Speed of Processing: Tests and Factor Structure

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Abstract
In the present study we examined Speed of Processing derived from a number of cognitive tests; the response speeds were nearly automatic for tests with minimal cognitive load. The tests were given to students across ages from 8 to 20 in schools and colleges located in various parts of India. The structure of the constellation of the test responses was determined by factor analyses. We report one stable factor of speed for ages 8-10 that splits into two separate but correlated factors for ages 11-14,15-17, and 18-20 representing speed of response to tests that contain letters and numbers versus colour stimuli. Developmental changes in response speed across the four adjacent age groups were examined; the trajectory was not consistently incremental, especially for naming colours that did not increase beyond age 11-14.In conclusion, a fairly reasonable deconstruction of the concepts of RAN has been presented in this report. The major components are encoding and articulation, and the necessity of distinguishing alpha-numeric naming time and colour naming. The later requires the additional time for semantic access. At the end, we suggest that in a follow-up research RAN(alpha-numeric&colour) should be viewed as a part of a broader cognitive speed of processing.Our objective is to determine the association between tests of basic executive processes such as cognitive flexibility,attention &inhibition and working memory on the one hand and speed on the other.Consequently not to search for the tests that would not involve speed, but be aware of the value of the correlation of an executive test with sp eed.This will be useful information or example in investigations into the effect of ageing on executive functions. A worthy agenda for future research.
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Concept of Speed of Processing
Individuals differ both in their speed of processing information, as well as how accurately they process information. If speed means the rate of accurately processing information, it may be useful as a measure of intelligence as several researchers have advocated (Jensen, 2006; Vernon, 1987). However, there are at least three issues that need to be settled.

First, we may naively ask 'speed of what?' Speed depends on the kind of information that is being processed. To explain further the issue concerns automatic contrasted with control or deliberate processing. Some information may be processed quickly and automatically (reading a single digit), while other information may be processed slowly and intentionally (reading only the odd, avoiding even numbers in the same list of single digits from 1 to 9) The information processing load is minimal in automatic processing in contrast to tasks that require control or intentional processing (see Schneider and Shiffrin, 1977, who distinguished between two kinds of processing).

For a recent update on speed, refer to the following article *The Structure of Speed of Processing Across Cultures* (Papadopoulos et al., 2018). What do we know from the above article before we begin delineating the tests for speed of processing?

What we know:

1. Speed of processing can be categorized under different types of information, representing major cognitive processes.
2. Processing can also be classed as automatic, and intentional. The Speed of response, then, should be derived from tasks or tests that are automatic and require a minimal cognitive load.
3. Such tasks have a minimal cognitive load; in contrast, a general speed of processing may include complex cognitive abilities such as the speed of reading words, and speed of comprehension, as well as mathematical computations. When speed of complex cognitive processing was included, the structure of speed of processing then was found to be composed of different factors corresponding to specific cognitive processes that were required by the tasks (Papadopoulos et al., 2018).

Broadly speaking, it is difficult to obtain a general factor of speed from tasks that require several different categories of cognitive processing. Some tasks need deliberation and some others may have instantly available responses as Kahneman persuasively argues in *Thinking, Fast and Slow:*(Kahneman, 2011)

The best strategy for measuring speed of response should be to select tests that are nearly automatic and require a minimal cognitive load. Jensen (2006) therefore recommends using *elementary* cognitive tasks for measurement of mental speed mostly in reaction time in his final book *Clocking the Mind*. The above discussion leads us to consider the structure of naming speed tasks in tests of rapid automatized naming (RAN).

The present study reported RAN as a measure of automatized naming speed. Its major objectives comprise identification of the tests, and the trajectory of naming speed development across ages from 8 to 20. Simultaneously, asking 'what develops' we offer a theoretical model of processes involving encoding and articulation in serial naming.

A brief background of RAN tests

Rapid Automatized Naming (RAN) is a task to test how quickly an individual can name letters, digits, colours, or pictures of objects. These are highly familiar items that are presented in continuous rows. The stimulus items in our study comprised letters, digits, and colours.

As is well known, RAN was originally used by Denckla & Rudel (1974). The objective of their research related to using RAN as a possible diagnostic marker for developmental dyslexia. Since then, RAN has been studied mostly in relation to Reading (Norton & Wolf 2012). Variations in rapid automatized naming time in children provide a strong predictor of their later ability to read, and its relationship with other predictors such as phonological awareness, verbal IQ, and existing reading skills (See Kirby et al., 2003 for a review, and Georgiou et al., 2020 for a recent discussion). Through these studies of RAN's relation with reading, we have learnt much about the nature of RAN as a speed measure. Paradoxically, explanation of RAN as a stand-alone concept might have been held back in favour of its 'consanguineous' kinship with reading.

RAN as a Unitary measure of speed

A typical RAN score is a composite of two kinds of stimulus items which are alpha-numeric (letters and single digits), and non-alpha-numeric (colours and naming pictures of objects). The question has been asked if the two different types of items should be combined to index a robust unitary composite, or break into two as separate but interdependent factors. Underpinning the question of a unitary factor is the assumption that the two types of items share exactly the same kind of cognitive processes. Obviously, these are different kinds of stimulus items. If they do share the same what kind of processes are these, and if they do not, what cognitive processes are unique to each kind of items? There is some evidence that processes associated with RAN may be modulated by the age of the participants. The trajectory of development across age, that is tracking the developmental changes, and subsequently providing some plausible explanation would be a challenging task. This leads to the question: What processes change? What changes with development?

Major questions

Question 1: Is Speed of Processing as in RAN a unitary factor or a composite of two separate factors? The question relates to Hypothesis 1.

We are concerned with RAN as an instrument for measuring speed of alpha-numeric naming, and colours.

RAN—Tests and Factors

The speed tests, fashioned after RAN include two separate tests of colour naming, numbers and words, but no picture/object naming. Their stability as measures of speed, and invariance across ages from 8 to 20 years are examined with factor analysis. The question would then be if we would obtain one factor of RAN speed across all age groups, or with an increase in age, there could be two factors. Denckla and Rudel (1974,1976) asked this in their early papers and suggested that RAN for pictures (objects) and colour, can be separated from the speed of naming numbers and letters. More recently van den Boss (2002) working with Dutch samples report finding two factors for students aged 12 and 16, but not in samples of younger students.

Our present research was carried out in India with Indian students from ages 8 to 20. Although medium of instruction was in English, all of them can be classified as English Language Learners (ELL) whose native language was not English (none in our sample were from 'Anglo-Indian' communities whose first language is English). Naming proficiency of students at a younger age may be linked to the degree of automaticity that differentiates naming the two kinds of stimulus items. Younger children might not have developed a sufficient level of automaticity at a younger age but by age 8 (Grade 3), it is safe to assume that knowledge of English alphabets and numbers is well established as they learn English even in Kindergarten & Grade 1. Colour names in English, the other kind of stimulus material to name rapidly would certainly be at a lower level of recognition. Thus, as we explain, accessing colour names, and articulation are generally slow to develop due to more complex reasons.

Hypothesis 1.
RAN response times will show two separate but interdependent factors, one each for letters and numbers, and color naming across age groups 11-14, 15-17, and 18-20. However, for the youngest age group 8 to 10, both alpha-numeric and colors, a unitary factor solution could fit the RAN data.

Question 2 Next question concerns developmental trajectories of Naming Speed (RAN) relates to Hypothesis 2. Several studies on RAN have confirmed that RAN speed increases with age (Georgiou et al, 2020; Segalowitz & Segalowitz, 1993). However only up to a certain age, there is no general agreement as to when each of these response times may reach an asymptote.

Hypothesis 2.
The trajectory of development will be different across different age groups, and for alpha-numeric and colour stimulus material. This concerns the rate at which naming times for the three types of items are projected to increase and reach asymptote could be different and arranged hierarchically. The answer to 'what develops in RAN' may provide a clue to explaining the hierarchy.

A few studies have examined the age at which speed of response to the different stimuli (i.e., naming speed for colors, letters and numbers) may reach a climax modulated by the type of stimuli and the age of the respondent. Whereas some studies show that alpha-numeric naming speed (letters and numbers) may become nearly automatic after Grade 2, others found that that this automaticity is reached closer to Grade 5(average age 11). As an example, Georgiou et al (2020) followed the progression of RAN as related to reading and math from Grade 1 to 5 in primary schools. Their longitudinal study found that RAN tests given at an earlier grade could predict future reading efficiency and math fluency. However, in relation to our present question concerning age – related development in RAN, the investigation showed that RAN measures reached their highest level of performance earlier than Grade 5.

Albuquerque and Simões (2010) demonstrated in a cross-sectional study that covered the developmental span from 7 to 15 years of age that for digit naming an asymptote was not reached until the age of 14. Likewise, in a study spanning an unusually large age range, van den Bos et al. (2002) found that performance in letter and digit naming reached an asymptote at the age of 16. No asymptote was reached for color and object naming even among the group of adults (36–65 years old).

Whereas the focus of tracking the trajectory of naming speed development in the present research report is between ages 8 to 20, one would ask what would be the trajectory of speed beyond age 20? A study by van den Boss (2002) provided some additional data, but a definitive investigation of typical adults must be credited to the work of Jacobson et al (2004). Here we highlight two of the results. First, one may ask why naming time for number and letter required about 12 sec. less time than naming for form, animal, or object? The reasons are not clear either in van den Bos, et al.,(2002) or in Jaobson(2004).

A general agreement appears to emerge in reviewing the age at which naming speed of letters and digits (RAN) compared to colours & objects reach an asymptote. The first group of stimuli (alpha-numeric) approximates an asymptote at an earlier age (16 years) whereas the other group continues to gain in naming speed (Georgiou et al.; 2020; Georgiou & Stewart, 2013; van den Bos et al., 2002). A theoretical model contrasting the two kinds of stimuli can be presented if our results will provide supporting evidence for the hypothesis. Our proposal on how we determine that increment in speed is approaching asymptote will be given in a later section on statistical design.

Secondly, the reader will notice how Jacobson et al. (2004) have designed a study taking into account simple and complex naming speed. They have made an important contribution to the literature on normal decline with ageing, contrasted with early signs of Dementia of Alzheimer Type. In regards to the second point, age-related decline in naming time, is not one of the objectives of the present paper.

As we proceed to read further, it will be apparent that we have proposed a reasonable discussion of the longer latency for naming colours (as well as objects and shapes) in terms semantic access time compared to alpha-numeric. Our proposed explanation can perhaps be one answer to the question why naming time for number and letter required less time than naming for form, animal, object, and colour is not established (Jacobson et al., 2004).

The hypothesis to test is simply stated: Trajectory of development will be determined jointly by age, and the stimulus type. The next and final question concerns *'What develops*? This is discussed in the next section. An answer to the question is relevant for the two hypotheses above.

Hypothesis 3.
Naming time is a composite of cognitive processes comprising pause time and articulation within the broad framework of successive (sequencing) information integration. This hypothesis is examined in terms of analyses and interpretations of existing research.

Pause Time and Articulation Time: Which components may increase with age?
Rapid automatic naming actually involves several different processes. Especially, while naming objects and colours, a semantic lexicon needs to be accessed. Time for rapid naming of letters and numbers do need lexical

access, but it is so fast and overly practiced, one would be safe to assume that pause time and articulation time explanations proposed below are true of objects and colours for accessing the semantic lexicon.

Rapid naming tasks can be divided into the time taken for the articulation of the name of an object, or colour. Research has shown that in case of young children, major individual difference exists in the pauses, rather than in the articulation time. However, among older samples, that is above age 7 and certainly older adolescents and adults, this is not true (Al Dahhan et al., 2020).

How can we explain pauses in terms of cognitive processes? The first component of the pause is disengagement of attention. The child has to give up what he/she has just said and get ready to say the name of the next color or letter. The remainder of the gap time could be broadly named encoding, which ends after finding a name for the next color, assembling the pronunciation for the color name, and forming a motor program for articulation. Each of these three different processes could contribute to the gap time. Moreover, what makes it complex is that even in grade 2, the eyes are fixated on a letter that is after the one being processed, and that one is after the one being said. So an important part of the executive function here is managing this separation and coordination of processing. Of course this is not conscious executive processing, as it is happening within fractions of a second (personal communication, J. Kirby, Nov, 2020). It is suggested that while repeating the stimuli over and over again (as in the typical naming time test of some 40 or 50 items), some amount of reactive inhibition may build up due to the continuous demand on fast reading. Reactive inhibition is expected to arise during massed practice (Eysenck, 1967). When this happens, naming time may be temporarily depressed.

Notice that in Figure 1 the two major components, articulation (the wavy and tall marks of speech) and pause time, are shown. In this case, a child is naming colors (i.e., red, yellow, green, blue). The pauses between the color naming and the articulation of the color name itself are distinctly visible. As the child progresses from kindergarten through Grade 1, he/she is, perhaps, now able to encode faster, to disengage attention more efficiently, and to prepare for articulation by assembling a pronunciation that has become easier.

Method

Participants

The total number of participants was 1700 students within an age range of 8-20 years. The entire set of data was collected from 5 different states of India. At each age from 8 to 20, the number of participants was not less than 80 students. Medium of instruction in schools was English for all students. Administration of RAN tests was a part of a larger project of standardization of an intelligence test. Parents/guardians and the students 15 years and older consented to taking the tests. Teachers and the school authorities permitted the testing.

Tests

Rapid Automatized Naming (RAN) - Letters

The participant was asked to name, as quickly as possible 5 recurring letters that are arranged randomly in five rows of ten. The time taken to name all the stimuli in each task was recorded in seconds.

Rapid Automatized Naming (RAN) - Colors

A page of 40 rectangular **color strips arranged in 8 rows and 4 columns printed in 4 different colours (red, green, blue, and yellow) was presented to the participant. The participant was required to name the color strips quickly without making a mistake.** The time taken to name all the stimuli in each task was recorded in seconds.

Administration Directions

The participant was asked to identify the colors in a series of coloured rectangles. The following instructions were given: *"Look at this page, tell me the names of the colours as fast as you can. Start here* (point to the first rectangle of the top row), *then go across this way* (gesturing from left to right). *When you finish the row, go on to the next one. Ready? Start.* As the participant names the colours, immediate feedback was provided. A second trial was given to the participant. This time feedback was not provided and number of correct responses and the total time to complete the item was recorded. If the participant was still working after 3 minutes (180 seconds), the trials was stopped and the recorded time was 181 seconds.

Color Naming 2nd task (Colour-Shape shifting)

This task comprised two rectangles of either blue colour or red colour. The rectangles were arranged in 4 columns by 4 rows. Each colour rectangle contained an embedded shape (outline of a box or a cross). The participant was instructed to disregard the shape, and name the colour instead.

Two stimulus pages were presented for naming the colours. Time for naming colours in each page was recorded. The total time for naming 32 colour strips was the task score. The two repetitions of naming each page are likely to increase the reliability of the colour naming response.

Statistical Procedure

Naming response speed maybe best represented in two factors, one for RAN letters and Digits, and the other for colour naming. However, this may be influenced by the degree to which automatize of naming matures with age. Factor Analysis is suggested as the preferred statistical procedure. Three different statistical indices are recommended: (1) a decrement in RAN means as an index of increment in speed, (2) and corresponding decrement in SDs until an asymptote is reached. (3) Additionally, a decrement in coefficient of variation, dividing SD by reaction or response time (Jensen, 2006[1]), is suggested as a reliable index rather than variation in mean. This is the preferred statistics especially for speed data collected from different age groups in varied locations of samples of participants. Asymptote is reached when the mean RAN time, SDs and coefficient of variance decrease (Segalowitz & Segalowitz, 1993). Additionally, when naming speed is not likely to gain through practice for a simple task such as RAN for digits and letters at a higher age, 18-20 years, SDs reflect random variation.

Results

We have presented the findings of the study by linking statistical analyses to the hypotheses.

Hypothesis 1

RAN response times will show two separate but interdependent factors, one each for letters and numbers, and color naming across age groups 11-14, 15-17, and 18-20. However, for the youngest age group 8 to 10, both alpha-numeric and colors, a unitary factor solution could fit the RAN data.

Ages 8 to 10

RAN digit, RAN letter, Col naming in Stroop, Col naming in Shape-Col Shift

Parallel analysis suggests that the number of factors equals 1.

Proportion of variance explained is 72% for the combined speed factor. As evident in examining the loadings of the 4 tests, the RAN letters and numbers had very high loadings. In contrast the two colour tests had high loadings, but not as high as letters and numbers. Accordingly, common variance contributed by the letters and numbers tests are as high as possible whereas the two colour tests contributed with a moderate proportion of common variance, their unique variance therefore is visibly higher.

Ages 11 to 14

RAN Digit, RAN Letter, Col naming in Stroop, Col naming in Shape-Col Shift parallel analysis suggests that the number of factors equals 2. The factor correlation is 0.89.

As tables 2 and 3 suggest, two separate factors are obtained. One primarily represents the alpha-numeric (numbers and letters), and the other a colour naming factor. The two separate factors are highly correlated factors (0.89). Proportion of variance explained by alpha-numeric items is slightly higher.

In comparison with the younger age group, it may be suggested that students by that age are in middle school; their naming speed for colours in contrast to naming alpha-numeric items access a different cognitive process.

Ages 15 to 17

Parallel analysis suggests that the number of factors equal 2 and the number of components are 2. The factor correlation is 0.42.

Tables 4 and 5 showed two strong factors can be easily distinguished: an alpha-numeric and a colour naming factor. Both factors have comparable proportions explaining around 0.50; as well, unique variance is relatively small for both kinds of items.

Age 18-20

Parallel analysis suggests that the number of factors equals 2 and the number of components equals 2. The factor correlation is 0.15.

Hypothesis 2

When the ages are grouped into four, the trajectories of speed development showed a relatively stable picture. The corresponding tables and graphs are presented next.

Trajectories of speed development age group by age group.

Table 8 show means, SDs, and coefficient of variation. The age at which an asymptote has been reached for naming the 4 kinds of stimulus items.

A visual inspection of the values of the 4 items reveals a gradual trend of faster speed over adjacent age groups in means. However, are the values in adjacent age groups significantly different? ANOVAS followed by a significance of difference for adjacent age groups are reported separately in Table 9.

The results showed that mean speed of RAN increases gradually across the age groups except when ages 15 to 17 are compared to ages 18 to 20. In contrast colour-naming did not show a consistent increment across age groups. Especially, the Col naming time for the second item.

We present a comparison of total RAN (letters and numbers) and total colours in a user-friendly table across

[1]Coefficient of variation is introduced as an "Intra-individual trial to trial variability in RT measured as standard deviation of individual RTs over *n* trials (...) it is more important from a theoretical view point than the measures of central tendency." (Jensen, 2006, p.202)

age. The results are as follows: As Table 9 shows, main-effect for age group variance yielded a significant F ratio. This was followed up by comparisons between adjacent age groups using Tukey's Post-hoc test of alphanumeric RAN (numbers and letters), and the two Colour Naming tasks.

The results for comparison of adjacent age groups are given below.

(1) Colour naming takes longer than RAN (letters and numbers)
(2) RAN reaches an asymptote by ages 15 to 17. In contrast, naming speed for colours does not seem to stop increasing by that age.
(3) On the whole, comparison of adjacent age groups showed (a) naming speed for RAN (letters and digits) increases with age for 8 to 10, and 11 to 14 year-old participants. As an exception, the speed difference between the two older age groups (15 to 17 and 18 to 20 yrs.) are not significantly different.
(b) Colour naming time across adjacent age groups were not significantly different.
(4) In terms of coefficient of variation which indicates the percentage of stability, Colours on the whole are less stable; and the second col shift naming task by the oldest age group (18 to 20 yrs.) is the least stable of them all. This may be anticipated from the sudden increase in coefficient of variation in age 18 to 20. In regard to this result, factor loadings in Factor Analyses should be inspected.

The graphs first showed group differences for the 4 stimulus items. In the next set of graphs RAN letters and numbers have been combined. Similarly, the two colour naming items have been combined. Inspecting the overall trends of change, it is apparent that deviant trend is observed in Coefficient of Variation. It is largely because of one of the color tasks (colour shift) reflecting the behaviour of the four age group, 18 to 20 age group.

ANOVA tests among the four age groups for RAN numbers, RAN letters, Color shift, and Color differences across the 4 age-groups were significant. The mean naming time graph showed that generally speed became faster but differences among adjacent age-groups in speed was not significantly faster as post hoc comparisons revealed in Tuckey's test were not always significant.

DISCUSSION

Question 1: The question relates to Hypothesis 1

The results of factor analysis clearly allow us to conclude that whereas for the youngest age group,8-10, only one robust factor of speed seems to emerge, two factors a) alpha-numeric, and b) colour-naming are obtained for the remaining three age-groups. A finer analysis of the factor loadings for the oldest age-group reveals that Color naming contributes significantly more to common variance than do RAN numbers and letters. A reasonable interpretation rests on the idea that since RAN numbers and letters naming speed have clearly reached asymptotes and exhibit automaticity even by age 15-17, variance beyond this age has a minimal contribution to common variance, and thus have a larger unique variance. This is supported by an examination of ANOVAs and further analyses of trajectories of development comparing adjacent age-groups as reported in the Results.

Question 2: Developmental trajectories of Naming Speed(RAN) & Hypothesis 2

Examination of the result in the descriptive statistics Table 8 revealed that the means expressed as time taken to name the 4 items -RAN numbers, letters, and the two colour naming item- appeared to decrease; that is a gradual descending trend could be detected across the ages except that for the older age groups, 15 to 17 years, and 18 to 20 years, there is no visible decrement. ANOVA followed by tests of significant decrements in adjacent age groups supports this. If we were to conclude that RAN letters, numbers, and the two colour naming scores have reached an asymptote starting with ages 15 to 17 and 18 to 20, our conclusion will be revised when we consider the coefficient of variation (ratio scores in the corresponding graphs). We noticed an erratic response for the oldest age-group in regard to one of the colour-naming tasks On the whole, color naming speed is distinctly unstable in comparison with alpha-numeric naming speed. Mean differences between the two appear to be generally decreasing that indicates that naming speed gets faster. However, the finding is moderated by using coefficient of variation.

In conclusion, (a) overall speed of naming colours is slower than naming RAN numbers and letters (b)whereas speed of naming RAN numbers and letters appear to have reached an asymptote by ages 15 to 17, this does not apply to colour naming. There may be a good reason for this. The participants may need to be trained to use particular colour names in English of the 4 colours during practice trials simply because in their own mother-tongue (not English) they may not be automatically using the same colour names. For example in Odia, there is a confusion between naming 'green' and 'blue' .

Question 3. What develops with age?

As shown in the prototype Figure1, naming time is a composite of cognitive processes comprising encoding, pause time, and articulation of items serially presented in a typical RAN task. What is the child doing during the gap or pause time? As noted in the Figure 2, pause time may be divided into disengagement of attention from the just articulated stimulus, encoding that is finding the name of the next stimulus, and assembling a motor programme for articulation of the next stimulus. These operations are repeated for each successive stimulus. However, it is not easy to explain the operations that occur simultaneously during 'pause time'.

What makes the pause time and articulation time division more challenging is that while the eyes are looking at a letter (C), the brain is processing information from the preceding letter (B), and the voice is saying the name of the letter before that (A). So the pause could also be managing these separate tasks. Things are happening simultaneously, not just successively (personal communication, J. Kirby, Nov, 2020; Dahhan et al., 2020)

Summary and conclusions.

The present study was motivated by presenting RAN as a concept and a test in its own right independent of the concept of reading. Towards this goal we asked two major questions that could be answered by the present study.

To recapitulate, the first question: Do we expect that using factor analysis RAN response times will yield one or two separate factors? Our expectation was based on findings of several studies. Mainly in a Dutch (van den Bos et al., 2002) study that provided a review and similar findings to our present study which was carried out on participating students in India. We proposed a theoretical deconstruction of cognitive processes that may explain naming time. These processes are suggested in the diagram (Figure 1). Briefly, the gap between articulation of two serially presented stimuli can be divided into time for encoding, assembling a motor programme for articulation, and overt articulation. These processes are repeated for *stimulus* items 40 times in a *serial order* in the RAN task.

Let it be said in discussion that we have sufficient evidence to distinguish between processing of two types of stimulus item; colours and objects on the one hand, and alpha-numeric symbols on the other. Whereas semantic lexicon must be accessed in finding the names of colours (and objects) before these may be processed further for naming alpha-numeric do not have to access the semantic lexicon. The names for letters and numbers are readily available in the lexicon for symbols; thus, no search is needed. We suggested that the above discussion provides the ground for expecting a two-factor solution for rapid automatic naming.

The next question and the associated hypothesis concerned the expectation that naming speed should generally increase with age. However, the speed of development will be moderated by two factors; (a) differentiation of increment in speed between the two categories of stimulus items, alpha-numeric and non-alpha-numeric, and (b) by what age between 8 and 20 years, naming speed for one of the categories may approximate an asymptote. Another question is what happens at the other end of development, with aging. Do digit and letter stay automatic longer, while colour and object start to lose automaticity sooner? This is to be determined in a future study.

On the basis of previous research, as the literature shows (Georgiou et al; 2020; Georgiou & Stewart, 2013) speed of naming alpha-numeric is likely to reach an asymptote earlier than colours and objects. The reason for this has been hinted in the Figure 1, and elaborated in the preceding paragraphs. Continuing with this line of argument, beyond 14 years of age, our study results show that semantic access time for non-alphanumeric colour stimulus remains less automatized whereas alpha-numeric naming speed is closer to get automatized. In fact, alpha-numeric time reaches asymptote past an age 14, whereas colour naming speed may continue to improve as several studies have reported (Albuquerque & Simões, 2010; van den Bos et al, 2002). A neurophysiological explanation in addition to the cognitive one we have provided may help. Do these component processes of RAN (i.e., encoding, articulation and continuous serial naming) have a basis in the brain? This is beyond the scope of the present study.

A limitation of our present report is the lack of biological or neurophysiological procedure to determine changes associated with behavioural variations in encoding and articulation, and broadly with automatized processes. A few studies are now available for deconstructing naming speed embedded as these are in the context of understanding reading processes. For example, Al Dahhan et al., (2020) compared typically-achieving readers and readers with dyslexia; the dyslexia sample usually had poorer naming speed performance which was the primary question of interest in their research.

Next, we may ask if articulation has a separate brain signature apart from other components of reading. Using neuroimaging measures, it was reported that articulatory/motor processing as related to speech production did not activate the same area that was associated with phonological and orthographic processing during reading (Al Dahhan et al., 2020). It adds to the evidence for characterizing RAN as somewhat independent of reading processes. The strongest relation between serial RAN and reading suggests that the serial format of the RAN tasks is essential in the RAN-reading relationship (Altani et al., 2018, Protopapas et al., 2018). We should widen the scope of RAN to explore its relation with serial and other cognitive processes.

Specifically, Executive Functions comprising tests of Cognitive flexibility, Inhibition&Attention control,&Working memory(Miyake,Friedman et al 2000).

Our objective is to be aware of the association of Executive Functions with Speed of Processing.This will be useful information, for example investigation into Ageing and Executive Functions. A worthy aim for future studies.

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Tables

Table 1

Result of factor analysis of RAN alpha-numeric and colour naming.

	PA1	h2	u2	com
ran_letters	0.97	0.95	0.051	1
ran_numbers	0.95	0.91	0.089	1
colornaming	0.77	0.59	0.413	1
colornaming_shift	0.67	0.45	0.548	1

NOTE: PA refers to the factor, *h2* is the communalities (common variance), *u2* is the uniqueness (specific variance), and *com* is the complexity of the component loadings for that variable. *SS loadings* is the sum of squared loadings of a factor. *Proportion Var* is the variances in the observed variables/indicators explained by each factor. *Cumulative Var* is the cumulative proportion of variance explained by all factors.

Table 2.

Standardized loadings based upon correlation matrix: Ages 11-14

	PA1	PA2	h2	u2	com
ran_numbers	1	-0.03	0.94	0.055	1
ran_letters	0.93	0.05	0.96	0.042	1
colornaming	-0.06	0.91	0.73	0.271	1
colornaming_shift	0.1	0.84	0.87	0.13	1

Table 3.

Standardized loadings based upon correlation matrix: Ages 11-14

	PA1	PA2
SS loadings	1.92	1.58
Proportion Var	0.48	0.39
Cumulative Var	0.48	0.88
Proportion Explained	0.55	0.45
Cumulative Proportion	0.55	1

Note: Loadings are 1 on factor 1 and -0.03 on factor 2 which is nearly zero. The negative factor loadings mean that the item explains the reversed meanings of the latent factor.

Table 4

Standardized loadings based upon correlation matrix: Ages 15-17

	PA1	PA2	h2	u2	com
ran_letters	0.87	-0.03	0.73	0.27	1
ran_numbers	0.87	0.03	0.77	0.23	1
colornaming	0.02	0.85	0.75	0.25	1
colornaming_shift	-0.02	0.85	0.7	0.3	1

Table 5

Standardized loadings based upon correlation matrix: Ages 15-17

	PA1	PA2
SS loadings	1.5	1.45
Proportion Var	0.38	0.36
Cumulative Var	0.38	0.74
Proportion Explained	0.51	0.49
Cumulative Proportion	0.51	1

Table 6
Standardized loadings based upon correlation matrix: Ages 18-20

	PA1	PA2	h2	u2	com
colornaming_shift	0.9	-0.08	0.79	0.21	1
colornaming	0.89	0.08	0.82	0.18	1
ran_numbers	0.04	0.6	0.38	0.62	1
ran_letters	-0.04	0.57	0.32	0.68	1

Table 7
Standardized loadings based upon correlation matrix: Ages 18-20

	PA1	PA2
SS loadings	1.6	0.7
Proportion Var	0.4	0.18
Cumulative Var	0.4	0.57
Proportion Explained	0.69	0.31
Cumulative Proportion	0.69	1

Table 8
Means, Standard Deviations, and Coefficients of variation.

Age		8-10	11-14	15-17	18-20
N		205	328	200	168
RAN Digits	Mean	31.14	25.75	20.79	18.52
	SD	15.23	13.41	10.41	6.71
	Ratio	0.49	0.52	0.50	0.36
RAN Letters	Mean	32.85	25.62	20.65	18.60
	SD	16.31	13.60	9.42	9.72
	Ratio	0.50	0.53	0.46	0.52
Color Naming in WS	Mean	39.78	33.39	29.30	28.82
	SD	11.82	10.63	13.92	19.38
	Ratio	0.30	0.32	0.48	0.67
Color Naming in CSS	Mean	34.04	29.29	30.11	25.35
	SD	26.42	24.76	22.11	24.49
	Ratio	0.78	0.85	0.73	0.97
RAN = RAN Digits + RAN Letters	Mean	63.99	51.38	41.44	37.12
	SD	31.15	26.68	15.85	13.56
	Ratio	0.49	0.52	0.38	0.37
COLOR = Color Naming in WS + Color Naming in CSS	Mean	73.81	62.68	59.41	54.17
	SD	34.39	33.82	33.58	41.53
	Ratio	0.47	0.54	0.57	0.77
SPEED = RAN + COLOR	Mean	137.80	114.05	199.84	91.29
	SD	61.24	58.13	43.75	44.79
	Ratio	0.44	0.51	0.22	0.49

Table 9.
Results of ANOVAs

		Df	*F*	*p*
RAN_Numbers	Age_Group	3	40.52	<.001
	Residuals	897		
RAN_Letters	Age_Group	3	47.21	<.001
	Residuals	897		
Color_Shift	Age_Group	3	3.936	<01
	Residuals	897		
Color_Naming	Age_Group	3	27.16	<.001
	Residuals	897		
RAN	Age_Group	3.00	46.80	<.001
	Residuals	897.00		
COLOR	Age_Group	3.00	10.52	<.001
	Residuals	897.00		
Speed	Age_Group	3.00	27.14	<.001
	Residuals	897.00		

Table 10.
Tukey's test comparisons between adjacent age groups.

RAN Letters+Numbers	Difference	*p*
8~10-11~14	12.61	0.00
15~17-11~14	-9.94	0.00
18~20-15~17	-4.31	0.33
COLOR(shift+Stroop)	Difference	*p*
8~10-11~14	11.14	0.00
15~17-11~14	-3.27	0.73
18~20-15~17	-5.24	0.49
SPEED (RAN+COLOUR)	Difference	*p*
8~10-11~14	23.75	0.00
15~17-11~14	-13.21	0.03
18~20-15~17	-9.55	0.32

Figures

Fig. 1

Cognitive activities related to articulation and the gap in Rapid Automatized Naming (The Figure below represents color naming in young children (in Grade 1). It is excerpted from *Reading Difficulties and Dyslexia* (Das, 2020) with some modifications.)

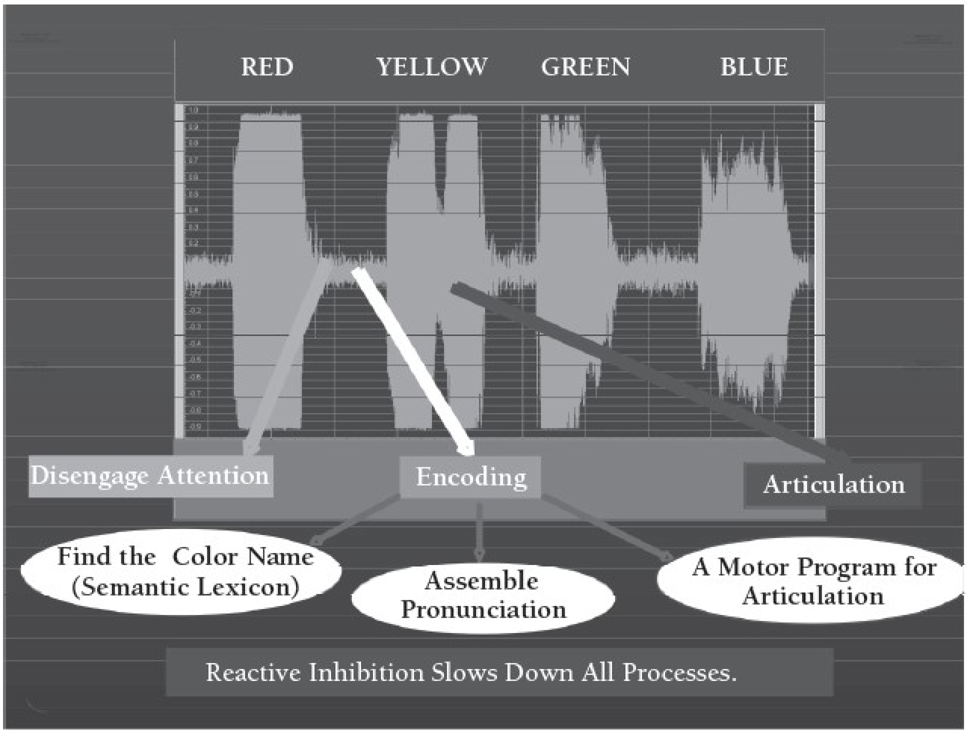


Fig. 2

Trajectory of development of Naming Time (RAN=alphanumeric) Age by Age

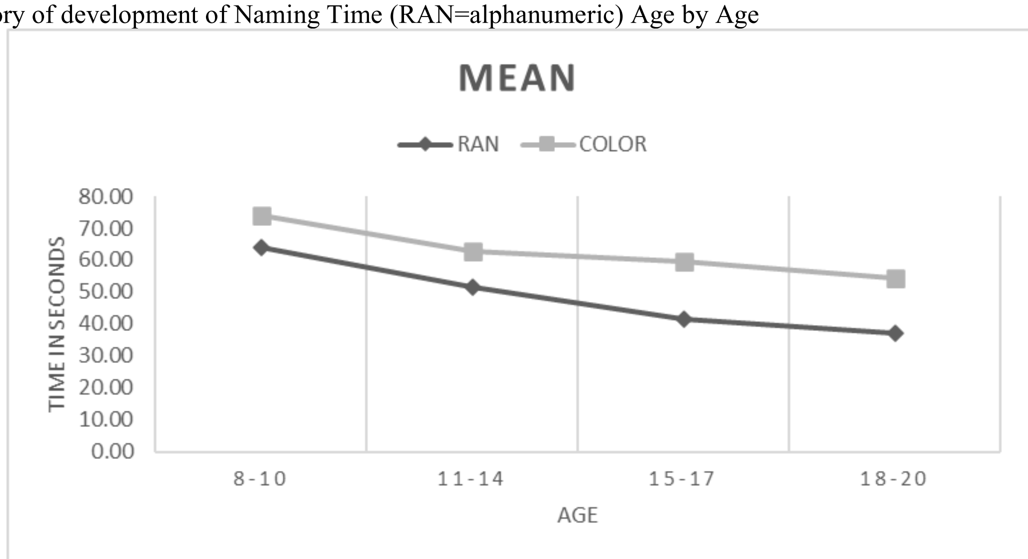
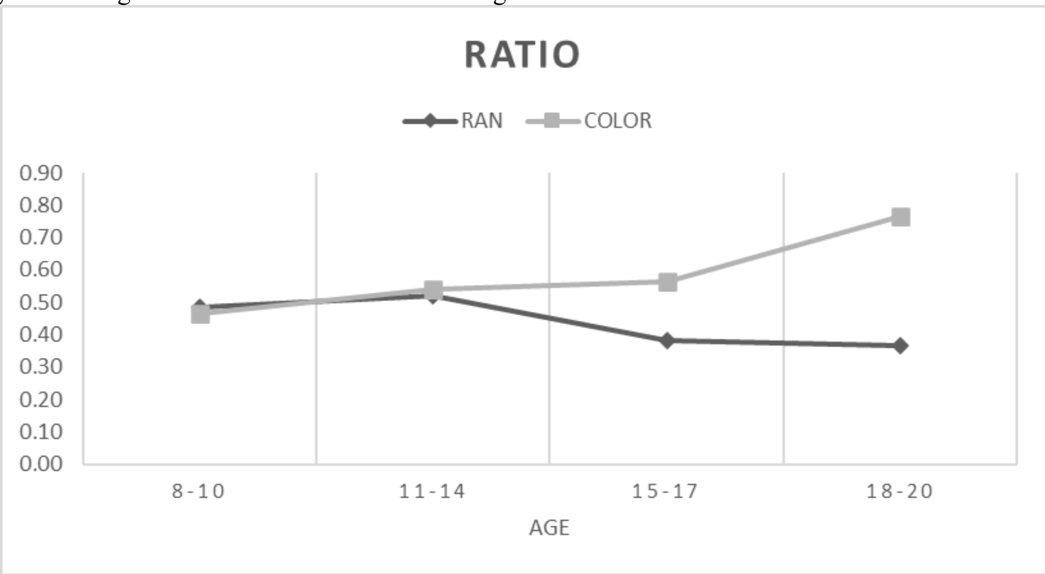


Fig. 3
Stability of Naming Time of RAN and Colour-Naming



Note: Colour Naming is markedly unstable at the two higher age groups.