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BRIEF REPORT

A Literacy-Related Color-Specific Deficit in Rapid Automatized Naming: Evidence From Neurotypical Completely Illiterate and Literate Adults

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There is a robust positive relationship between reading skills and the time to name aloud an array of letters, digits, objects, or colors as quickly as possible. A convincing and complete explanation for the direction and locus of this association remains, however, elusive. In this study, we investigated rapid automatized naming (RAN) of everyday objects and basic color patches in neurotypical illiterate and literate adults. Literacy acquisition and education enhanced RAN performance for both conceptual categories but this advantage was much larger for (abstract) colors than everyday objects. This result suggests that (a) literacy/education may be causal for serial rapid naming ability of non-alphanumeric items and (b) differences in the lexical quality of conceptual representations can underlie the reading-related differential RAN performance.

Keywords: literacy, rapid automatized naming, object naming, color naming, conceptual knowledge

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Naming speed is one of the most important constructs in the investigation of reading acquisition, and rapid automatized naming (RAN) performance is a powerful predictor of normal and impaired reading ability (Araújo et al., 2015). RAN is assessed in simple naming tasks in which participants name aloud an array of letters, digits, objects, or colors as quickly as possible (Denckla & Rudel, 1976). A particularly intriguing and robust finding is that RAN with non-alphanumeric materials such as pictures of everyday objects or basic colors are also moderate predictors of reading performance (albeit less than alphanumeric RAN; e.g., Georgiou et al., 2008; Protopapas et al., 2013) and children and adults with dyslexia are slower on these tasks than unimpaired readers (Araújo & Faísca, 2019; Reis et al., 2020). The societal importance of good literacy skills and the fact that the moderate-to-strong relationship between reading ability and (non)alphanumeric RAN holds across languages, development, and levels of expertise (Araújo et al., 2015; Landerl et al., 2019) makes understanding it an important goal for the cognitive sciences. There have been many suggestions about what may explain the direction and locus of the RAN-reading association but a complete account remains elusive. The aim of this study was thus to test the role of literacy acquisition on non-alphanumeric RAN and to explore a potential mechanism of such a literacy effect. Investigating it promises to shed new insights into the limits and possibilities of cultural influences such as literacy on cognitive systems beyond the reading domain, in particular, at the interface of visual and language processing. It is also valuable for understanding reading disabilities and the reciprocal influences between cognitive and literacy skills.

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Meta-analyses have estimated the positive correlation between RAN (composite) and reading ability to be between 0.43 (Araújo et al., 2015) and 0.46 (Swanson et al., 2003). What might explain this relationship? Much work (including primarily, but not exclusively, alphanumeric symbols) focused on the notion that RAN taps mechanisms that are causally related to the growth of reading fluency skills (e.g., Lervåg & Hulme, 2009; Verhagen et al., 2008; Wei et al., 2015). In particular, RAN would tap the automaticity of mapping visual symbols to phonological forms (Georgiou et al., 2009; Pan et al., 2013) and the speed of phonological retrieval from long-term memory (Chiappe et al., 2002; Lervåg & Hulme, 2009; Pennington et al., 2001; Schatschneider et al., 2002; Torgesen et al., 1994; for an overview of other suggested causes see Kirby et al., 2010). Less attention has been paid to the converse argument, that RAN performance is itself contingent upon general reading *experience*. Yet, Araújo et al. (2019) demonstrated that learning to read enhances the naming speed for everyday objects, with better RAN performance in *both* early-schooled and -unschooled literate adults than in illiterate adults. Recent longitudinal studies with children have provided convergent evidence (using non/alphanumeric RAN; Peterson et al., 2017; Powell & Atkinson, 2021).

Moreover, a recent review (Huettig et al., 2018) assessing the effect of (lack of) reading experience in illiterates/low-literates and people with dyslexia concluded that almost all observed deficits occur to a similar extent in these two populations. The authors concluded that reduced or suboptimal reading experience may explain performance differences in many cognitive tasks (including RAN). There is a lack of (truly) causal evidence in this regard but it is noteworthy that in line with such a suggestion it has been found that literacy acquisition is associated with an increase in mirror image discrimination abilities (Fernandes et al., 2021; Kolinsky et al., 2011; Pegado et al., 2014), face recognition (Van Paridon et al., 2021), visual search (Olivers et al., 2014), verbal memory (Demoulin & Kolinsky, 2016; Smalle et al., 2019), phonological awareness (Lukatela et al., 1995; Morais et al., 1986, 1979), and prediction of spoken language (Favier et al., 2021; Huettig & Pickering, 2019).

What could be a general mechanism in which reading experience and education affect RAN? An often overlooked possibility is that literacy-contingent enhanced lexical quality (i.e., sharpened lexical representations[1]) results in increased accuracy and fluency of word identification but also, and importantly, faster retrieval of *conceptual* representations (see for review, Perfetti, 2007; Perfetti & Hart, 2002). In fact, literate individuals performed much better than illiterates in semantic fluency tasks (e.g., Kolinsky et al., 2014; Kosmidis et al., 2004; Reis & Castro-Caldas, 1997), in similarities subtests (Ostrosky et al., 1998), and also generated more superordinate names (e.g., *furniture*) for coordinate words (e.g., *sofa-table-cupboard*; Kolinsky et al., 2014), all tasks taping into conceptual knowledge and processes. It seems thus plausible to assume that more reading-related activities, as well as more education in general, increases not only the number of words and concepts but also the conceptual detail that is acquired. More refined and sharper lexical representations (Huettig & Pickering, 2019) and high lexical quality (Perfetti, 2007) would in turn allow for faster conceptual access[2] and also lead to faster naming of (depicted) concepts.

Here we investigate this hypothesis by examining the serial naming of familiar objects and colors by neurotypical illiterate adults and early-schooled literate adults. The comparison of object and color naming is particularly interesting because demands upon phonological retrieval are equivalent and performance is conceptually driven in both tasks (Glaser, 1992; Roelofs, 2003), but conceptual processes are likely to be more effortful (Anyan & Quillian, 1971; Bornstein, 1985a; Braisby & Dockrell, 1999; Kowalski & Zimiles, 2006; Pitchford & Mullen, 2001) and might play a more prominent role in color naming (with sufficient practice; see Protopapas et al., 2017; Roelofs, 2003). Neuropsychological evidence confirms that abilities important for color naming may also be involved in the conceptualization of color as an abstract property, detachable from object representation, even in the adult cognitive system (Siuda-Krzywicka et al., 2020). Hence, testing the interaction between literacy and type of RAN seems to be a useful way to investigate whether reading experience sharpens the strength and precision of conceptual representations, in turn allowing for their faster access and retrieval (with major consequences for abstract concepts such as colors). We hypothesize that illiterate adults, as a consequence of a lack of reading experience and education, have *comparatively* less robust conceptual color representations (despite being able to *accurately* name the colors) than conceptual representations of everyday objects and that such a difference should manifest itself in a color-specific RAN deficit in illiterate participants compared to literate.[3]

Material and Method

Participants

Twenty-two illiterate and eighteen age-matched literate adults, all female, participated after informed consent was obtained. With this sample size, the study had sufficient sensitivity to detect a medium-sized interaction effect ($\eta p^2 \geq 0.07$, calculated using G*Power software, v.3.1.9.4v) with 80% power ($\alpha = .05$); this effect size is larger than the observed in prior work ($\eta_p^2 = 0.15$ in Araújo et al., 2019). Detailed information about participants and screening tasks is found in the online supplemental materials. All participants came from the same informal settlement in New Delhi, India, and had a nearly overlapping socioeconomic background. None of them had any known neurological disease or cognitive deficits, and all illiterates self-reported that it was only for cultural and socioeconomic reasons that they did not attend school or receive reading instruction. Table 1 shows that the two groups differed considerably on literacy knowledge and word-reading, and also on Raven's scores of nonverbal intelligence (Raven et al., 2000). This is a common finding

[1] We define lexical quality and sharpened lexical representations as the amount of detail and interconnectivity of lexical representations (e.g., the amount of detail and interconnectivity of conceptual/semantic representations).

[2] We suggest that one index of the quality of (conceptual) representations is the speed with which representations are accessed and retrieved to support oral production (though we stress how concepts are mentally represented is a complex process, see e.g., Morton & Preston, 2021, which is beyond the scope of the present study).

[3] We must recognize the complexity of the RAN task beyond individual stimulus processing (Gordon & Hoedemaker, 2016; Henry et al., 2018; Kuperman et al., 2016; Protopapas et al., 2018) and that multiple mechanisms may contribute to performance, most notably, multi-element sequence processing, executive attentional mechanisms, and verbal working memory (e.g., Amtmann et al., 2007; Jongman et al., 2016; Kuperman et al., 2016; Protopapas et al., 2018). Importantly however, these mechanisms per se would not be anticipated to produce differential effects of literacy in object- versus color-naming (e.g., Kolinsky et al., 2014).

as even non-verbal intelligence is affected by formal education (see Ceci, 1991; Neisser et al., 1996). Important, previous studies with similar populations as ours showed that literacy enhances non-verbal intelligence rather than that group differences in non-verbal intelligence caused differences in experimental results (Olivers et al., 2014; Skeide et al., 2017).

The study was approved by the Institutional Ethics Board of the Jawaharlal Nehru University and followed the guidelines of the Helsinki declaration.

Materials and Design

The object- and color-RAN tasks were adapted from the standard RAN paradigm (Denckla & Rudel, 1976). Hence, we used many repetitions of a small set of items which, importantly, does not preclude the finding of a robust RAN-reading association (see Araújo et al., 2015). Participants were instructed to name as fast as possible, in left-to-right order, five common objects (shoe—ɟuːt̪ɑː, banana—keːlaː, spoon—tʃəmmətʃ, chair—kursiː, glass—kɑːŋtʃ; IPA pronunciation of Hindi is given) and five basic color patches (green—ɦəɾɑː, red—lɑːlə, black—kɑːlɑː, yellow—piːlɑː, blue—niːlɑː) that were arranged pseudo-randomly in four individual lines presented one at a time but in positions analogous to the classic RAN (see Figure 1); the task was experimenter-paced, and participants' spoken output was recorded in parallel. By using an easier variant of the classic RAN task, that is, with no need for participants to coordinate the eyes and the voice across line breaks, we aimed to minimize any potential group differences due to task complexity. Each object/color was repeated four times, hence, 20 items were presented in total per RAN task. Two blocks in each task (same objects/colors but in a different arrangement) were presented to the participants, and the task order was counterbalanced. Presentation of stimuli and data collection were carried out using E-Prime. Participants were first given a practice, with corrective feedback. The mean time necessary to name the items (button-press RT, which was validated in a subsidiary analysis; see online supplemental materials) was used as a measure of RAN speed, for each task.

Database and material are available at https://osf.io/sycmr/?view_only=40b36dc4ec414b248ba58d37083c97cf.

Results

Accuracy was close to the ceiling in both tasks (>97% in both groups) and did not differ statistically between groups (*Fs* < 1). For the whole-trial naming time measure, the extreme values were winsorized (Wilcox, 2005; ∼5% of the data), and RTs were log-transformed prior to analysis. In the mixed group-by-stimulus type ANOVA executed on mean RTs, there was a main effect of group, $F(1, 38) = 33.5$, $p < .001$, $\eta_p^2 = 0.47$. Naming times were faster in literate (mean RT = 18,309 ms, 95% CI [16,622, 19,606]) than in illiterate participants (Mean RT = 25,154 ms, [22,397, 27,024]). There was also a main effect of stimulus type, $F(1, 38) = 11.7$, $p = .001$, $\eta_p^2 = 0.24$, and this effect interacted robustly with group, $F(1, 38) = 7.0$, $p = .012$, $\eta_p^2 = 0.16$. As illustrated in Figure 2, the performance of literate participants was not affected by stimulus type (Bonferroni post hoc test, $p > .99$), while illiterate participants were much slower at naming colors than line drawings of objects ($p < .001$). We also observed a larger literacy advantage in performance for color- than for object-RAN. The same pattern of results was obtained with a linear mixed-effects model with Raven's scores as a covariate, and also when comparing IQ-matched subgroups (see online supplemental materials for both analyses).

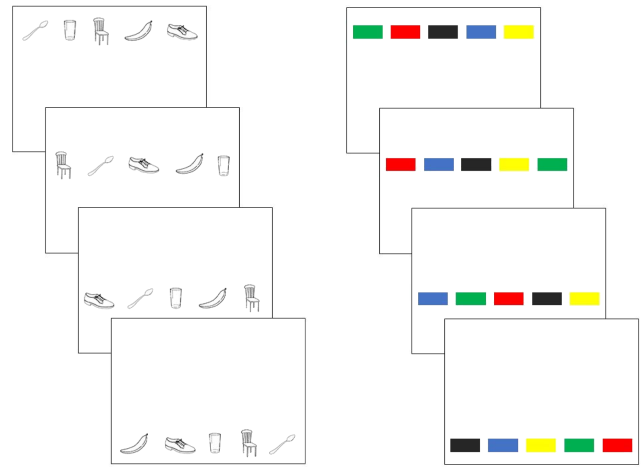
Additional analyses explored whether there were any literacy-driven differences in RAN performance as a function of stimulus

Table 1
Means ± Standard Deviations of Participant Characteristics

Profile	Literate ($n = 18$)	Illiterate ($n = 22$)
Mean age (years)	24.8 ± 6.5	27.7 ± 3.0
Years of schooling	12.3 ± 2.3	0.0 ± .0*
Monthly income (in Rupees)	2,697 (700–7,000)	1,847 (600–4,000)
Raven's Progressive Matrices (max. = 60)	36.9 ± 11.3	15.2 ± 4.2*
Akshara knowledge scores (max. = 44)	43.4 ± 1.1	0.7 ± 2.1*
Word reading scores (max. = 75)	73.3 ± 2.4	0.4 ± 1.0*

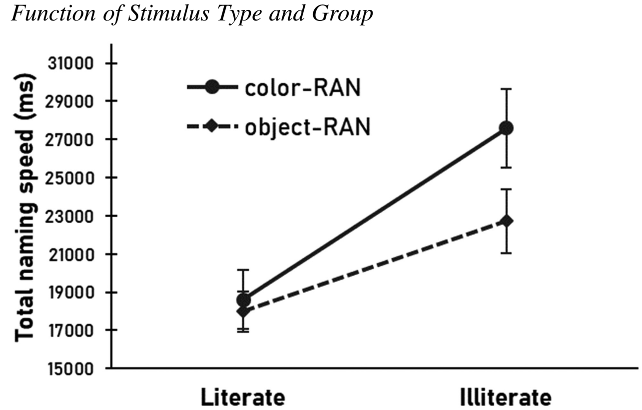
Note. The range appears in parentheses.
*$p < .001$.

Figure 1
Example Display of One Trial of the Object-RAN (Left) and the Color-RAN (Right) Tasks



Note. See the online article for the color version of this figure.

Figure 2
Mean Total Naming Times (With 95% Confidence Intervals) as a Function of Stimulus Type and Group



repetition (from the first to fourth presentation of the same object/color per block, corresponding to each individual line within the matrix). There were no significant interactions involving block for color- or object-RAN (all $ps > .1$). In color-RAN, the stimulus repetition-by-group interaction, $F(3, 114) = 3.7$, $p = .014$, $\eta^2_p = 0.09$, reveals a steeper decrease in naming times for literate (pairwise tests of a sequential set of stimuli; all $ps < .001$) than for illiterate participants ($ps > .3$) across repeated stimulus within each block. *Post hoc* tests (Bonferroni correction for multiple comparisons) also show that illiterate participants (vs. literate) were slower in naming on the very first encounter of the colors and this delay remained for all four stimulus repetitions (all $ps < .001$). Figure 3 shows that the magnitude of the difference (i.e., the literacy advantage) increased after the first presentation of the item. In object-RAN, the main effect of stimulus repetition was significant, $F(3, 114) = 9.0$, $p < .001$, $\eta^2_p = 0.19$, as both groups benefited from repetition from the first to the second presentation of an object ($p < .001$). There was no group-by-stimulus repetition interaction ($p = .338$).

Discussion

The present experiment, testing an under-studied non-WEIRD population, clearly shows that literacy and formal education are associated with enhanced RAN of everyday objects and basic color patches (extending Araújo et al., 2019, using object-RAN). Considered together with recent longitudinal (Peterson et al., 2017; Powell & Atkinson, 2021) and intervention (Wolff, 2014) studies, our results thus suggest that the literacy-RAN link is at the very least bidirectional, namely that reading experience may have a causal influence on the improvement of non-alphanumeric RAN performance in addition to RAN abilities supporting the reading acquisition. Ultimately these findings also contribute to the debate about the hallmark RAN deficits in dyslexia (Araújo & Faísca, 2019), which may be partially a consequence of a lack of training on reading (Huettig et al., 2018), while also indicating possible limits of RAN tasks for neuropsychological and psychoeducational assessment (e.g., Blomert & Vaessen, 2009; Moura et al., 2018).

Our findings further show that naming colors poses a different challenge to illiterate people than naming of everyday objects. This occurs even though illiterate individuals are as accurate in naming the colors as literate people, who do not show such a strong category distinction. This result is consistent with our suggestion of a role for lexical quality and sharpness of conceptual representations in determining nonalphanumeric RAN performance. Although learning to read and write bolsters the activation of phonological representations used in RAN (Araújo et al., 2019), it seems unlikely that this is the (only) driving factor here. Both tasks used high-frequency words that are likely to be well-specified, and hence easily accessed, at the phonological level even in illiterate samples (RAN: Araújo et al., 2019; word repetition: Reis & Castro-Caldas, 1997). Furthermore, if anything, phonological length was shorter for color names (see methods), which generally accelerates rather than slowing RTs[4] (e.g., Bates et al., 2003).

In short, we can have considerable confidence that the locus of the large and robust interaction between literacy and stimulus category, whereby the literacy benefit for RAN was greater for colors than objects, is contingent on differences in the *conceptual* representations (as discussed in the introduction). We must acknowledge that the present experiment cannot isolate the impact of literacy and formal education/schooling. Yet, studies comparing matched populations equally deprived of early schooling (ex-literates vs. illiterates) showed that literacy per se indeed augments RAN ability (Araújo et al., 2019) and also the richness and precision of conceptual representations (Kolinsky et al. 2014), and consequently the speed of access to them. This would in turn be an important part of reading-related differential non-alphanumeric RAN performance, as we found[5] (see Jones et al., 2010, for a similar concept-access account to naming delays in dyslexia). Bates et al. (2003) raised the possibility that "conceptual accessibility" explains why there are strong correlations in naming latencies across languages even after controlling for within-language factors (e.g., lexical frequency effects). This arguably fits with our interpretation that colors as concepts are simply less accessible for illiterate participants because they have less crystallized conceptual color representations. Conversely, the illiteracy cost in the naming of items that are (presumably) not conceptually mediated, such as numbers, seems to be reduced (Deloche et al., 1999).

Nonetheless, it could be argued that the effects of literacy and education found here could rather be due to vocabulary size differences (Nation et al., 2001; Poulsen & Elbro, 2013) or merely because literates had more practice in naming colors, given that schooling seems to provide a crucial opportunity to use color names (Bornstein, 1985b). What speaks very much against such an interpretation is that we used highly familiar names. Moreover, illiterates were not more likely to be corrected during the practices (*t*-tests, $ps > .4$), performed at ceiling in a word-to-picture matching task (Smalle et al., 2019, with a similar population) and were able to provide adequate verbal definitions for words (Ventura et al., 2007; Experiment 2), despite lower RAN performance than unschooled ex-illiterate adults (Araújo et al., 2019) with an equivalent vocabulary (cf. Morais & Kolinsky, 2002). In what regard possible practice confounds, note that a delay in naming colors did not depend upon previous practice in prior studies (Brown, 1915; Ligon, 1932; see also Protopapas et al., 2017). We also have no strong reason to believe that literate adults compared to illiterates have an extensive history of practice in color-to-name mapping (as naming colors at school mostly happens in the first grades). In sum, both alternative interpretations seem unlikely, but we acknowledge that our study does not rule them out.

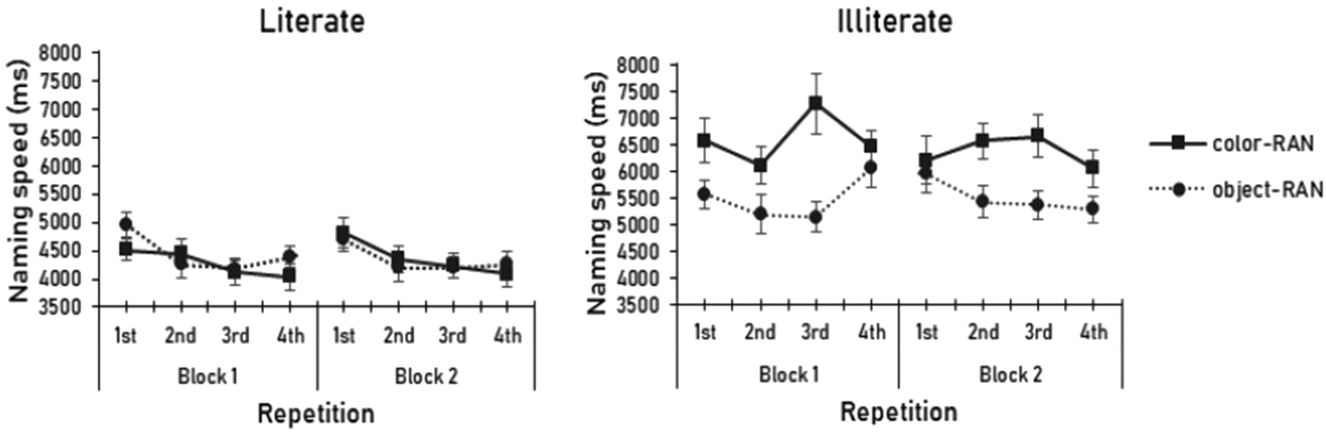
A final possibility that future research may usefully explore is that illiterates are less able to allocate sufficient processing capacity to the task. It is conceivable that the limited capacity to monitor and update

[4] It should be noted that color names were also more phonologically similar than object names, hence, material properties were not fully matched. However, we believe that this did not have an impact on the pattern of results: although a recent study (Easson et al., 2020) showed that processing demands in object-RAN task increase with increased phonological similarity of the items, this is not evident in naming speed efficiency (Figure 3A) which was the specific measure used here (see also e.g., Damian & Dumay, 2009; Wang et al., 2018, for rather facilitation effects in production).

[5] We point out here that it is possible that the nature (and direction) of influence varies with development. It may be that earlier letter knowledge and phoneme awareness enhance (early) alphanumeric-RAN (e.g., Lervåg & Hulme, 2009; Wagner et al. 1994), but once knowledge of letter and digit names are fully automatized, only nonalphanumeric RAN is augmented by increased literacy, via enhanced lexical quality and sharpness of conceptual representations.

Figure 3

Naming Speed Performance in Object- and Color-RAN as a Function of Stimulus Repetition



Note. Naming times (in ms) after back-transforming from the log scale (means ± SE). Two-way interaction was observed in color-RAN.

verbal memory representations (Smalle et al., 2019) may affect naming performance (e.g., Amtmann et al., 2007), and specifically the efficiency of conceptual processes (Shao et al., 2012). This would have been more detrimental for color naming, and might also explain why illiterates compared to literate controls showed a less steep decrease in color naming times after the first row of the task, and still showed increased times for completing the later parts of the task.

Context of the Research

The research in this article was inspired by previous findings by Araujo, which have explored the relationship between RAN and reading proficiency. This line of research had previously shown that healthy illiterate adults and children and adults with dyslexia are slower in RAN of nonalphanumeric items (objects). The current study is the first to test whether literacy has a differential impact on RAN for different categories of stimuli (concrete: objects, abstract: colors) in a sample drawn from an under-studied population. Our findings open up new perspectives for how specifically a cultural acquisition (literacy) shapes cognitive systems beyond the reading domain, and prompt a new direction in research examination of the role of literacy in grounding abstract and concrete concepts. More research will be needed to fully test our proposed account across task variants and materials.

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