An examination of the cognitive functions associated with rapid naming of objects and letters in children and adults

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ABSTRACT

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To date, it is unclear which cognitive functions influence performance in rapid automatized naming (RAN) tasks. Potential underlying processes include phonological processing (Vaessen et al., 2009), processing speed (Kail et al., 1999), retrieval automaticity (Meyer et al., 1998), visual perception (Ammawat et al., 2019), lexical access (Decker et al., 2013) and orthographic processing (Wolf & Bowers, 1999). The lack of consensus in the cognitive processes involved in RAN creates the need for further investigation of the underlying functions. Thus, the present thesis aimed to explore the joint and unique contributions of visual attention and memory-related processes to naming speed in neurotypical adults and children. The data included 74 Finnish-speaking children aged 12-13 years and 21 Finnish-speaking adults. The participants completed visual attention and visual short-term memory test (NEPSY-II), attentional network test, phonological short-term and working memory tests (WISC-IV Digit Span Forward and Backward) and serial object RAN. Children further completed serial letter RAN. The results indicate that visual attentional and visual short-term memory processes are associated with children's object RAN performance. Phonological short-term memory, working memory, alerting, orienting and inhibition were shown not to explain a significant amount variance in RAN performance in children or adults. Taken together, visual attentional and memory-related processes are involved in rapid naming in children.

Keywords: Rapid automatized naming, visual attentional processes, working memory, phonological short-term memory

CONTENTS

1 INTRODUCTION

Naming speed is the capability to verbally name familiar stimuli, such as objects, colors, digits or numbers. The task requires the coordination of multiple complex cognitive functions, such as attentional, phonological, memory and articulatory processes (Wolf et al., 2000). For instance, individuals need inhibition to maintain a state of sensitivity to incoming stimuli as well as focus and select relevant information while ignoring distractors. In short, attentional processes are required to perform (i.e., Pham et al., 2011). The speed of processing is also influenced by the identification and recognition processes that integrate the current visual information with previously known mental representations. Therefore, naming of stimuli also requires access and retrieval of phonological codes from long-term memory. In addition, slow processing in the articulatory loop in the working memory may result in difficulties performing naming tasks (Aguilar-Vafaie et al., 2012). The combination of these cognitive requirements makes naming speed a significant predictor of reading ability (i.e., meta-analysis by McWeeny et al., 2022). Consequently, naming speed deficits have been robustly associated with reading difficulties, such as dyslexia (i.e., Araújo & Faísca, 2019; Araújo et al., 2021; Christoforou et al., 2021).

Currently, the reason naming speed is predictive of reading remains a matter of debate (i.e., Kirby et al., 2010). Due to the multi-componential nature of naming speed tasks, any or several of the complex cognitive functions may drive the relationship between naming speed and reading. Thus, the present thesis aimed to explore the joint and unique contributions of visual attention and memory-related processes to naming speed in neurotypical adults and children aged 12 to 13.

1.1 Rapid automatized naming (RAN)

Rapid automatized naming (RAN) is the ability to name as quickly as possible a set of highly familiar symbols. The stimuli may be non-alphanumeric, such as objects or colours, or alphanumeric, such as digits or letters. Generally, object naming is slower than naming letters or digits (Denckla & Rudel, 1974; Misra et al., 2004; Papadopoulos et al., 2016). One hypothesis to explain this is the "semantic hypothesis"; object naming requires access to semantic information, which prolongs the performance. Further, letter and object processing have been observed to activate different brain areas: Joseph et al. (2003) used fMRI and found that both object and letter processing is not completely shared given that letter processing exclusively activated areas in the left inferior parietal cortex and left insula during a passive viewing and silent naming of objects and letters.

Due to these differences, alphanumeric stimuli may be more closely associated with reading: a meta-analysis by Araújo et al. (2015) demonstrated that letter RAN is significantly more correlated with reading compared to stimuli consisting of colors and objects. Similarly, Pham et al. (2011) found that letter RAN is more strongly associated with reading, however non-alphanumeric stimuli (i.e., objects and colors) also contributed to the prediction of reading fluency. Therefore, research suggests that letter RAN is more associated with reading while object RAN is less connected. Meanwhile, non-alphanumeric stimuli may to be more related to attentional processes: Pham et al. (2011) found that inattention had a more pronounced effect on object RAN out of the two types of RAN composites. Therefore, attentional processes seem to influence both RAN composites but have a stronger effect on object RAN.

Currently, several hypotheses aim to explain which cognitive functions influence performance in RAN. Potential underlying processes include phonological processing (i.e., Wagner et al., 1997; Vaessen et al., 2009), processing speed (i.e., Kail et al., 1999), retrieval automaticity (Meyer et al., 1998), visual perception (Ammawat et al., 2019) and orthographic processing (Wolf & Bowers, 1999). Then again, Wolf et al. (2000) proposed that several of the aforementioned cognitive processes are required simultaneously. Similarly, several researchers have pointed out that phonological processing, processing speed, retrieval automaticity, visual perception or orthographic processing do not account for all variance and the involvement of other cognitive functions should be considered (i.e., Pham et al., 2011; Papadopoulos et al., 2016). In short, the lack of consensus in the cognitive processes involved in RAN creates the need for further investigation of the underlying functions.

1.2 Visual attention and naming speed

Visual attention is a cognitive process that mediates the selection of relevant stimuli while ignoring irrelevant information (Lockhofen & Mulert, 2021). Visual attention is critically important for higher-order cognitive functions, such as the location and recognition of objects in the environment. Visual attentional processes are involved in focusing, locating and recognizing relevant objects and shifting attentional resources from one stimulus to another. Arguably, similar cognitive processes are required to perform rapid naming tasks. For instance, accuracy in the naming tasks has been shown to require allocation of visual attentional processes to upcoming items while suppressing those already named (Dahhan et al., 2014). Attentional deficits have also been found to influence speed in RAN (Wodka et al., 2009). Similarly, inattention negatively influences naming speed in children (Pham et al., 2011). Further, visual attention span (VAS) task has been shown to affect serial RAN (de Jong et al., 2021). Taken together, it may be suggested that visual attentional processes influence naming speed.

Visual attention may be further sub-categorized in the separate networks, namely alerting, orienting and inhibition (Posner & Petersen, 1990). The alerting system aims to attain and maintain a state of sensitivity to incoming stimulus and may be characterized by a readiness to perceive and process information. Orienting requires focusing and selecting specific information and may be divided into three sub-functions, namely the engagement and disengagement of visual attention to a stimulus and the shifting of visual attention between the stimuli (Posner & Petersen, 1990). Finally, inhibition refers to the ability to resist interference from distracting stimuli and involves complex cognitive functions during the detection and resolution of conflicts between mental processes.

Research has observed independence between the three attentional networks. For instance, Fan et al. (2005) used event-related functional magnetic resonance imaging (fMRI) to explore the brain regions involved in the attentional networks and found separable anatomical networks related to the components of attention. Further, Ammawat et al. (2019) found no correlations in RTs between the sub-components. This indicates that the function of one sub-component does not predict the function of the other networks. However, Callejas et al. (2004) found that the alerting network may inhibit executive control during ANT. Further, orienting appeared to influence executive control while alerting influenced orienting.

Developmental changes in the functions of the attentional sub-components have been observed in research: Rueda et al. (2004) tested the development of each network by studying three age groups: children aged six to nine, 10-year-olds and adults. The research showed that alerting efficiency increased at each age interval while no changes in the orienting scores were found. Efficiency of the executive control appeared stable after age seven. However, the ability to shift attention has been shown to improve between 5 and 14 years of age and further into adulthood (i.e., Schul et al., 2003; Wainwright & Bryson, 2005) which indicates that orienting efficiency improves with age as well. These findings indicate that visual attentional networks are subject to changes during development, which may also have an effect on the associations between RAN and visual attention. Hence, the present thesis included both adults and children to observe developmental changes in the potential connections between RAN and attentional networks.

Rapid naming of stimuli may involve the functions of the sub-components (Ammawat et al., 2019). Alerting is required to detect targets and maintain readiness to perceive and process target stimuli and remain alert throughout the task. Orientation is required to focus, select and direct attention to relevant stimuli. Executive control resists interference from the distracting stimuli. Consequently, connections between RAN and the attentional sub-components have been observed in research: Ammawat et al. (2019) assessed the behavioral connections between the sub-components and naming speed in children aged five to seven and found that all three attentional networks explained 27% of variance in both letter and object naming speed. However, it is not yet known whether similar findings may be observed in older children and adults.

1.3 Memory and naming speed

Serial naming of stimuli often involves naming 50 stimuli from a set of 5 familiar exemplars. This implies that phonological representations are retrieved from long-term memory and the five exemplars are maintained in short-term memory (STM) in an accessible condition while working memory (WM) processes and structures the relevant information. The connections between memory-related processes and RAN have been debated in literature: Torgesen et al. (1997) suggested that RAN and reading may be related because they both involve quick access to, and retrieval of, phonological codes from long-term memory. Further, phonological short-term memory (PSTM) has been shown to relate to naming speed in 5-year-old children (Parrila et al., 2004). However, it is not yet known whether similar findings may be observed in children and adults or whether the importance of PSTM in naming tasks diminish with development.

The relations of PSTM with reading has been observed in research: PSTM influence reading accuracy in Finnish participants (Ziegler et al., 2010). Further, the meta-analysis by Araújo et al. (2015) proposed that reading accuracy is related to RAN performance. This could imply that PSTM may be required in both RAN and accurate reading, suggesting that similar memory-related processes are required. Then again, Albuquerque (2017) and Kirkby et al. (2010) suggest that RAN is a stronger predictor of reading fluency rather than reading accuracy. This contradicts the idea that reading accuracy and RAN are both affected by the functions of PSTM since Ziegler et al.'s study implied that RAN does not influence reading fluency in Finnish participants. Then again, longitudinal study of dyslexia has provided contrary evidence and showed that reading fluency and RAN performance are related in Finnish speakers (Puolakanaho et al., 2007; Lohvansuu et al., 2018).

Further ideas of the importance of PSTM in RAN are provided by research in dyslexia. Smith-Spark and Fisk (2007) found that the storage capacity of PSTM is impaired in developmental dyslexia. Further, Aguilar-Vafaie et al. (2012) found that dyslexics had poorer performance in both Digit Span Forward task and rapid naming of digits. These findings suggest that working memory systems may be associated with reading ability and RAN and the connections are significant in dyslexics. However, it is yet unclear whether the connections are observable in children and adults without reading difficulties and whether the connections differ depending on stimuli (i.e., letters and objects).

The importance of PSTM and WM in RAN performance has also been debated: studies have suggested a multi-componential model of RAN in which memory-related processes are included but do not explain most of the variance (i.e., Närhi et al., 2005; Wolf et al., 2000). This implies that memory-related processes are required but they are not as significant as other cognitive functions, such as lexical access (Decker et al., 2013).

In addition, the connections of visual short-term memory and rapid automatized naming should be considered. Visual short-term memory stores visual information for a short duration so that it may be used in the service of ongoing cognitive tasks. For instance, visual short-term memory deficits have been shown to influence reading: slow readers and typical readers performed differently on tasks designed to assess visual short-term memory ability (i.e., Swanson & Sachse-Lee, 2001). Slower reading speed was associated with higher inaccuracy and slower processing speed of visual information. This indicates that visual short-term memory processes may be required in RAN.

1.4 Rationale for the present thesis

The present thesis aims to explore whether performance in visual attention and memory-related tasks are predictive of the speed of naming objects in children and adults and naming letters in children. To this date, the connections between naming speed and cognitive functions remain a matter of debate. The aim is to explore whether visual attention and memory-related processes are related to naming speed in typical participants.

Visual attention is tested with two types of paradigms. One of these is NEPSY-II Visual attention task (Korkman et al., 2007), The task requires attentional resources, processing speed, visual discrimination and memory-related processes. These cognitive functions have previously been associated with RAN (i.e., Papadopoulos et al., 2016; Araújo et al., 2015; Kail et al., 1999; Swanson & Sachse-Lee, 2001). Since the current thesis aims to explore other cognitive processes required to perform RAN, NEPSY-II Visual Attention task is included since it does not require phonological or orthographic processing, which have previously been associated with RAN but shown not to explain all variance (Wagner et al., 1997; Vaessen et al., 2009; Wolf & Bowers, 1999). Therefore, NEPSY-II Visual Attention is included to explore the potential need for accuracy of visual attention, processing speed, memory-related processes and visual discrimination in performing RAN.

Another visual attentional paradigm is an attentional network test (Posner & Petersen, 1990) in which visual attention is divided in three sub-components: alerting, orienting and inhibition. The test is a reaction time (RT) task, which combines Posner's cued detection (Posner, 1980) and Eriksen's flanker task (Eriksen & Eriksen, 1974). In line with the previous research, developmental changes in the sub-components may be observable since efficiency has been shown to improve with age. However, it is not yet clear whether stronger connections between the sub-components and naming speed are observed in 12-13-year-old children in contrast to adults.

The capacities of WM and PSTM may be tested with two types of digit span task. Digit Span Forward requires the participants to repeat the digits as heard while Digit Span Backward requires repeating the digits in a reverse order. The tasks increase in difficulty. The Digit span tasks require phonological short-term memory and the functions of the articulatory loop in the working memory system as verbal information (digits) must be temporarily held in working memory before repeating them. Visual short-term memory is tested with NEPSY-II Visual Attention task, which requires participants to memorize two types of images before completing the task. The images are held in the visual short-term memory while working memory resources are required for accurate discrimination between the following images and the initially observed stimuli.

1.5 Hypotheses

H1: Visual attention and the sub-components (alerting, orienting and inhibition) correlate with and explain variance in object RAN in children.

This hypothesis assumes that visual attentional processes are required in object RAN (Pham et al., 2011). Accuracy in naming tasks require allocation of visual attention to upcoming items while suppressing those already named (Dahhan et al., 2014). Inattention also affects naming speed (Pham et al., 2011). The need for visual attentional processes in naming speed may not be as significant in adults (Rueda et al., 2004) and hence, the connections between visual attention and naming speed are expected to be observable in children. This hypothesis also aims to explore other functions than phonological or orthographic processing, which have previously been associated with RAN in children (Wagner et al., 1997; Vaessen et al., 2009; Wolf & Bowers, 1999) but shown not to explain all variance. Correlations are expected to indicate whether visual attention and the sub-components is required significantly more in children than adults. Further analyses (i.e., linear regression) were conducted only with children's data due to the small adult sample size.

H2: Children with slower object RAN performance are expected to perform worse in the cognitive tasks requiring visual attention, contrary to fast object RAN performers.

This hypothesis aims to explore the debate of the need for visual attentional processes in RAN. By comparing both extremities of RAN performers (i.e., fast and slow performers), the connections between visual attentional processes and naming speed may be observable in typically developed participants. This hypothesis is further based on the assumption that object RAN is more associated with attentional processes than letter RAN (i.e., Pham et al., 2011). This hypothesis only applies to the children since the adult sample was not large enough for group comparisons.

H3: PSTM correlates with and explains variance in both object and letter RAN performance.

This hypothesis assumes that phonological short-term memory is associated with RAN (Torgesen et al., 1997; Parrila et al., 2004). Since RAN requires the retrieval of and quick access to phonological codes from long-term memory, PSTM capacity is expected to influence RAN performance. This hypothesis also aims to explore whether memory-related processes have significant explanatory power in addition to the previously suggested cognitive functions, such as lexical access, orthographic processing, and visual perception (Wagner et al., 1997; Vaessen et al., 2009; Wolf & Bowers, 1999). Correlations are expected to indicate whether PSTM is required in both adults and children. Further analyses (i.e., linear regression) were conducted only with children's data due to the small adult sample size.

H4: Children with slower letter RAN performance are assumed to perform worse in the tasks requiring either WM or PSTM, contrary to fast letter RAN performers.

This hypothesis assumes that slower performance in naming tasks may be explained by STM and WM delays, particularly in phonological short-term memory (Smith-Spark and Fisk, 2007; Aguilar-Vafaie et al., 2012) This hypothesis aims to explore whether similar findings may be observed in non-dyslexic children with slower letter naming speed ability. This hypothesis only applies to the children since the adult sample was not large enough for group comparisons.

2 RESEARCH METHODS

2.1 Research participants

The participants were divided into two age-related groups: adults and children. The adults consisted of native Finnish speaking participants (n=21). The children's group included 74 native Finnish speaking participants aged between 12 and 13 years (35 males and 40 females, M=12.39, SD= .490). All participants had normal or corrected vision and had no history of neurological problems or head injuries. The participants and the children's parents provided signed informed consent prior to the study. The ethical statement was obtained from the Ethics Board of University of Jyväskylä.

The participants were recruited via the eSeek project (Internet and Learning Difficulties: A Multidisciplinary Approach for Understanding Reading in New Media), funded by Academy of Finland. The data were collected from about 420 sixth graders in Jyväskylä and Central Finland, out of whom a sub-sample participated in the individual cognitive assessments at the university research facilities. Adult participants were separately recruited for individual assessments only.

2.2 Behavioural measures

2.2.1 Rapid automatized naming (RAN).

RAN (Denckla & Rudel, 1974) tests for children included two subtests: one for objects and one for letters. Adults only completed RAN of objects.

RAN of objects included black and white pictures of a car, a house, a fish, a pen and a ball. RAN of letters consisted of five capital letters: O, A, S, T and P. Both tasks included 50 items, placed in 5 rows of 10 items. Each row contained the items in a random order. Each item was presented twice in a row. The participants were instructed to follow the rows in a right-to-left reading order and to name each item verbally as quickly and accurately as possible. The task was timed by the examiner. Scoring included the total time (seconds) spent in naming all the stimuli, the number of errors, uncorrected and self-corrected mistakes.

2.2.2 NEPSY-II Visual attention.

NEPSY-II Visual attention test is part of NEPSY-II test battery intended to measure of children’s neurocognitive processes (Korkman et al., 2007). Children and adults both completed NEPSY-II Visual Attention task.

The participant was first asked to observe images of two different types of faces. The images were then followed by rows of faces, which were either similar or different to the originally observed faces. The participants were instructed to search the rows of faces in a right-to-left reading order and locate images of either of the two originally observed faces simultaneously. A recognition was indicated by crossing the image over with a pencil. The task was timed by the examiner and the maximum length was 180 seconds. The maximum score was 38 points and final score was calculated by subtracting the incorrect answers from the total.

2.2.3 Attention Network Test (ANT).

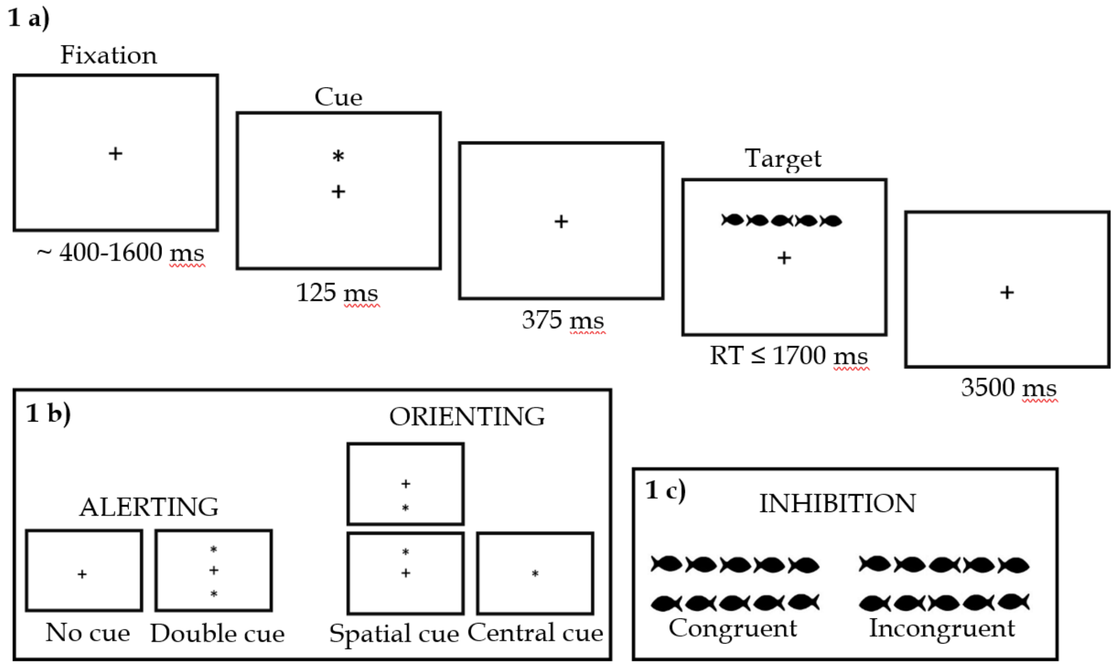
ANT was originally a part of an EEG experiment (Santhana Gopalan el al., 2018) and behavioural results of the research were used in the present thesis. Participants were asked to lean on a chinrest located 60 cm from a 24-inch computer screen (resolution of 1920 x 1080). The stimulus consisted of a horizontal row of five black fish (modified version of ANT: Kratz et al., 2011). The participants were asked to report the direction of the middle fish by pressing a corresponding button. The stimulus was preceded by a cue, which was either center, double or spatial. Alternatively, there was not a cue preceding the stimulus (see figure 1 b) for an illustration).

As shown in figure 1 a, each trial began with a fixation period. The participants were asked to look at a fixation cross, which remained on center of the screen for a random time between 400 ms and 1600 ms. After the fixation period, a cue appeared on the screen. The cue remained on the screen for 125 ms and was followed by a second fixation period, which lasted for 375 ms.

In the center cue trials, the fixation cross was replaced by an asterisk. In the double cue trials, two asterisks appeared above and below the fixation cross at a 1° angle. Spatial cue indicated the location of the upcoming stimulus and appeared either above or below the fixation cross. In the no cue trials, no asterisk was presented on the screen. The direction of the target stimulus was either congruent or incongruent in relation to the flanking objects. In the congruent trials, the fish were swimming in the same direction while in the incongruent trials, the middle fish was swimming in the opposite direction (see figure 1 c)). The participants were asked to report the direction of the middle fish quickly and accurately by pressing a corresponding button. The cue remained on the screen for 1700 ms or until a response was detected. The maximum duration of each trial was 4000 ms.

Figure 1

Schematic illustration of the sequence of events in the modified ANT: 1 a) denotes a fixation period of a random duration between 400 and 1600 ms, 1 b) the four cue conditions used in ANT, and 1 c) the two congruency conditions for which the participant had to decide the swimming direction of the middle fish.



One ANT session consisted of 288 pseudo-randomized trials, which were divided into four experimental blocks of 72 trials. Each block consisted of all possible conditions in equal proportions (four cue conditions x two target stimulus conditions). Performance was measured by reaction times. Both adults and children completed the ANT task.

2.2.4 WISC-IV Digit span tasks.

The Digit Span is part of Wechsler Intelligence Scale – Fourth Edition (WISC-IV; Wechsler, 2003). The task was completed by both age groups. The stimuli included digits between 1 and 9. No digit appeared more than once in one digit span. The test included two subtests: Digit Span Forward and Digit Span Backward. The participants first completed Digit Span Forward in which they were asked to verbally repeat the digits as said aloud by the examiner. Secondly, the participants completed Digit Span Backward where they were instructed to repeat the spans in reverse order.

The examiner recited each span once. In both subtests, the number of digits increased in each alternative sequence, beginning with two digits and finishing with eight digits (i.e. two sequences of two digits, two sequences of three digits and two sequences of four digits, finishing with two sequences of eight digits). For each sequence, 1 point was scored for a correct response and 0 points for an incorrect response or no response. The task was discontinued when the participant failed to repeat the string of digits twice in each sequence dyad. The maximum score was 16 points.

2.3 Data analysis

Analyses were performed using SPSS version 28 statistic software. Prior to conducting correlations, relevant assumptions were tested. Tests of normality indicated that the variables were normally distributed. Consequently, children's data was subjected to parametric measures. Non-parametric measures were used for the adults' data due to the small sample size (n=21).

Mean RTs were calculated for each participant in each ANT trial condition: no cue, double cue, central cue, spatial cue and congruent and incongruent trials. *Alerting* sub-component was calculated as the mean RT difference between no cue-double cue, *orienting* as the mean RT difference between central cue-spatial cue and *inhibition* as mean RT difference in congruent-incongruent trials. Performance in the NEPSY-II Visual Attention task performance was calculated for each participant by subtracting incorrect answers from the total.

The strength and direction of the relationship between RAN and the cognitive tasks were tested with Pearson correlation coefficient and Spearman's rank correlation coefficient. Fisher's z-test were used to find differences in correlations between children and adults.

Linear regression analysis (method Enter) was used to measure how much of the variation in RAN is explained by the variation in the different cognitive tasks. The dependent variable was object or letter RAN measures and 6 independent variables included NEPSY-II Visual attention, visual attention sub-components (alerting, orienting and inhibition) and WISC-IV Digit Span Forward and Backward. All variables were interval. Prior to conducting a linear regression, the relevant assumptions were tested. In children, the sample size of 74 children was adequate given six independent variables to be included in the analysis (Tabachnick & Fidell, 2013). However, adult data sample size (n= 21) was not adequate for the linear regression model.

In order to compare both extremities of RAN performers (i.e., fast and slow performers), children's RAN data was divided into three equal sized groups based on the speed (i.e., fast, medium and slow performers). See table 1 for the descriptive statistics. Adults' data was deemed too small for speed-related group comparisons.

Table 1

Descriptive statistics of the children's speed-related groups, including sample size (n), mean (M) and standard deviation (sd).

	Speed-related groups		
	n	M	SD
LETTERS			
Fast	25	18.46	1.71
Medium	25	22.26	1.21
Slow	24	28.69	5.29
OBJECTS			
Fast	25	34.35	2.32
Medium	25	40.38	2.17
Slow	24	47.76	2.76

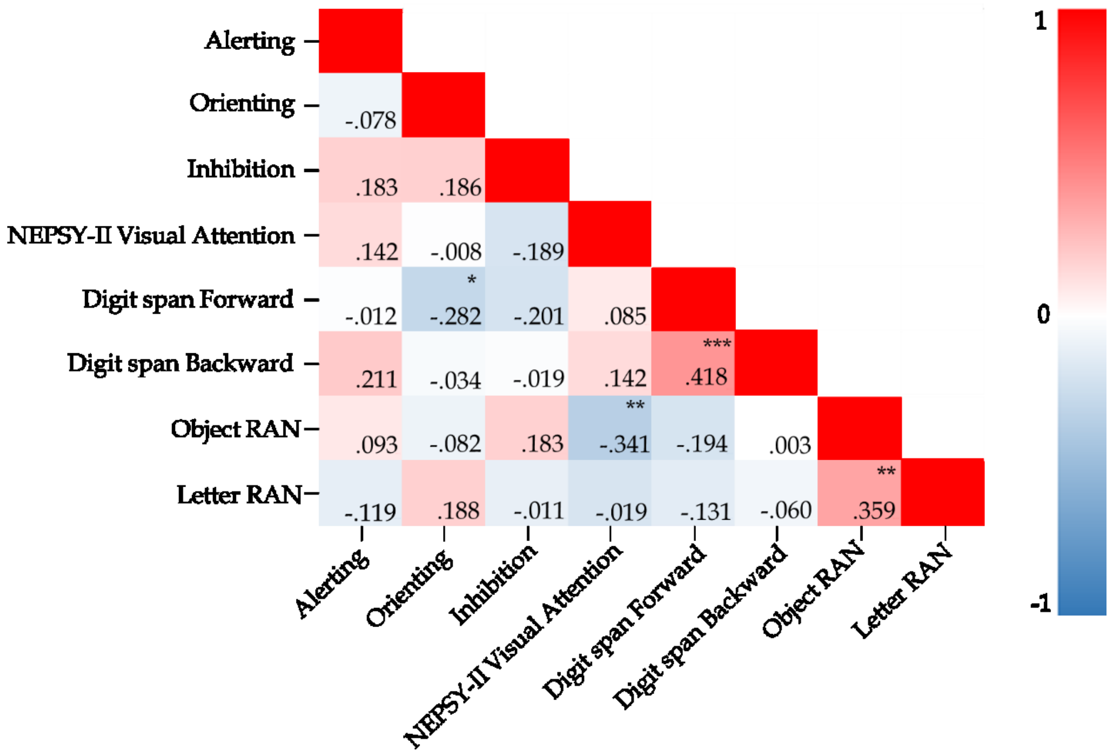
3 RESULTS

3.1 The relationship between RAN and the cognitive tasks

The children. A Pearson's correlation coefficient was computed to assess the relationship between the cognitive tasks and two RAN tasks in children. The correlation matrix illustrated in figure 2 did not indicate significant correlations between the letter RAN and the cognitive tasks. However, there was a negative correlation between the NEPSY-II Visual Attention task and object RAN (p = .003).

Figure 2

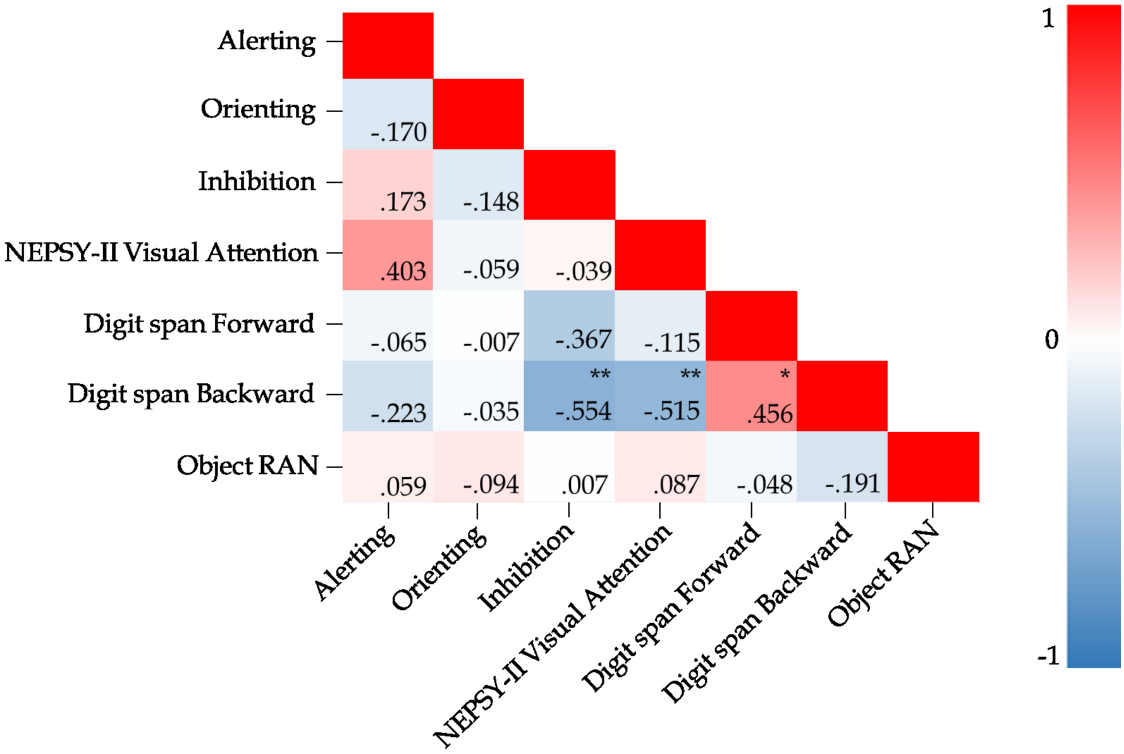
*Pearson's correlation matrix of the children's performance. Significances are flagged with an asterisk (one asterisk * = p <.05, two asterisks ** = p <.01 and three asterisks *** = p <.001).*



Adults. Spearman's correlation was used to test the relationship between RAN and the cognitive tasks in adults. Spearman's correlation matrix is illustrated in figure 3: no significant correlations were found between the object RAN and the cognitive tasks.

Figure 3

*Spearman's correlation matrix of the adults' performance. Significances are flagged with an asterisk (one asterisk * = p <.05, two asterisks ** = p <.01 and three asterisks *** = p <.001).*



In both age groups, the ANT sub-components were found to be independent from each other: no significant correlations were found in either children or adults. Similarly, NEPSY-II Visual Attention task did not correlate with any of the sub-components in ANT. In adults, inhibition sub-component correlated negatively and significantly with Digit Span Backward (p =.009). In children, a significant negative correlation was found between Digit Span Forward and orienting ($p = .015$). The two Digit span tasks correlated significantly and positively in both age groups (children: $p < .001$, adults: $p = .038$). Further positive significant correlations were found between object and letter RAN in children ($p = .002$).

Fisher z-test showed that the correlations between NEPSY-II Visual attention and object RAN differed significantly between children and adults ($z = -2.20$, $p = .01$). Children had a significantly stronger relationship between NEPSY-II and object RAN. No significant differences were obtained in the correlations between children and adults in the ANT sub-components (alerting: $z = .17$, $p > .05$, orienting: $z = -.88$, $p > .05$, inhibition: $z = .89$, $p > .05$) or the digit span tasks (Digit Span Forward: $z = -.74$, $p > .05$, Digit Span Backward: $z = .98$, $p > .05$).

3.2 Cognitive tasks and the variance in RAN performance

An examination of the correlations (see: figure 2) indicated significant correlations between the two Digit Span tasks. However, as the collinearity statistics (i.e., VIF) were within accepted limits (1-1,38), there was no multicollinearity within the independent variables. Residual and scatter plots indicated the assumptions of normality, linearity and homoscedasticity were all satisfied.

First, a linear regression (method Enter) was conducted with object RAN as the dependent variable. The regression statistics are reported in table 1. The linear regression showed that the cognitive tasks explained a significant amount of variance in object naming speed ($F(6, 73) = 2.79$, $p = .018$) and accounted for 20% of variance. From these, NEPSY-II Visual Attention was a significant predictor of object RAN performance (see: table 1): accurate performance in NEPSY-II Visual Attention predicted faster object naming speed. Other cognitive tasks did not have a significant main effect.

Table 2

Summary of linear regression analysis for variables predicting object RAN in children.

Object RAN

	B	Std. error	β	p
Constant	49.52	5.309		<.001
NEPSY-II Visual attention	-.300	.102	-.335	**.004**
Alerting	.013	.018	.082	.488
Orienting	-.021	.015	-.160	.176
Inhibition	.011	.014	.087	.464
Digit Span Forward	-.939	.486	-.248	.058
Digit Span Backward	.599	.561	.134	.290

Second, a linear regression was conducted with letter RAN as the dependent variable. A linear regression showed that none of the cognitive tasks contributed significantly to the regression model ($F(6, 73) = 1.08$, $p = .383$).

3.3 Analysis of the speed-related group differences in the cognitive tasks

The independent samples t-test for object RAN indicated equal variances between groups in all cognitive tasks except for Digit Span Forward for which the Levene's test was $p = .018$. Table 3 indicates that NEPSY-II Visual attention accuracy differed significantly between the groups. Fast object RAN performers performed more accurately in the NEPSY-II Visual Attention task compared with the slow object RAN performers. There were no significant differences in the other cognitive task performances between the fast and slow performers.

Table 3

Independent samples t-test results for object RAN in children. In the mean and standard deviation column, F=Fast performers and S=Slow performers.

Object RAN					
	M (*sd*)	T	df	p	Cohen's d
NEPSY-II Visual attention	F: 24.56 (*6.9*) S: 20.25 (*6.8*)	2.215	47	**.032**	.633
Alerting	F: 53.69 (*38.6*) S: 67.2 (*39.2*)	-1.216	47	.230	-.348
Orienting	F: 59.75 (*38.4*) S: 44.6 (*57.4*)	1.037	47	.305	.296
Inhibition	F: 112.05 (*40.9*) S: 130.96 (*51.9*)	-1.421	47	.162	-.406
Digit Span Forward	F: 8.2 (*1.2*) S: 7.67 (*1.8*)	1.235	40.9	.227	.353
Digit Span Backward	F: 7.56 (*1.4*) S: 7.75 (*1.6*)	-.446	47	.658	-.127

The independent samples t-test for letter RAN indicated equal variances between groups in all cognitive tasks. There were no significant differences in the cognitive task performance between the fast and slow performers (see: table 4).

Table 4

Independent samples t-test results for letter RAN in children. In the mean and standard deviation column, F=Fast performers and S=Slow performers.

Letter RAN					
	M (*sd*)	T	df	p	Cohen's d
NEPSY-II Visual attention	F: 21.96 (*5.6*) S: 20.58 (*6.9*)	.765	47	.448	.219
Alerting	F: 57.97 (*37.9*) S: 53.67 (*32.8*)	.424	47	.674	.121
Orienting	F: 40.42 (*55.4*) S: 61.38 (*38.4*)	-1.533	47	.132	-.438
Inhibition	F: 119.54 (*45.7*) S: 118.89 (*56.9*)	.044	47	.965	.013
Digit Span Forward	F: 8.36 (*1.6*) S: 7.5 (*1.6*)	1.870	47	.068	.534
Digit Span Backward	F: 7.84 (*1.3*) S: 7.38 (*1.2*)	1.288	47	.204	.368

4 DISCUSSION

The present thesis aimed to explore the joint and unique contributions of visual attention and memory-related processes to naming speed in neurotypical adults and children aged 12 to 13. The aim was to explore the strength and direction of the relationship between the cognitive functions and naming speed and whether visual attentional or memory-related processes are predictive of the speed of naming objects in adolescents and adults and naming letters in children. Although the hypotheses of the thesis were not fully supported, the results indicated that both visual attentional and memory-related processes (i.e., NEPSY-II) may influence object RAN performance in children and these relations fade with development.

In line with the previous research, the results indicated that object naming is slower than naming of letters or digits in children (see table 1). Equivalent findings have been reported by Denckla & Rudel, (1974), Misra et al. (2004) and Papadopoulos et al. (2016). One of the hypotheses explaining this difference in speed is the “semantic hypothesis”, which suggests that object naming requires access to the semantic information and prolongs the performance. The present thesis did not attempt to investigate the semantic hypothesis; however, it may be concluded that object naming speed in adolescents is slower than rapid letter naming. Hypothetically, this may be due to the semantic nature of the object stimuli and further influenced by the participants’ reading ability, suggesting that recalling the phoneme of each letter is more automatic than the recall of the name of the object.

In contrast to Araújo et al. and Pham et al., the results of this thesis implied that attentional processes only influenced object RAN in adolescents in contrast to both RAN composites. The two RAN composites correlated significantly with each other (see figure 2), which may indicate that similar processes are required in both tasks. However, the inclusion of the NEPSY- II Visual attention task provided support for the idea that object RAN performance is more driven by the attentional processes. Interestingly, visual attention or the sub-components (*alerting*, *orienting* and *inhibition*) did not seem to influence letter naming speed, even in the speed-related group analysis. Arguably, the potential connections may be observable when comparing letter RAN performer extremities, such as slow and fast performers. Since no connections were found, it may be suggested that attentional sub-components are not associated with RAN in adolescents or adults.

From the visual attentional processes, the connections between NEPSY-II Visual attention task and RAN was significant in all analyses conducted in this thesis. For instance, the linear regression analysis indicated that the performance in NEPSY-II Visual Attention was a significant predictor of the children's object RAN performance. Indeed, from the variables, NEPSY-II Visual attention was the only one with a significant explanatory power (see table 2). The relationship was further supported by the speed-related group analysis, which showed that fast RAN performers were more accurate in the NEPSY-II Visual attention task than slow performers (see table 4).

This relationship may indicate the need for several different cognitive functions in naming objects. Firstly, the task requires visual attentional resources as the participants were asked to search for certain images from rows of other images. Therefore, visual attentional processes are allocated to each image while suppressing distracting stimuli. The results of this thesis indicated that visual attentional processes are required in RAN. However, this result contradicts Posner and Petersen's (1990) idea of the attentional networks; orienting requires focusing and selecting information and shift visual attention between the stimuli while inhibition refers to the ability to resist interference from distracting stimuli. Arguably, these processes would be required in NEPSY-II Visual attention task as well. However, the results indicated no relationship between NEPSY-II Visual attention task and the sub-components. Therefore, one of the conclusions is that NEPSY-II Visual attention performance is more strongly driven by other cognitive functions. One of these may be rapid visual processing speed, which is also significantly important in the task since it was time-limited (180 seconds) and the accuracy of performance was measured in correct answers minus incorrect answers. This provides support for Kail et al. (1999) who suggested that processing speed is a critical cognitive function for RAN.

Secondly, NEPSY-II Visual attention task is assumed to require visual short-term memory since the participants were asked to memorize two types of facial images and later find them in the rows of images. The accuracy in the task was measured by the participant's ability to hold a visual representation of the image in visual short-term memory for the duration of the task. Since there were no connections between the other tasks that are proposed to test working memory capacity (i.e., the digit span tasks), the memory-related processes required for NEPSY-II Visual attention is hypothesized to be related to the visual nature of the task. Hence, the results of this thesis indicated that in object RAN, visual representations of each object are held in visual short-term memory, similar to NEPSY II Visual attention task. Therefore, memory-related processes may be required for accurate object RAN performance. This supports previous findings that have linked visual working memory processes to reading and RAN in children (Swanson & Lee, 2001) and further provided substantial evidence for the continuing requirement for these functions in later childhood.

Thirdly, visual discrimination is required to perform NEPSY-II Visual attention: participants had to discriminate between two types of facial images and decide whether they are similar or dissimilar. This may indicate that both NEPSY-II Visual attention task and object RAN require rapid access to the semantic information in order to discriminate between the types of images that are held temporarily in the visual short-term memory and the rapidity and accuracy of this cognitive function affects both NEPSY-II Visual attention and object RAN.

The relationship between NEPSY-II Visual attention and object RAN provides support for Wolf and the colleagues (i.e., 2000) and suggests that multiple cognitive functions are required in RAN. Similarly, Pham et al. (2011)

and Papadopoulos et al. (2016) pointed out that the previously proposed cognitive processes do not account for all variance and that the involvement of other cognitive functions should be considered. NEPSY-II Visual Attention task was included since it does not require phonological or orthographic processing, which have previously been associated with RAN but shown not to explain all variance (Wagner et al., 1997; Vaessen et al., 2009; Wolf & Bowers, 1999). The results of this study imply that visual attention, processing speed, memory-related processes and visual discrimination are also required for accurate object RAN performance. However, one of the limitations in this thesis is that the tasks did not include alternative paradigms that are proposed to test processing speed and visual discrimination, which would have provided support for the idea that these cognitive functions are required to perform the NEPSY-II Visual attention task. Hence, these assumptions should be considered with caution.

The present thesis promoted the idea of independence of the attentional networks, namely alerting, orienting and inhibition. The independence of each network was originally proposed by Posner and Petersen (1990) and further supported in fMRI study by Fan et al. (2005). Similar to Ammawat et al. (2019) no correlations in RTs between the sub-components were found (see figures 2 and 3). Ammawat and colleagues demonstrated this absence of connections in attentional networks in children aged five to seven. The present thesis showed that similar findings may be observed in children aged 12 and 13 as well as adults. Indeed, in both age groups, the correlations between the networks are almost non-existent (see figures 2 and 3). However, the present thesis did not attempt to find connections between the sub-components by comparing specific trials (i.e., trials that followed no cue or double cue) within each other and aim to find whether the functions of the networks influence each other. This has previously been proposed by Callejas et al. (2004). Hence, it may only be concluded that there were no correlations between the attentional networks in this thesis.

Contrary to the thesis hypothesis, visual attentional sub-components did not seem to be related to RAN in either children or adults since the correlations of the sub-components and RAN (see figures 2 and 3) indicated an almost an absent relationship between the variables. The absence of a relationship was further demonstrated by the linear regression and speed-related group analysis. Linear regression showed that none of the networks explained a significant amount of variance in either RAN composite. Speed-related groups analysis indicated similar findings by showing that alerting, orienting and inhibition RTs were not significantly different between fast and slow RAN performers. This indicates that the functions of attentional networks are not required to perform either object or letter RAN.

One of the explanations for this finding may be found in development. According to Ammawat et al. (2019), the three attention networks explained 27% of variance in both letter and object naming speed. However, the sample consisted of children aged five to seven years. Therefore, it may be assumed that the functions of the attention networks influence RAN performance in younger children but fades with development and the relations are not observable in children aged 12-13 years. Ammawat and colleagues argued that the influence of the attentional sub-components to RAN performance may indicate reading readiness. In short, the sub-components may be related to RAN performance before learning to read. Accordingly, it may be hypothesized that the absence of the connections between the sub-components and RAN performance in 12-13-year-olds may be due to their reading efficiency. Since the sample in this thesis consisted of neurotypical children without reading difficulties, the functions of the sub-components did not influence RAN performance and that there were no differences between the two RAN composites.

The present thesis hypothesized that the functions of PSTM would influence naming speed but the findings were not supported by the results. Interestingly, all analyses provided contradictory evidence and suggested that no relationship between PSTM and RAN is present in either children or adults.

This contradicts the idea by Torgesen et al. (1997) who suggested that RAN involves quick access to, and retrieval of, phonological codes from long-term memory. Then again, Parrila et al. (2004) proposed that phonological short-term memory relates to naming speed in 5-year-old children. The results of the present thesis indicated that this relationship may fade with development and be non-existent in 12-13-year-olds and adults.

The thesis further hypothesized that slower letter RAN performance may be explained by the functions of PSTM and WM. This hypothesis was based on Smith-Spark and Fisk (2007) and Aguilar-Vafaie et al. (2012), who demonstrated this relationship in dyslexic individuals. The results of this thesis implied that these connections are not observable in neurotypical children and adults. This may indicate that only more significant delays in STM and WM may result in slower naming speed. However, these findings should be further investigated by comparing the differences between dyslexics and non-dyslexics in a single research.

Taken together, the findings of this thesis contribute to the existing literature in three different ways. First, Wolf et al. (2000) proposed a multi-componential model of naming speed and the idea was supported by the findings in this thesis. For instance, visual attention and memory-related processes were found to explain 20% of variance in object naming speed performance. This implies that 80% of the variance in object RAN is explained by alternative cognitive functions. These functions remain unclear. It is also uncertain whether the 80% of variance is explained by a single cognitive function or whether there are multiple processes that are required. It may also be concluded that the cognitive functions influencing letter naming speed in 12-13-year-old children were not identified in this thesis. Therefore, future research may further explore the relations of other functions with letter RAN.

Second, the results showed that there may exist developmental differences in the cognitive functions influencing object naming. This idea was supported by the results in which Fisher's z-test showed a significant difference in the correlations between NEPSY-II Visual Attention and RAN between children and adults. This finding implies that the children may be more dependent on certain cognitive functions when naming object stimuli. However, this assumption is not valid due to the small adult sample size (n=21) and therefore, future research may investigate these developmental differences with larger samples.

Third, this thesis attempted to explore the importance of PSTM and WM in RAN performance, which has previously been debated in research. According to the multi-componential model of RAN, memory-related processes are required but do not explain most of the variance (i.e., Närhi et al., 2005; Wolf et al., 2000). The results of this thesis implied that visual short-term memory may be required. However, this hypothesis should be further investigated in future since the NEPSY-II Visual attention task requires multiple cognitive functions and it is not yet clear which of these proposed processes explain most of the variance in object RAN performance.

In conclusion, this thesis provided support for the idea that multiple cognitive processes are required in rapid automatized naming and proposed that visual attentional and memory-related processes influence rapid object naming speed in neurotypical adolescents. These results further indicated that these cognitive functions do not explain most of the variance in either letter or object RAN performance and that the requirement for other cognitive processes should be considered.

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