Exploration of the Rapid Automatized Naming (RAN) Task:

(1) What should the “A” in RAN really stand for?
(2) Meta-analysis of empirical evidence

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of Learning and Performance)
OUTLINE:

• Background & Rational
• Major Research Questions
• Experimental Findings
• Meta-Analysis:
  Summarizing empirical data on RAN-to-reading association
• General Discussion & Implications
Background:
Diagnosis & Prognosis of Developmental Dyslexia

- Defining developmental dyslexia: The role of cognitive factors (e.g., Snowling, 2000)
  - Phonological awareness - grapheme / phoneme correspondence (e.g., Rayner et al., 2001, Stanovich, 2000)
  - Naming speed: Measured by RAN task performance (Denckla & Rudel, 1974, 1976)
NON-SYMBOLIC (COLORS) RAN
NON-SYMBOLIC (OBJECTS) RAN
SYMBOLIC (DIGITS) RAN

2 4 6 9 4 6 7 9 7 2
6 2 7 6 7 4 2 6 9 4
4 9 2 4 2 9 4 2 6 7
9 7 4 2 9 7 6 4 2 9
7 6 9 7 6 2 9 7 4 6
Background: RAN & reading

• Wolf, Bowers, & Biddle (2000), Wolf et al. (2002):
  • Cross-sectional
  • Longitudinal
  • Different ages
  • Different languages

• Savage et al. (2005), Torgesen & Burgess (1998):
  *Phonological nature of RAN*
• Schatschneider et al. (2002):
  *Research design concern*
• Swanson et al. (2003), Hammill (2004):
  *Emphasis on other correlates of reading*

• The cognitive nature of RAN remains an open question…
Major Research Questions

• What should the “A” in RAN stand for?
  Does RAN performance reflect automatic or attention-based processing?
  • Specifying and testing automaticity account
  • Exploring aspects of attention account
  Estimating relative contributions of automaticity and attention-based processing to RAN task performance

• How different are symbolic and non-symbolic RAN subtasks?
  • In underlying cognitive mechanisms
  • In connection with different aspects of reading skills
MAJOR FINDINGS:

• Attention > Automaticity

• Symbolic RAN ≠ Non-symbolic RAN

• $r \ (\text{RAN, reading}) = f \ (\text{Attention Demand})$
READING

RAN task performance

AUTOMATICITY:

BALLISTIC AUTOMATICITY

EFFICIENCY OF AUTOMATIC STIMULUS RECOGNITION

AUTOMATIC DETECTION EFFICIENCY

LEXICAL ACCESS EFFICIENCY

ATTENTION:

INDEX OF GENERAL ATTENTION

CONTROLLED SEARCH EFFICIENCY

WORKING MEMORY

ATTENTION SHIFT COST

Three experimental studies: N=68, N=16, & N=97
Symbolic RAN (letter)

Symbolic RAN (digit)

Non-symbolic RAN (colors)

Non-Symbolic RAN (objects)

Legend:
- Automatic detection
- Lexical access
- Working memory
- Attention shift cost
- Controlled search
- Unexplained
READING

RAN task performance

AUTOMATICITY:
- BALLISTIC AUTOMATICITY
- EFFICIENCY OF AUTOMATIC STIMULUS RECOGNITION
- AUTOMATIC DETECTION EFFICIENCY
- LEXICAL ACCESS EFFICIENCY

ATTENTION:
- INDEX OF GENERAL ATTENTION
- ATTENTION SHIFT COST
- CONTROLLED SEARCH EFFICIENCY
- WORKING MEMORY
Major Research Questions

• What should the “A” in RAN stand for? Does RAN performance reflect automatic or attention-based processing?
  • Specifying and testing automaticity account
  • Exploring aspects of attention account
  Estimating relative contributions of automaticity and attention-based processing to RAN task performance

• How different are symbolic and non-symbolic RAN subtasks?
  • In underlying cognitive mechanisms
  • In connection with different aspects of reading skills
READING

SYMBOLIC RAN

NON-SYMBOLIC RAN

AUTOMATICITY:

BALLISTIC AUTOMATICITY
EFFICIENCY OF AUTOMATIC STIMULUS RECOGNITION
AUTOMATIC DETECTION EFFICIENCY
LEXICAL ACCESS EFFICIENCY

ATTENTION:

INDEX OF GENERAL ATTENTION
ATTENTION SHIFT COST
CONTROLLED SEARCH EFFICIENCY
WORKING MEMORY
Observed pattern of the results - modified RAN subtasks performance time

<table>
<thead>
<tr>
<th>Stimulus Type</th>
<th>F(1,95)</th>
<th>p</th>
<th>( \eta^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Symbolic RAN</td>
<td>910.72</td>
<td>&lt;.001</td>
<td>.906</td>
</tr>
<tr>
<td>Symbolic RAN</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The observed pattern shows that the performance time decreases as the attention demand increases.

- **Non-Symbolic RAN**
  - Light: 36.25 sec
  - Heavy: 43.28 sec
- **Symbolic RAN**
  - Light: 20.62 sec
  - Heavy: 25.31 sec
17

AUTOMATICITY:

- Ballistic Automaticity
- Efficiency of Automatic Stimulus Recognition
- Automatic Detection Efficiency
- Lexical Access Efficiency

READING

r-values: < .25 (1/8)

- Symbolic RAN
- Non-Symbolic RAN

ATTENTION:

- Index of General Attention
- Attention Shift Cost
- Controlled Search Efficiency
- Working Memory
AUTOMATICITY:

- Ballistic Automaticity
- Efficiency of Automatic Stimulus Recognition
- Automatic Detection Efficiency
- Lexical Access Efficiency

ATTENTION:

- Index of General Attention
- Attention Shift Cost
- Controlled Search Efficiency
- Working Memory

r-values: < .25 (1/8)

r-values: ≤ .41 (3/8)
AUTOMATICITY:

- BALLISTIC AUTOMATICITY
- EFFICIENCY OF AUTOMATIC STIMULUS RECOGNITION
- AUTOMATIC DETECTION EFFICIENCY
- LEXICAL ACCESS EFFICIENCY

ATTENTION:

- INDEX OF GENERAL ATTENTION
- ATTENTION SHIFT COST
- CONTROLLED SEARCH EFFICIENCY
- WORKING MEMORY

r-values: < .25 (1/8)
r-values: < .41 (3/8)
r-values: < .265 (2/8)
**READING**

**AUTOMATICITY:**
- Ballistic Automaticity
- Efficiency of Automatic Stimulus Recognition
- Automatic Detection Efficiency
- Lexical Access Efficiency

**ATTENTION:**
- Index of General Attention
- Attention Shift Cost
- Controlled Search Efficiency
- Working Memory

**SYMBOLOGIC RAN**

$\textit{r-values: } < .40 \ (3/8)$

**NON-SYMBOLIC RAN**

$\textit{r-values: } < .25 \ (1/8)$

$\textit{r-values: } < .265 \ (2/8)$

$\textit{r-values: } < .451 \ (7/8)$
AUTOMATICITY:

- Ballistic Automaticity
- Efficiency of Automatic Stimulus Recognition
- Automatic Detection Efficiency
- Lexical Access Efficiency

ATTENTION:

- Index of General Attention
- Attention Shift Cost
- Controlled Search Efficiency
- Working Memory

$r$-values: .389*** & .402***
AUTOMATICITY:

- Ballistic Automaticity
- Efficiency of Automatic Stimulus Recognition
- Automatic Detection Efficiency
- Lexical Access Efficiency

ATTENTION:

- Index of General Attention
- Attention Shift Cost
- Controlled Search Efficiency
- Working Memory

r-values: 0.389*** & 0.402***

.138 & .128
AUTOMATICITY:
- Ballistic automaticity
- Efficiency of automatic stimulus recognition
- Automatic detection efficiency
- Lexical access efficiency

ATTENTION:
- Index of general attention
- Attention shift cost
- Controlled search efficiency
- Working memory

r-values: **.307** & .187
AUTOMATICITY:

- BALLISTIC AUTOMATICITY
- EFFICIENCY OF AUTOMATIC STIMULUS RECOGNITION
- AUTOMATIC DETECTION EFFICIENCY
- LEXICAL ACCESS EFFICIENCY

ATTENTION:

- INDEX OF GENERAL ATTENTION
- ATTENTION SHIFT COST
- CONTROLLED SEARCH EFFICIENCY
- WORKING MEMORY

READING RATE

r-values: .307** & .187

READ COMPREHENSION

r-values: .259* & .155

SYMBOLIC RAN

NON-SYMBOLIC RAN
AUTOMATICITY:

BALLISTIC AUTOMATICITY

EFFICIENCY OF AUTOMATIC STIMULUS RECOGNITION

AUTOMATIC DETECTION EFFICIENCY

LEXICAL ACCESS EFFICIENCY

ATTENTION:

INDEX OF GENERAL ATTENTION

ATTENTION SHIFT COST

CONTROLLED SEARCH EFFICIENCY

WORKING MEMORY

MODIFIED RAN (M-RAN-HEAVY)

r-values: .180* - .415*** (4/4) .229** - .368*** (4/4)
META-ANALYSIS:

Summarizing empirical evidence of RAN-to-reading association

• What is the point estimate (an average effect size) of the degree of association between the RAN task and reading?
• What factors (methodological and substantive study features) affect (increase or reduce) the strength of this association and to what extent?
• What is known from previous meta-analytical research?
• Swanson et al. (2003)
  RAN/Word Reading: \( r^+ = .49 \)
  RAN/Reading Comprehension: \( r^+ = .53 \)
• Hammill (2004)
  RAN/Reading: \( r^+ = .44 \)
• RAN definition & selection of Study Features
META-ANALYSIS:
Summarizing empirical evidence of RAN-to-reading association

• Searches (1976 - 2006): 735 studies
  ("RAN"/"rapid naming"/"automatized naming"/"serial naming"/"naming speed") &
  ("literacy", "read*", "dyslex*")
  PSYCInfo, PubMed, ERIC, ProQuest Dissertations and Theses & branching

• Inclusion/Exclusion review:
  N-NSM – study contains no naming speed measure
  N-RPM – study contains no measure of reading performance
  N-PER – not a primary empirical research study
  N-MDA – study does not report any measure of degree of association
    between RAN & reading

• Inter-rater agreement:
  Abstract review – 92.65 % ($r = 0.852$, $p < 0.01$)
  Full-text review – 93.33 % ($r = 0.846$, $p < 0.01$)
  Number and selection of the effect sizes (on a selected sample) – 93.18 %
  Study Features coding (on a selected sample) – 89.09 %.
META-ANALYSIS:
Summarizing empirical evidence of RAN-to-reading association

- Effect Size: Weighted Pearson product-moment correlation coefficients ($r$)
- Cross-sectional studies
- Longitudinal studies
- Study Features:
  - Type of RAN task: Symbolic / Non-symbolic
  - Type of reading measure:
    - Decoding / Word reading / Reading rate / Reading comprehension / Vocabulary / Spelling / Orthography / Composite
  - Participants' age:
    - Kindergarten / Elementary school / Secondary school / Adolescents / Adults / Mixed groups
  - Dominant language:
    - English / Romance-Germanic family / Not alphabet based / Fluent bilinguals
  - Reading abilities:
    - Dyslexia / Learning disabilities / Age-adequate / Mixed groups
  - Time lag: Within a year / Several years longitudinal
META-ANALYSIS:
Summarizing data on RAN-to-reading association

- A representative sample of 65 empirical studies reporting RAN-to-reading correlations
- Cross-sectional design: $k = 422$, $N = 6495$, $r^+ = .345$
- Longitudinal design: $k = 108$, $N = 2060$, $r^+ = .398$
- Predictive power of RAN
- Symbolic RAN subtasks are more consistently associated with speed-dependent aspects of reading
- Non-symbolic RAN subtasks are primarily connected to rule-based and comprehension-oriented aspects of reading
- Efficient attention management
META-ANALYSIS:
Summarizing data on RAN-to-reading association

RESULTS (Cross-sectional design):

Effect size ($r^+$) for the overall RAN-to-reading association

<table>
<thead>
<tr>
<th>Model</th>
<th>$k$</th>
<th>Effect size</th>
<th>95% confidence interval</th>
<th>Test of null</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$r^+$</td>
<td>Lower limit</td>
<td>Upper limit</td>
</tr>
<tr>
<td>Fixed</td>
<td>422</td>
<td>0.345</td>
<td>0.334</td>
<td>0.355</td>
</tr>
<tr>
<td>Random</td>
<td>422</td>
<td>0.350</td>
<td>0.334</td>
<td>0.367</td>
</tr>
</tbody>
</table>

*** $p < .001$

Heterogeneity analysis ($Q$ and $I^2$) for the overall RAN-to-reading association

<table>
<thead>
<tr>
<th>RAN $r$</th>
<th>$k$</th>
<th>Effect size</th>
<th>95% confidence interval</th>
<th>Test of null</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total:</td>
<td>422</td>
<td>890.713</td>
<td>421</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>
META-ANALYSIS:
Summarizing data on RAN-to-reading association

RESULTS (Longitudinal design):

Effect size ($r+$) for the overall RAN-to-reading association

<table>
<thead>
<tr>
<th>Model</th>
<th>$k$</th>
<th>Effect size</th>
<th>95% confidence interval</th>
<th>Test of null</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$r+$</td>
<td>Lower limit</td>
<td>Upper limit</td>
</tr>
<tr>
<td>Fixed</td>
<td>108</td>
<td>0.398</td>
<td>0.373</td>
<td>0.422</td>
</tr>
<tr>
<td>Random</td>
<td>108</td>
<td>0.394</td>
<td>0.360</td>
<td>0.426</td>
</tr>
</tbody>
</table>

*** $p < .001$

Heterogeneity analysis ($Q$ and $I^2$) for the overall RAN-to-reading association

<table>
<thead>
<tr>
<th>RAN Ğreading $r+$</th>
<th>$k$</th>
<th>Heterogeneity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Q-value</td>
</tr>
<tr>
<td>Total:</td>
<td>108</td>
<td>149.175</td>
</tr>
</tbody>
</table>
### Effect size (r+) of RAN -to-reading associations for RAN type / reading measure interactions (cross-sectional design)

<table>
<thead>
<tr>
<th>RAN type X Type of reading measure:</th>
<th>k</th>
<th>Effect size</th>
<th>95% confidence interval</th>
<th>Test of null</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Symbolic RAN X Decoding skills</strong></td>
<td>65</td>
<td>0.384</td>
<td>0.357 - 0.410</td>
<td>25.377***</td>
</tr>
<tr>
<td><strong>Symbolic RAN X Word reading</strong></td>
<td>95</td>
<td>0.438</td>
<td>0.416 - 0.461</td>
<td>33.164***</td>
</tr>
<tr>
<td><strong>Symbolic RAN X Reading rate</strong></td>
<td>20</td>
<td>0.438</td>
<td>0.380 - 0.492</td>
<td>13.272***</td>
</tr>
<tr>
<td><strong>Symbolic RAN X Comprehension</strong></td>
<td>44</td>
<td>0.396</td>
<td>0.362 - 0.429</td>
<td>20.505***</td>
</tr>
<tr>
<td><strong>Symbolic RAN X Vocabulary</strong></td>
<td>25</td>
<td>0.091</td>
<td>0.038 - 0.142</td>
<td>3.399**</td>
</tr>
<tr>
<td><strong>Symbolic RAN X Orthography</strong></td>
<td>11</td>
<td>0.407</td>
<td>0.320 - 0.487</td>
<td>8.411***</td>
</tr>
<tr>
<td><strong>Symbolic RAN X Spelling</strong></td>
<td>18</td>
<td>0.270</td>
<td>0.228 - 0.311</td>
<td>12.085***</td>
</tr>
<tr>
<td><strong>Non-symmetric RAN X Decoding</strong></td>
<td>24</td>
<td>0.302</td>
<td>0.261 - 0.342</td>
<td>13.680***</td>
</tr>
<tr>
<td><strong>Non-symmetric RAN X Word reading</strong></td>
<td>37</td>
<td>0.321</td>
<td>0.282 - 0.358</td>
<td>15.404***</td>
</tr>
<tr>
<td><strong>Non-symmetric RAN X Reading rate</strong></td>
<td>10</td>
<td>0.319</td>
<td>0.216 - 0.415</td>
<td>5.814***</td>
</tr>
<tr>
<td><strong>Non-symmetric RAN X Comprehension</strong></td>
<td>18</td>
<td>0.341</td>
<td>0.285 - 0.396</td>
<td>11.070***</td>
</tr>
<tr>
<td><strong>Non-symmetric RAN X Vocabulary</strong></td>
<td>11</td>
<td>0.244</td>
<td>0.188 - 0.299</td>
<td>8.249***</td>
</tr>
</tbody>
</table>

**Overall** | 422 | 0.345 | 0.334 - 0.355 | 58.861***

**Note**: only interactions with k > 10 are included into the table.
<table>
<thead>
<tr>
<th>RAN type X</th>
<th>Type of reading</th>
<th>measure:</th>
<th>$k$</th>
<th>Effect size</th>
<th>95% confidence interval</th>
<th>Test of null hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbolic RAN</td>
<td>X</td>
<td>Decoding skills</td>
<td>14</td>
<td><strong>0.445</strong></td>
<td><strong>0.344</strong></td>
<td><strong>0.537</strong></td>
</tr>
<tr>
<td>Symbolic RAN</td>
<td>X</td>
<td>Word reading</td>
<td>14</td>
<td><strong>0.537</strong></td>
<td><strong>0.495</strong></td>
<td><strong>0.577</strong></td>
</tr>
<tr>
<td>Symbolic RAN</td>
<td>X</td>
<td>Reading rate</td>
<td>18</td>
<td><strong>0.470</strong></td>
<td><strong>0.273</strong></td>
<td><strong>0.629</strong></td>
</tr>
<tr>
<td>Symbolic RAN</td>
<td>X</td>
<td>Comprehension</td>
<td>21</td>
<td><strong>0.355</strong></td>
<td><strong>0.266</strong></td>
<td><strong>0.438</strong></td>
</tr>
<tr>
<td>Symbolic RAN</td>
<td>X</td>
<td>Vocabulary knowledge</td>
<td>1</td>
<td>0.020</td>
<td>-0.302</td>
<td>0.388</td>
</tr>
<tr>
<td>Symbolic RAN</td>
<td>X</td>
<td>Orthographic skills</td>
<td>2</td>
<td><strong>0.523</strong></td>
<td><strong>0.303</strong></td>
<td><strong>0.690</strong></td>
</tr>
<tr>
<td>Non-symbolic RAN</td>
<td>X</td>
<td>Decoding</td>
<td>9</td>
<td><strong>0.261</strong></td>
<td><strong>0.180</strong></td>
<td><strong>0.338</strong></td>
</tr>
<tr>
<td>Non-symbolic RAN</td>
<td>X</td>
<td>Word reading</td>
<td>10</td>
<td><strong>0.343</strong></td>
<td><strong>0.274</strong></td>
<td><strong>0.408</strong></td>
</tr>
<tr>
<td>Non-symbolic RAN</td>
<td>X</td>
<td>Reading rate</td>
<td>4</td>
<td><strong>0.357</strong></td>
<td><strong>0.230</strong></td>
<td><strong>0.472</strong></td>
</tr>
<tr>
<td>Non-symbolic RAN</td>
<td>X</td>
<td>Comprehension</td>
<td>8</td>
<td><strong>0.324</strong></td>
<td><strong>0.256</strong></td>
<td><strong>0.389</strong></td>
</tr>
<tr>
<td>Non-symbolic RAN</td>
<td>X</td>
<td>Orthography</td>
<td>4</td>
<td><strong>0.318</strong></td>
<td><strong>0.215</strong></td>
<td><strong>0.413</strong></td>
</tr>
<tr>
<td>Mixed RAN X Decoding skills</td>
<td></td>
<td></td>
<td>1</td>
<td><strong>0.530</strong></td>
<td><strong>0.356</strong></td>
<td><strong>0.668</strong></td>
</tr>
<tr>
<td>Mixed RAN X Composite index</td>
<td></td>
<td></td>
<td>2</td>
<td><strong>0.473</strong></td>
<td><strong>0.208</strong></td>
<td><strong>0.674</strong></td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td></td>
<td>108</td>
<td>0.398</td>
<td>0.373</td>
<td>0.422</td>
</tr>
</tbody>
</table>

**$p < .01$ & *** $p < .001$**

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META-ANALYSIS:
Summarizing data on RAN-to-reading association

RESULTS (Cross-sectional design):

<table>
<thead>
<tr>
<th>Moderator variable:</th>
<th>$k$</th>
<th>Effect size $r^+$</th>
<th>95% confidence interval</th>
<th>Test of null</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kindergarteners</td>
<td>41</td>
<td>0.329</td>
<td>0.294 - 0.362</td>
<td>17.623***</td>
</tr>
<tr>
<td>Secondary school students</td>
<td>22</td>
<td>0.359</td>
<td>0.302 - 0.413</td>
<td>11.514***</td>
</tr>
<tr>
<td>Other (Romance-Germanic) with more transparent phonemic structure</td>
<td>33</td>
<td>0.349</td>
<td>0.313 - 0.384</td>
<td>17.526***</td>
</tr>
<tr>
<td>Other languages (e.g., Japanese etc.)</td>
<td>30</td>
<td>0.303</td>
<td>0.262 - 0.343</td>
<td>13.786***</td>
</tr>
</tbody>
</table>

*** $p < .001$
META-ANALYSIS:
Summarizing data on RAN-to-reading association

RESULTS (Longitudinal design):

<table>
<thead>
<tr>
<th>Moderator variable:</th>
<th>k</th>
<th>Effect size</th>
<th>95% confidence interval</th>
<th>Test of null</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$r^+$</td>
<td>Lower limit</td>
<td>Upper limit</td>
</tr>
<tr>
<td>Kindergarteners</td>
<td>46</td>
<td>0.348</td>
<td>0.315</td>
<td>0.380</td>
</tr>
<tr>
<td>Elementary school students</td>
<td>62</td>
<td>0.480</td>
<td>0.373</td>
<td>0.422</td>
</tr>
<tr>
<td>Other from Romance-Germanic group with more transparent phonemic structure</td>
<td>8</td>
<td>0.368</td>
<td>0.303</td>
<td>0.429</td>
</tr>
<tr>
<td>Longer than a year</td>
<td>88</td>
<td>0.359</td>
<td>0.327</td>
<td>0.391</td>
</tr>
<tr>
<td>Reading impaired (dyslexics)</td>
<td>43</td>
<td>0.423</td>
<td>0.347</td>
<td>0.493</td>
</tr>
</tbody>
</table>

*** $p < .001$
MAJOR FINDINGS:

- Attention > Automaticity

- Symbolic RAN ≠ Non-symbolic RAN

- $r \ (\text{RAN, reading}) = f \ (\text{Attention Demand})$
IMPLICATIONS

- Applied value of RAN
- Selectivity in use
- Potential for increased efficiency
- Attention to practice
- Attention to attention
- Cognitive complexity
- Further research
Acknowledgment:

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Table 6.6a. Effect size ($r^+$) of RAN-to-reading association by languages (cross-sectional design)

<table>
<thead>
<tr>
<th>Language:</th>
<th>$k$</th>
<th>Effect size</th>
<th>95% confidence interval</th>
<th>Test of null</th>
</tr>
</thead>
<tbody>
<tr>
<td>English</td>
<td>330</td>
<td>0.355</td>
<td>0.344 0.367</td>
<td>54.575***</td>
</tr>
<tr>
<td>Other (Romance-Germanic) with more transparent phonemic structure</td>
<td>33</td>
<td>0.349</td>
<td>0.313 0.384</td>
<td>17.526***</td>
</tr>
<tr>
<td>Other languages (e.g., Japanese etc.)</td>
<td>30</td>
<td>0.303</td>
<td>0.262 0.343</td>
<td>13.786***</td>
</tr>
<tr>
<td>Bilinguals</td>
<td>29</td>
<td>0.173</td>
<td>0.112 0.233</td>
<td>5.478*</td>
</tr>
<tr>
<td>Overall</td>
<td>422</td>
<td>0.345</td>
<td>0.334 0.355</td>
<td>58.861***</td>
</tr>
</tbody>
</table>

* $p < .05$ & ***) $p < .001$
Table 6.7a. Effect size ($r+$) of RAN-to-reading association by population type (cross-sectional design)

<table>
<thead>
<tr>
<th>Population type</th>
<th>$k$</th>
<th>Effect size ($r+$)</th>
<th>95% confidence interval</th>
<th>Test of null</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading impaired (dyslexics)</td>
<td>140</td>
<td>0.355</td>
<td>0.338 - 0.371</td>
<td>39.408***</td>
</tr>
<tr>
<td>Normal (age adequate) readers</td>
<td>179</td>
<td>0.349</td>
<td>0.332 - 0.366</td>
<td>36.625***</td>
</tr>
<tr>
<td>Mixed (age adequate and impaired readers together)</td>
<td>93</td>
<td>0.336</td>
<td>0.310 - 0.361</td>
<td>23.690***</td>
</tr>
<tr>
<td>Readers with learning (but not reading) problems</td>
<td>10</td>
<td>0.196</td>
<td>0.129 - 0.261</td>
<td>5.690***</td>
</tr>
<tr>
<td>Overall</td>
<td>422</td>
<td>0.345</td>
<td>0.334 - 0.355</td>
<td>58.861***</td>
</tr>
</tbody>
</table>

*** $p < .001$
Table 6.2a. Effect size ($r^+$) of RAN-to-reading association for each type of RAN (cross-sectional design)

<table>
<thead>
<tr>
<th>Type of RAN:</th>
<th>$K$</th>
<th>Effect size</th>
<th>95% confidence interval</th>
<th>Test of null</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$r^+$</td>
<td>Lower limit</td>
<td>Upper limit</td>
</tr>
<tr>
<td>Symbolic RAN</td>
<td>279</td>
<td>0.371</td>
<td>0.358</td>
<td>0.385</td>
</tr>
<tr>
<td>Non-symbolic RAN</td>
<td>119</td>
<td><strong>0.292</strong></td>
<td><strong>0.272</strong></td>
<td><strong>0.313</strong></td>
</tr>
<tr>
<td>Mixed measures</td>
<td>24</td>
<td>0.335</td>
<td>0.304</td>
<td>0.366</td>
</tr>
<tr>
<td>Overall</td>
<td>422</td>
<td>0.345</td>
<td>0.334</td>
<td>0.355</td>
</tr>
</tbody>
</table>

*** $p < .001$
Table 6.9a. Effect size ($r^+$) of RAN-to-reading association for each type of RAN (longitudinal design)

<table>
<thead>
<tr>
<th>Type of RAN:</th>
<th>$k$</th>
<th>Effect size</th>
<th>95% confidence interval</th>
<th>Test of null</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$r^+$</td>
<td>Lower limit</td>
<td>Upper limit</td>
</tr>
<tr>
<td>Symbolic RAN</td>
<td>70</td>
<td>0.481</td>
<td>0.446</td>
<td>0.514</td>
</tr>
<tr>
<td>Non-symbolic RAN</td>
<td>35</td>
<td>0.318</td>
<td>0.281</td>
<td>0.353</td>
</tr>
<tr>
<td>Mixed measures</td>
<td>3</td>
<td>0.511</td>
<td>0.369</td>
<td>0.630</td>
</tr>
<tr>
<td>Overall</td>
<td>108</td>
<td>0.398</td>
<td>0.373</td>
<td>0.422</td>
</tr>
</tbody>
</table>

*** $p < .001$