A New Perspective on Visual Word Processing Efficiency

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Previous Findings

- Letters in words are read faster than letters in random sequences (Cattell, 1886; Erdmann & Dodge, 1898)
- Target letters are found faster in words (Kreuger, 1970)
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- Target letters are found faster in words (Kreuger, 1970)

- Letters in words are more accurately perceived than individual letters. (Reicher, 1969; Wheeler, 1970)
- Letters in pronounceable non-words (pseudowords) are more accurately perceived than unpronounceable sequences of letters.
- Letters in pseudowords are more accurately perceived than single letters. (Aderman & Smith, 1971; Baron & Thurston, 1973; Carr et al., 1978; McClelland & Johnston, 1977)
What’s missing?

- There is little evidence of the word superiority effect from the response time domain, and even evidence of word inferiority (e.g., Massaro & Cohen, 1994; Allen & Emerson, 1991).
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There is little evidence of the word superiority effect from the response time domain, and even evidence of word inferiority (e.g., Massaro & Cohen, 1994; Allen & Emerson, 1991).

Even in the accuracy domain, there is some disagreement about the nature of the word superiority effect:

- The surprise *inefficiency* in the accuracy domain. (Pelli et al., 2003)

Models of word recognition that are independent and parallel but still account for the word superiority effect are possible.
The Task
Adapted from Goldstone (2000) and Blaha and Townsend (Under Revision)

- The string task
  - Control for guessing
    - Both target and distractors are same class
  - Ensure each character is (at least partially) perceived
    - One distractor for each position
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- The single character task
  - Used to determine processing rates of characters in isolation
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Instructions

Example stimulus

care  bare  cure  cave  card

- The string task
  - Control for guessing
    - Both target and distractors are same class
  - Ensure each character is (at least partially) perceived
    - One distractor for each position

- The single character task
  - Used to determine processing rates of characters in isolation
  - Stimuli are briefly shown and participant must identify whether it is a target or distractor.
  - High contrast, post-masking, 100ms presentation time.
Defining a Baseline

\[ P\{RT_{\text{care}} \leq t\} = P\{RT_c \leq t, RT_a \leq t, RT_r \leq t, RT_e \leq t\} \]
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\[ P\{RT_{\text{care}} \leq t\} = P\{RT_c \leq t, RT_a \leq t, RT_r \leq t, RT_e \leq t\} \]

- If we assume unlimited capacity, independent, parallel processing of letters (UCIP),

\[ F_{\text{care}}(t) = F_c(t)F_a(t)F_r(t)F_e(t) \]
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If we assume unlimited capacity, independent, parallel processing of letters (UCIP),

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\[ \ln(F_{care}) = \ln(F_cF_aF_rF_e) \]
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F_{care}(t) = F_c(t)F_a(t)F_r(t)F_e(t)
\]

\[
\ln(F_{care}) = \ln(F_cF_aF_rF_e)
\]

\[
= \ln(F_c) + \ln(F_a) + \ln(F_r) + \ln(F_e)
\]

\[
K_{care} = K_c + K_a + K_r + K_e
\]
Defining a Baseline

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- If we assume unlimited capacity, independent, parallel processing of letters (UCIP),

\[ F_{\text{care}}(t) = F_c(t)F_a(t)F_r(t)F_e(t) \]
\[ \ln(F_{\text{care}}) = \ln(F_cF_aF_rF_e) = \ln(F_c) + \ln(F_a) + \ln(F_r) + \ln(F_e) \]
\[ K_{\text{care}} = K_c + K_a + K_r + K_e \]
\[ C(t) = \frac{K_c + K_a + K_r + K_e}{K_{\text{care}}} = 1 \]

\[ C(t) = \frac{\sum K_{\text{character}}}{K_{\text{string}}} \]
Example Capacity Data
Example Capacity Data
The Interpretation

Workload capacity coefficients different from 1 imply a violation of at least one of the assumptions of the UCIP model.

- Independence
  - Inhibitory interaction leads to lower values
  - Facilitatory interaction leads to higher values

- Parallel
  - Serial leads to lower values
  - Coactive leads to higher values

- Unlimited Capacity
  - Limited resources lead to lower values
  - More resources for more processes leads to high values

(Townsend & Wenger, 2004)
## The Stimuli

<table>
<thead>
<tr>
<th>Distractors</th>
<th>Target</th>
<th>Word</th>
<th>Pseudoword</th>
<th>Random</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>care</td>
<td>care</td>
<td>lerb</td>
<td>rlkf</td>
</tr>
<tr>
<td></td>
<td>bare</td>
<td>bare</td>
<td>nerb</td>
<td>vlkf</td>
</tr>
<tr>
<td></td>
<td>cure</td>
<td>cure</td>
<td>lerb</td>
<td>rtkf</td>
</tr>
<tr>
<td></td>
<td>cave</td>
<td>cave</td>
<td>lemb</td>
<td>rlhf</td>
</tr>
<tr>
<td></td>
<td>card</td>
<td>card</td>
<td>lerb</td>
<td>rlkj</td>
</tr>
<tr>
<td></td>
<td>cb</td>
<td>cb</td>
<td>ln</td>
<td>rv</td>
</tr>
<tr>
<td></td>
<td>au</td>
<td>au</td>
<td>ea</td>
<td>lt</td>
</tr>
<tr>
<td></td>
<td>rv</td>
<td>rv</td>
<td>rm</td>
<td>kh</td>
</tr>
<tr>
<td></td>
<td>ed</td>
<td>ed</td>
<td>bf</td>
<td>fj</td>
</tr>
</tbody>
</table>
Mean Level Results

- Significant effect of condition on accuracy and correct RT ($p < .001$)

<table>
<thead>
<tr>
<th>Participant</th>
<th>RT</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>W (P) R</td>
<td>W P R</td>
</tr>
<tr>
<td>2</td>
<td>W P R</td>
<td>(P W R)</td>
</tr>
<tr>
<td>3</td>
<td>(W R P)</td>
<td>(W P) R</td>
</tr>
<tr>
<td>4</td>
<td>(W P R)</td>
<td>(W P R)</td>
</tr>
<tr>
<td>5</td>
<td>W P R</td>
<td>W P R</td>
</tr>
<tr>
<td>6</td>
<td>W P R</td>
<td>(W (P) R)</td>
</tr>
<tr>
<td>7</td>
<td>W (P) R</td>
<td>W P R</td>
</tr>
<tr>
<td>8</td>
<td>(W P) R</td>
<td>(P W) R</td>
</tr>
<tr>
<td>9</td>
<td>(P W) R</td>
<td>(W (P) R)</td>
</tr>
<tr>
<td>10</td>
<td>W (R P)</td>
<td>(W (R) P)</td>
</tr>
<tr>
<td>11</td>
<td>W P R</td>
<td>W (P R)</td>
</tr>
<tr>
<td>12</td>
<td>(W P) R</td>
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- This does not imply an ordering of efficiency (some letters may be faster than others)
Individual Data: Graphic
Group Data: Graphic

Word

Pseudo

Random

C(t)

Time

C(t)

Time

C(t)

Time
## Z Statistic

<table>
<thead>
<tr>
<th>Participant</th>
<th>$Z_{\text{Word}}$</th>
<th>$Z_{\text{Pseudo}}$</th>
<th>$Z_{\text{Random}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.47 ***</td>
<td>2.40 *</td>
<td>3.91 ***</td>
</tr>
<tr>
<td>2</td>
<td>6.44 ***</td>
<td>2.36 *</td>
<td>-1.77</td>
</tr>
<tr>
<td>3</td>
<td>-0.874</td>
<td>10.5 ***</td>
<td>4.43 ***</td>
</tr>
<tr>
<td>4</td>
<td>3.84 ***</td>
<td>8.33 ***</td>
<td>3.60 **</td>
</tr>
<tr>
<td>5</td>
<td>4.35 ***</td>
<td>5.54 ***</td>
<td>-3.67 **</td>
</tr>
<tr>
<td>6</td>
<td>13.0 ***</td>
<td>8.99 ***</td>
<td>-0.035</td>
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<td>7</td>
<td>4.62 ***</td>
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<td>-2.68 **</td>
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<tr>
<td>8</td>
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<td>0.779</td>
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<td>15.1 ***</td>
<td>13.9 ***</td>
<td>5.24 ***</td>
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* $< .025$; ** $< .005$; *** $< .0005$
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- Word > Random ***
- Pseudoword > Random ***
- Pseudoword > Word

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Conclusions

Response Time Word Superiority Effect

- We have ruled out the unlimited capacity, independent parallel model of word processing (for most participants)
  - Participants are more efficient at perceiving letters in words than individually
  - Participants are more efficient at perceiving words than non-words
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Response Time Pseudoword Superiority Effect

- Unlimited capacity, independent parallel model was also falsified for most participants on pseudowords.
  - Participants are more efficient at perceiving letters in words than individually
  - Participants are more efficient at perceiving pseudowords than non-words
Future Directions

- Sensitivity to ‘holistic’ manipulations
  - Compare capacity for upside words and pseudowords.
  - Examine effect of crowding on $C(t)$. 
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  - Examine effect of crowding on \( C(t) \).
- Low accuracy conditions
  - Connect current findings with standard accuracy based results.
- Clinical Populations
  - Dyslexic: Better methodology for characterizing the deficit.
  - High Functioning Autistic: Test theory of dysfunctions in holistic processing.
Thank you!

This work was supported by NIH-NIMH MH 05771707 and AFOSR FA9550-07-1-0078 awarded to JTT.
The Details

- 12 participants, 10 Females and 2 Males, Ages 19-34, native English speakers
- Participants reported
  - No problems reading English
  - No reading disorders
  - Normal or corrected to normal vision
- 10 Sessions, 2 of each condition, lasting between 45 and 60 minutes
- Each block begins with 40 practice trials, then 100 targets and 100 distractors were presented in random order.
- The character or characters were written in black in 29pt Courier onto a gray (200) background, then doubled in size.
- Stimuli shown for 100ms followed by a mask.


Cattell, J. M. (1886). The time it takes to see and name objects.


