Because the texts that college students use are increasingly digital in form, visual-syntactic parsing software could help many college readers, including the 30 to 40% of college freshmen who require remedial instruction to be able to read college-level material effectively. [31]

For high school students, visual-syntactic formatting directly improves both comprehension and long-term retention of content area texts, while strengthening students' reading proficiency

This dual benefit
on learning and
reading proficiency
creates an opportunity
to enhance literacy skills
with content-area classes,
enabling more students
to pass state-mandated
reading and academic achievement tests.[32]

References

[1] National Center for Educational Statistics. (1998) http://nces.ed.gov/nationsreportcard/pdf/main1998/1999500.pdf

[2] Fodor JA and Bever TG (1965). The psychological reality of linguistic segments. *Journal of Verbal Learning and Verbal Behavior, 4,* 471-483.

[3] Cupples L and Holmes VM. (1992) Evidence for a difference in syntactic knowledge between skilled and less skilled adult readers. *Journal of Psycholinguistic Research.* Vol. 21(4): 249-274.

[4] Frenck-Mestre C and Pynte J (1997). Syntactic ambiguity resolution while reading in second and native languages. *Quarterly Journal of Experimental Psychology. A. Human Experimental Psychology.* Vol 50A (1): 119-148, Feb 1997.

[5] Friederici AD, Opitz B, and von Cramon Y. (2000) Segregating Semantic and Syntactic Aspects of Processing in the Human Brain: an fMRI Investigation of Different Word Types. *Cerebral Cortex,* Vol. 10, No. 7, 698-705, July, 2000.

[6] Hanne A and Friederici AD (1999). "Rule-Application During Language Comprehension in the Adult and the Child." Chapter 3 in: *Learning: Rule Extraction and Representation,* Friederici AD and Menzel R (eds). Berlin/New York. Walter de Gruyter.

[7] Pinker S (1999). *Words and Rules: The Ingredients of Language.* New York. Basic Books.

[8] Keller TA, Carpenter PA, and Just MA. (2001) The Neural Basis of Sentence Comprehension: a fMRI Examination of Syntactic and Lexical Processing. *Cerebral Cortex,* Vol. 11, No. 3, 223-237, March 2001.

---

[9] Kempen G. (1999). "Sentence Parsing." Chapter 7 in: *Language Comprehension: A Biological Perspective, Second Edition.,* Friederici AD (ed). Heidelberg, Springer-Verlag.

[10] Steinhauer K, Alter K, Friederici AD. (1999). Brain potentials indicate immediate use of prosodic cues in natural speech processing. *Nature Neuroscience*. 2 (2): 191-196, February, 1999.

[11] Ferreira, Fernanda and Anes, Michael (1994) , "Why Study Spoken Language?", Chapter 2. In *Handbook of Psycholinguistics,* Mortan Ann Gernsbacher, ed., (pp 34-36). Academic Press, San Diego. 1994.

[12] Cutler AD, Dahan D, van Donselaar W (1997). Prosody in the comprehension of spoken language: a literature review. *Language and Speech* 40: 141-201.

[13] Fries CC (1963). *Linguistics and Reading.* New York: Holt, Rinehart, and Winston.

[14] Rayner K (1999). "What have we learned about eye-movements during reading?", Chapter 1 in: *Converging Methods for Understanding Reading and Dyslexia,* Klein RM and McMullen P (eds). Cambridge, MA. MIT Press.

[15] Hoffman D (1998). *Visual Intelligence: How We Create What We See.* New York: W.W. Norton.

[16] Petitot J (1995). "Morphodynamics and Attractor Syntax: Constituency in Visual Perception and Cognitive Grammar" in *Mind as Motion: Explorations in the Dynamics of Cognition*, (pp. 228-280). Cambridge, MA: MIT Press.

[17] Vidyasagar TR and K Pammer. (1999). Impaired visual search in dyslexia relates to the role of the magnocellular pathway in attention. *NeuroReport.* 1999 10:1283-1287

[18] Demb JB, et al (1997). "Brain activity in visual cortex predicts individual differences in reading performance." *Proc. Natl. Acad. Sci.* 1997 (Nov 25); 94: 13363-13366.

[19] Horowitz TS and Wolfe JM. (1998). Visual search has no memory. *Nature* 394: 505-507

[20] Conte B, Menyuk P, Bashir A.(1994) Facilitating reading comprehension in middle school students with language disorders. *International Jounal of Psycholinguistics.* Vol. 10 (3): 273-280.

[21] Mason JM and Kendell JR (1978) *Facilitating reading comprehension through text structure manipulation (Technical Report No. 92).* Champaign, Ill. Center for the Study of Reading, University of Illinois.

[22] Geoffrion LD and Geoffrion OP (1983) . *Computers and Instruction: Reading.* Addison-Wessley Publishing Co.

[23] Hindle D, Rooth M (1993). Structural ambiguity and lexical relations. *Computational Linguistics* 19: 103-120.

[24] Hauser MD, Chomsky N, and Fitch WT (2002) "The Faculty of Language: What is it, Who has it, and How did it Evolve?" *Science* 298: 1569-180

[25] http://www.rand.org/multi/achievementforall/reading/readreport.pdf

[26] http://www.nichd.nih.gov/publications/nrp/smallbook.htm

[27] Samuels SJ (1979). The method of repeated reading. *The Reading Teacher* 32: 403-408.

[28] Laberge D and Samuels SJ (1974). Toward a theory of automatic information processing in reading. *Cognitive Psychology,6,* 293-323.

[29] Legge BE, Ahn SJ, Klitz TS, Luebker A (1997). "Psychophysics of Reading –XVI. The Visual Eyespan in Normal and Low Vision." *Vision Research* 14: 1999-2010.

[30] Pollatsek A, Raney GE, La Gasse L, and Rayner K (1993). The use of information below fixation in reading and in visual search. *Can. J. Experiment. Psychol.* 47: 179-200.

[31] Wessel, David (1998) "Who Will Teach Johnny to Resd?" *Wall Street Journal*, page 1, November 9, 1998.

[32] The indented formatting shown is the direct output of the current visual-syntactic text-parsing engine.