Rapid Automatised Naming (RAN) and Reading Fluency: Implications for Understanding and Treatment of Reading Disabilities

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This review examines both rapid automatised naming (RAN) and reading fluency and how each has shaped our understanding of reading disabilities. The way automaticity that supports RAN affects reading across development, reading abilities, and languages is explored together with the biological bases of these processes. The contribution of collective studies of RAN and reading fluency to our goals of creating optimal assessments and interventions to help every child become a fluent, comprehending reader is also examined.

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Fluent reading depends on a complex set of cognitive processes that need to work perfectly together. Rapid automatised naming

(RAN) tasks provide insight into this system, acting as a microcosm of the processes involved in reading. This review examines both RAN and reading fluency and how each has shaped our understanding of reading disabilities. The way the automaticity that supports RAN affects reading across development, reading abilities, and languages is explored together with the biological bases of these processes. The contribution of collective studies of RAN and reading fluency to our goals of creating optimal assessments and interventions that help every child become a fluent, comprehending reader is also explored.

- To be a successful reader, it is necessary to rapidly integrate a vast circuit of brain areas with great accuracy and remarkable speed.
- This 'reading circuit' is composed of neural systems that support every level of language: phonology, morphology, syntax, and semantics – as well as visual and orthographic processes, working memory, attention, motor movements, and higher-level comprehension and cognition.
- When each of these components work smoothly with accuracy and speed, the reader develops what is called automaticity.
- As a cognitive process becomes automatic, it demands less conscious effort.
- The development of automaticity at all the lower levels of reading represents the great apex of development that provides us with the bridge to true reading with its capacity to direct cognitive resources to the deepest levels of thought and comprehension.
- It is imperative to comprehend the meaning of a text in order to go beyond what is on the page; in other words, to make connections to existing knowledge, to analyse the writer's argument, and predict the next twist in the story.

What is reading fluency?

- The term ‘fluency’ has been used to describe the speed and quality of oral reading (often emphasising prosody); however, this definition does not encompass all the goals of reading or reflect the fact that most of our reading is done silently rather than aloud.
- Here, reading fluency is examined in terms of what has been called ‘fluent comprehension’: a manner of reading in which all sub-lexical units, words, and connected text and all the perceptual, linguistic, and cognitive processes involved in each level are processed accurately and automatically so that sufficient time and resources can be allocated to comprehension and deeper thought.

What is rapid automatised naming?

- The seemingly simple task of naming a series of familiar items as quickly as possible appears to invoke a microcosm of the later developing, more elaborated reading circuit.
- RAN tasks are considered one of the best, perhaps universal, predictors of reading fluency across all known orthographies.
- RAN tasks and reading are considered to require many of the same processes (eye saccades, working memory, and the connecting of orthographic and phonological representations).
- RAN tasks depend on automaticity within and across each individual component in the naming circuit.
- RAN has been referred as one of the universal processes that predict the young child’s later ability to connect and automatise whole sequences of letters and words with their linguistic information, regardless of the writing system.
- RAN tasks have proven to have great potential because

children can perform RAN tasks (such as naming familiar objects or colours) well before they are able to read and because RAN is correlated with reading ability in kindergarten and beyond.

History of research on reading disabilities

- Reading difficulties can be classified into two main types: developmental and acquired.
- The effects of developmental dyslexia begin in childhood and makes learning to read and developing reading skills difficult.
- Acquired reading difficulties (usually called alexia) often result from a brain trauma, such as an injury or stroke.
- In the late 1800s, physicians including Jules Dejerine and Adolf Kussmaul described patients who suffered brain injury with subsequent reading difficulty (despite intact language and vision) using the term 'word-blindness'.
- John Hinshelwood and W. Pringle Morgan were among the first to describe 'congenital word blindness'; that is, reading difficulty beginning in childhood that is not due to injury.
- Neurologist Samuel Orton developed a theory that inappropriate cerebral dominance accounted for the reversed letters and words sometimes observed in children with reading difficulties.
- He noted that many struggling readers he observed had average or above-average intellectual abilities, that perhaps as many as 10% of children might suffer from reading difficulties, and that reading difficulties were not likely due to a single brain abnormality.

History of RAN tasks

- In the 1960s, neurologist Norman Geschwind conceptualised the core deficit in alexia as a disconnection between the visual and verbal processes in the brain.

- He emphasised the importance of connectivity among brain regions (particularly association areas such as the angular gyrus) that act as a switchboard or relay station for different brain regions.
- The first RAN measure was based on an array of 50 coloured squares arranged in a grid with five rows, where each of five familiar colours was repeated in a random order.
- Geschwind did not believe that colour naming was an aspect of reading; rather, the neural processes supporting rapid serial colour naming might be similar to those involved in reading.
- Neurologist Martha Denckla (1972) discovered five boys who had dyslexia and were particularly slow and inconsistent in serial colour naming for their age, despite typical intelligence and colour vision.
- Together with Rita Rudel, Denckla created three other versions of the speeded serial naming test using objects, letters, and numbers as stimuli.
- They coined the term ‘rapid automatised naming’ to describe these tasks that were designed to measure the speed of naming familiar items.
- They found that RAN latencies were not related to how early certain stimuli were learned, but how ‘automatised’ the naming process was.
- Performance on RAN tasks differentiated children with reading difficulties from typical readers of the same age and from children with other, nonlanguage-based learning disabilities.

Toward a multi-componential view of reading and reading disability

- LaBerge and Samuels’ (1974) model of reading was one of the first to emphasise what we now know as ‘fluency’; the idea that successful reading depends on not only accuracy but automaticity of multiple cognitive and linguistic processes, requiring minimal conscious effort.

- Another possible core deficit associated with dyslexia is difficulty with phonological awareness (PA), which involves the explicit ability to identify and manipulate the sound units that comprise words.
- Isabelle Liberman (1971) promoted the idea that reading development depends on explicit awareness of the sounds of language and that possibly the greatest challenge facing young readers is learning to match the phonemes of speech with the graphemes that represent them in print.
- It is now generally agreed that PA is a crucial precursor to reading acquisition in alphabetic languages, and that many (if not most) children with dyslexia have PA deficits.
- We know that the reading circuit is intrinsically complex and that a lack of accuracy or automaticity at one of any number of levels can cause reading difficulties.
- Wolf and Bowers (1999) found that phonological awareness and RAN contributed separately to reading ability.
- They proposed the double deficit hypothesis (DDH) to demonstrate how children can be characterised in various subgroups according to their performance in each set of processes.
- According to this hypothesis, a deficit in either PA or naming speed can cause reading difficulties, with RAN deficits indicating weakness in one or more of the underlying fluency-related processes (and not simply a naming speed deficit).
- These deficits can co-occur, and children with a double deficit in PA and RAN characterise the most severely-impaired readers.

- Studies have suggested that 60% to 75% of individuals with reading or learning disabilities exhibit RAN deficits.

Defining the RAN tasks

- RAN tasks have been described in the literature using slightly different terms, such as rapid serial naming, serial visual naming, continuous rapid naming, rapid naming, and naming speed. In this review, RAN is used to mean generally any rapid automatised naming task or process.
- **RAN tasks** involve timed naming of familiar stimuli presented repeatedly in a random order, in a left-to-right serial fashion. In some uses of the RAN task, self-corrections and errors are noted for the purposes of qualitative observations; however, the key dependent variable is the total time taken to name the items. It is crucial that the items to be named (whether objects, colours, letters, or numbers) are sufficiently familiar to the examinee.
- The two most widely used **standardised tests of RAN** in the USA are the Rapid Automatised Naming-Rapid Alternating Stimulus (RAN-RAS) Tests by Wolf and Denckla, and the rapid naming subtests of the Comprehensive Test of Phonological Processing (CTOPP) by Wagner and colleagues. The CTOPP uses a shorter format that is considered by its authors to measure phonological retrieval. Both these measures are standardised and normed on large samples. A child’s raw score on these tests can be used to derive a standard score and percentile rank, which provides information about how the child performed relative to others of the same age or grade level.
- **RAN-RAS Tests** include the four classic subtests of RAN measures: objects, colours, numbers, and letters, as well as two RAS subtests. Each of the subtests has 50

items arranged in 5 rows of 10 items each. The five different token items for each subtest are pseudorandomised with no item appearing consecutively on the same line. The RAS was first developed in the 1980s by Wolf to incorporate processes involved in switching and disengaging attention to rapid-naming tests. The RAN-RAS tests include a 2-set RAS composed of alternating letters and numbers and a 3-set RAS with alternating letters, numbers, and colours. Norms are available for individuals aged 5–18.

- **The CTOPP** conceptualises rapid naming as one of three subcomponents of phonological processing, along with phonological awareness and phonological memory. The rapid naming subtests measure rapid object, colour, digit, and letter naming. For each subtest, there are six token items, and the task is divided into two parts, with the items arranged in two arrays on separate pages. Each of the 2 arrays include 4 rows of 9 items, for a total of 72 items. The test is normed for individuals aged 5–24.
- The RAN-RAS tests treat rapid naming as a cognitive ability that includes phonology but also other linguistic and visual processes. In contrast, the CTOPP was designed based on a model of overall phonological processing that includes phonological awareness, phonological memory, and rapid naming as related subcomponents.
- Wolf and colleagues enumerated seven related **processes that are involved in rapid naming**: a) attentional processes to the stimulus; b) bi-hemispheric visual processes responsible for initial feature detection, visual discrimination, and pattern identification; c) integration of visual features and pattern information with stored orthographic representations; d) integration of visual and orthographic information with stored phonological representations; e) access and retrieval of phonological labels; f) activation and integration of

semantic and conceptual information with all other input; and g) motoric activation leading to articulation.

- There are several reasons **why RAN should be considered independent from phonological processing**: 1) RAN and PA are only moderately correlated and load on separate factors; 2) regression and structural equation models consistently report that RAN and PA account for unique variance in reading ability; and 3) genetic and neuroimaging studies find different biological bases for RAN and PA abilities. Functional brain imaging studies of the two tasks show some shared regions, as would be expected with their similar task demands, yet also separate areas of processing.

Characteristics and predictive value of RAN across development

- The measures that most consistently predict future reading difficulty in English are phonological processing/awareness, letter-name knowledge, and RAN.
- RAN-reading relationships are stronger in poor than in typical readers.
- **Prediction in kindergarteners and prereaders.** 5- and 6-year-olds often name the colour and object (nonalphanumeric) stimuli more quickly than letters and numbers (alphanumeric stimuli). With more practice and exposure, the alphanumeric stimuli become much more automatic and are named faster than nonalphanumeric stimuli. At this point, alphanumeric RAN becomes more strongly associated with reading ability. These differences underscore the importance of considering alphanumeric RAN separately from nonalphanumeric RAN stimuli.
- RAN and phonological processing tasks are valuable tools because both are excellent predictors of reading ability that can be assessed before children learn to read; thus, they can be used as easy indicators of risk for

reading difficulties.

- In a large longitudinal study from kindergarten to 2nd grade, RAN objects and PA predicted later outcomes on untimed passage comprehension in a similar way. However, RAN may have a stronger impact on timed reading measures (no timed measures were used in this study).
- **Prediction in school-age and beyond.** Longitudinal studies suggest that RAN scores measured in early school grades significantly predict later reading and spelling scores, and the predictive value of RAN seems to be stronger and more stable in poor readers than in typical readers. RAN seemed to be strongly related to decoding; however, it did not predict untimed reading comprehension measures in the later grades in typical or disabled readers. Unfortunately, the outcome measures did not include any timed reading or fluency tasks.
- RAN ability differences persist between young adults with and without dyslexia.
- A Dutch study found that the developmental trajectory of alphanumeric RAN reached an asymptote after age 16 but that RAN latencies for colours and objects continued to decrease through adolescence and adulthood.
- The correlations between alphanumeric RAN and reading are also significant through adulthood.

Cross-linguistic studies of RAN and fluency

- RAN and its relationship to reading have been studied in relation to many of the world's languages, with findings following the general pattern of what is known about RAN in English: that RAN predicts reading (both concurrently and longitudinally) in both typically developing and reading-impaired populations.
- Alphabetic languages can be considered on a continuum based on the complexity of the mapping between sounds and letters (or phonology and orthography). The orthography of English is considered very deep (or

opaque) because the correspondences from phonemes to graphemes are not consistent. Many other alphabetic languages such as German and Spanish have what is called a shallow or transparent orthography, where grapheme–phoneme correspondences are highly predictable. Learning sound-to-letter correspondences and decoding is more straightforward in these orthographically shallow languages.

- PA is important in early reading acquisition but as children essentially reach a ceiling in their ability to decode words accurately, a shift occurs in which the relationship between RAN and reading becomes much stronger. Children reading more transparent languages shift away from phonology earlier in schooling.
- Orthographic complexity affects the relationship of PA and reading ability; however, the relationship of RAN and reading is essentially consistent across languages.
- Nonalphabetic languages (such as Chinese and Japanese orthographies) are composed of thousands of characters that are essentially unrelated (or much less related) to phonemes. Phonological awareness is a weaker predictor of timed reading in Chinese. RAN is strongly correlated with reading in Chinese and accounts for additional variance after writing (orthographic) ability is controlled for.
- Overall, the differences in RAN across languages and orthographies are small in comparison with the number of similarities.

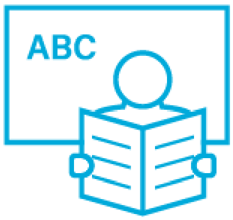
Contribution of neuroscience and genetics to understanding RAN and fluency

- Brain activation for reading-related tasks has been consistently identified in three main areas of the left hemisphere: the inferior frontal gyrus (IFG), the temporoparietal area, and the occipitotemporal area. For people with dyslexia relative to controls, the most consistent finding is an under-recruitment (hypoactivation) of the left temporoparietal and left occipitotemporal areas. Many individual studies have identified areas of the right frontal and temporal lobes that show greater activation in people with dyslexia relative to controls.

- There is some evidence that PA and RAN or fluency abilities may have separate neural substrates.
- Two studies (Misra et al., 2004; Christodoulou et al., 2011) found that for letter naming contrasted with fixation, the RAN task engaged the left inferior frontal gyrus, left posterior middle frontal gyrus, and bilateral inferior occipital areas.
- In one study (Christodoulou et al., 2011), adults with dyslexia had lower standardised RAN scores and lower in-scanner performance. The typical controls engaged several posterior areas in the occipital and parietal regions bilaterally more than the group with dyslexia, whereas the adults with dyslexia demonstrated greater activity than controls in a variety of bilateral temporal, motor, and left supramarginal gyrus (part of the temporoparietal area).
- From EEG research, it is known that different aspects of words are processed along a timeline. For example, initial visual processing occurs within the first 50 ms after a word is presented. Word-specific orthographic processing begins around 150 ms and executive and attention processes at about 200 ms, with phonological processes between 150 and 300 ms, followed by semantic and comprehension processes.
- The mismatch negativity (MMN) ERP component (a pre-attentive response to a difference within a series of auditory stimuli) has been studied as a possible correlate of automatic language processing. The MMN response is a significant predictor of reading outcomes (even better than a combination of behavioural assessments in children) and differs among infants with

and without a family history of reading disability. Recently, it has been found that the MMN response in children was significantly correlated with RAN, timed single word reading, and timed connected text reading (but not with PA or untimed reading).

- In Magnetic Resonance Imaging (MRI), children with dyslexia showed smaller volumes of the pars triangularis area of the IFG bilaterally as well as an area of the right cerebellum. These anatomical measurements were also significantly correlated with RAN scores.
- It may be the case that extreme asymmetries of the planum temporale in either direction may induce risk for dyslexia.
- In a sample (Pernet et al., 2009), 100% of adults could be accurately classified as typical or dyslexic based on the volumes of the right cerebellar declive and left lentiform nucleus (part of the basal ganglia). The concept of a U-shaped curve, in which extreme values on either the high or low end can cause a disorder, could help explain conflicting findings in asymmetry.
- Because RAN and fluency depend on the speed and integration of multiple processes throughout the brain, the extent and quality of white matter pathways may play a substantial role in enhancing understanding of the biological basis of fluency-related processes.
- Heritability estimates for dyslexia range widely, from 0.3 to 0.7 (where a trait that was 100% determined by genetics would measure 1.0).
- Several researchers have reported a set of common genetic influences that affect PA, RAN, and reading (that is, they are all affected by some common genes) but that there are also separate genetic influences on PA and RAN.
- At least nine major candidate genes for susceptibility to dyslexia have been identified located on eight different chromosomes. Most of these are related to neuronal migration and axon growth in utero.



Implications of RAN and fluency for identifying reading difficulties, instruction, and intervention

- RAN tasks can be best used by educators and psychologists as part of a clinical assessment to identify a risk of reading and learning difficulties and as a measure of the development and efficiency of processes related to word retrieval and reading fluency.
- RAN tasks take only a few minutes to administer and require only modest training to administer and score. Using published normed measures, examiners can determine how a child’s RAN ability compares with what is typical for a given age or grade.
- A second important reason for assessing RAN and other fluency issues is that speed and automaticity are essential components of what it means to be a good reader, yet we tend to measure reading too often only in terms of accuracy.
- Children with phonological weaknesses who receive high-quality phonological interventions tend to improve both their PA skills and decoding ability. Although our best interventions can improve most reading and language variables, the RAN changes little from pre- to post-treatment, indicating that RAN taps a more basic index of processing.
- One technique that has been widely used as purported way to improve fluency is repeated reading. However, the entire approach of repeated reading measures yield changes in speed that may not be related to improvements in our *sine qua non* of reading, fluent comprehension.
- There are numerous programmes designed to address phonological decoding skills; however, few explicitly

address multiple components of language (such as orthography, morphology, syntax, and semantics) with the goal of improving fluent comprehension.

- Children who received multi-componential interventions had significantly greater growth than other intervention groups on timed and untimed word and nonword reading and passage comprehension.
- The present review of the fluency research highlights the need for multi-componential interventions, especially for students with RAN or double deficits whose weaknesses are not adequately addressed by a phonological decoding programme.
- Successful intervention for reading disabilities depends on accurate assessment of a child’s profile in terms of both accuracy and speed across all levels of reading, from the sub-word to connected text. Multi-componential intervention programs that target phonology as well as multiple levels of language show the greatest promise in improving reading fluency.

Summary

- RAN measures act as a microcosm of the reading system providing an index of one’s abilities to integrate multiple neural processes.
- RAN and phonological awareness are both robust early predictors of reading ability, and one or both are often impaired in people with dyslexia. Longitudinal, cross-linguistic, genetic, and neuroimaging studies suggest that these two crucial reading-related processes should be considered distinct constructs rather than subcomponents of a single construct.
- It is advantageous to conceptualise fluent reading as a complex ability that depends on automaticity across all levels of cognitive and linguistic processing involved in reading, allowing time and thought to be devoted to comprehension.

- Multi-componential intervention programmes that target phonology as well as multiple levels of language show the greatest promise in improving reading fluency.