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# A New Perspective on Visual Word Processing Efficiency

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INDIANA UNIVERSITY
BLOOMINGTON

Midwest Cognitive Science Meeting
Michigan State University
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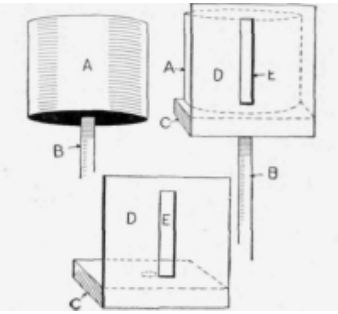
# Previous Findings



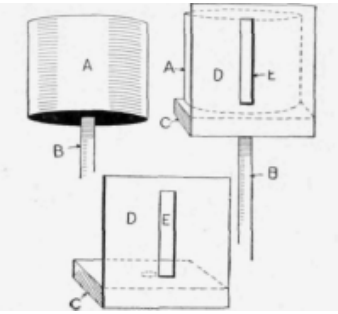

- Letters in words are read faster than letters in random sequences (Cattell, 1886; Erdmann & Dodge, 1898)
- Target letters are found faster in words (Kreuger, 1970)

E
or
D

CAR E
or
D

LER B
or
F

# Previous Findings

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- 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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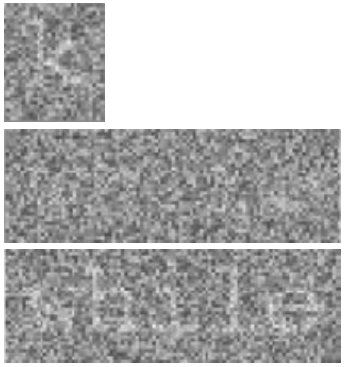
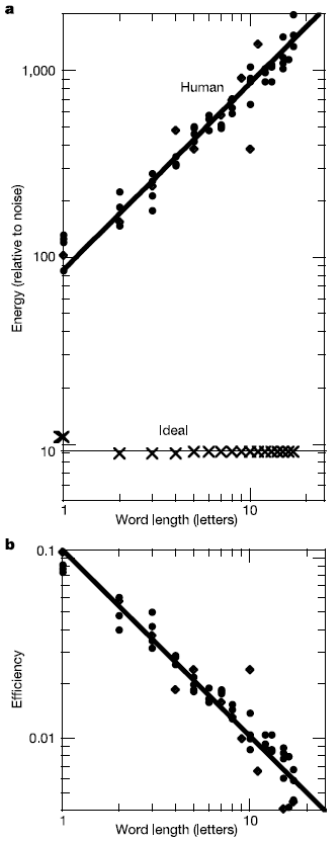
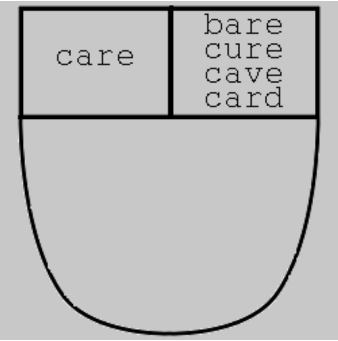




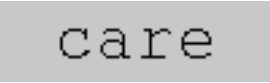

- There is little evidence of the word superiority effect from the response time domain, and even evidence of word inferiority (e.g., Massaro & Cohen, 1994; Allen & Emerson, 1991).
- Even in the accuracy domain, there is some disagreement about the nature of the word superiority effect
  - The surprise *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)

Instructions




Example stimulus




- 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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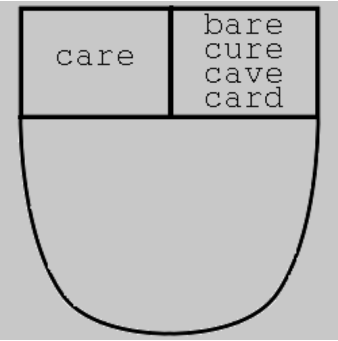


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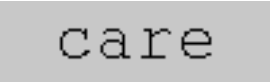


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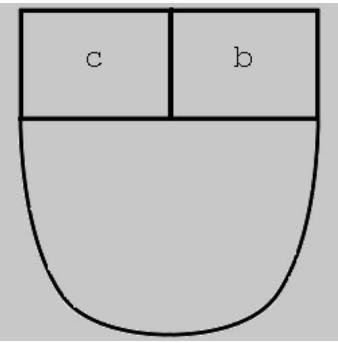


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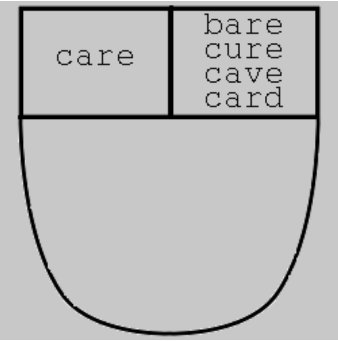


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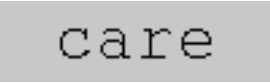


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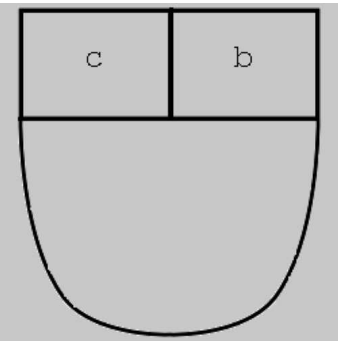
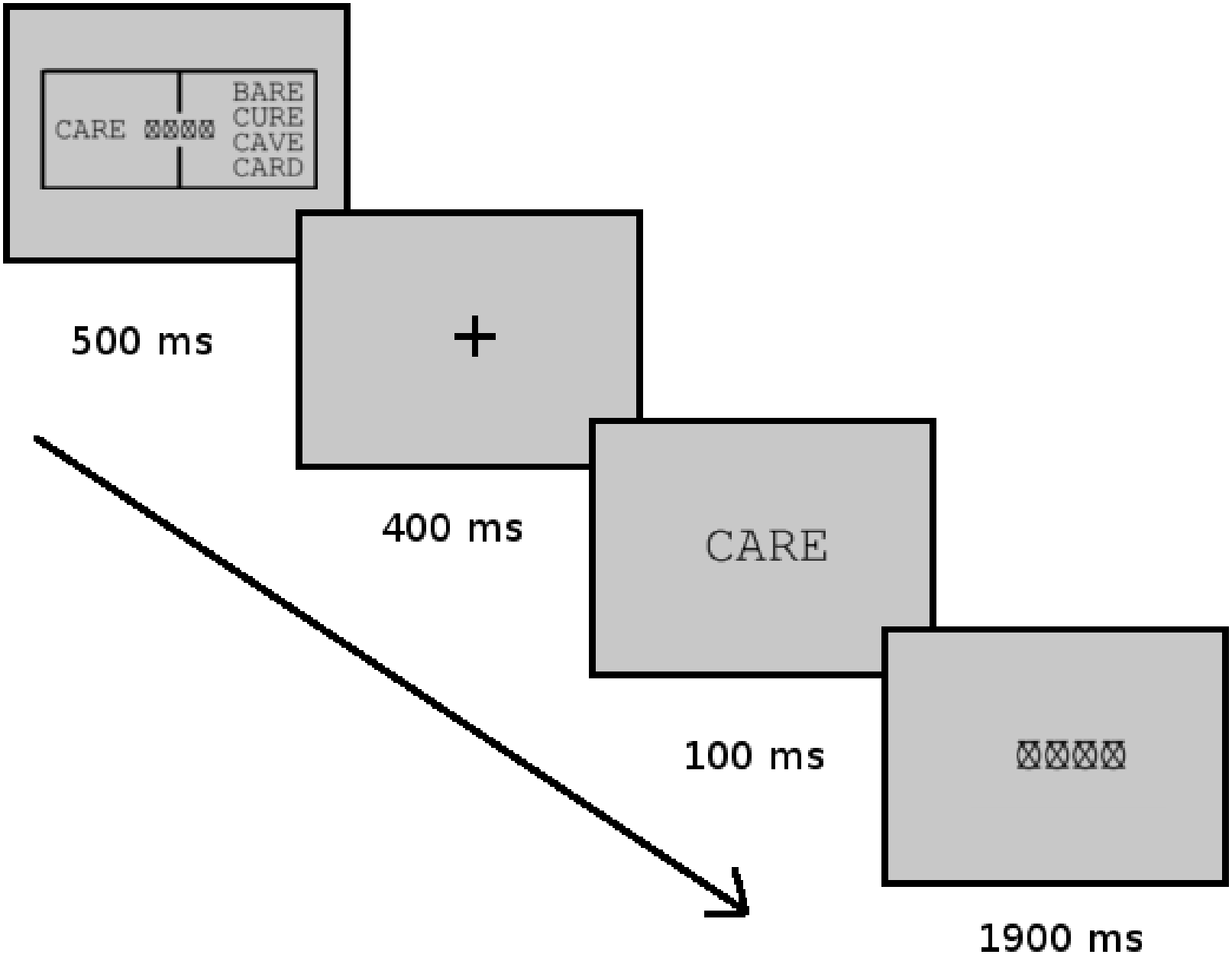



Example stimulus


- 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.

# The Task



# Defining a Baseline

$$P\{RT_{care} \leq t\} \quad = \quad P\{RT_c \leq t, RT_a \leq t, RT_r \leq t, RT_e \leq t\}$$

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$$F_{care}(t) \quad = \quad F_c(t)F_a(t)F_r(t)F_e(t)$$

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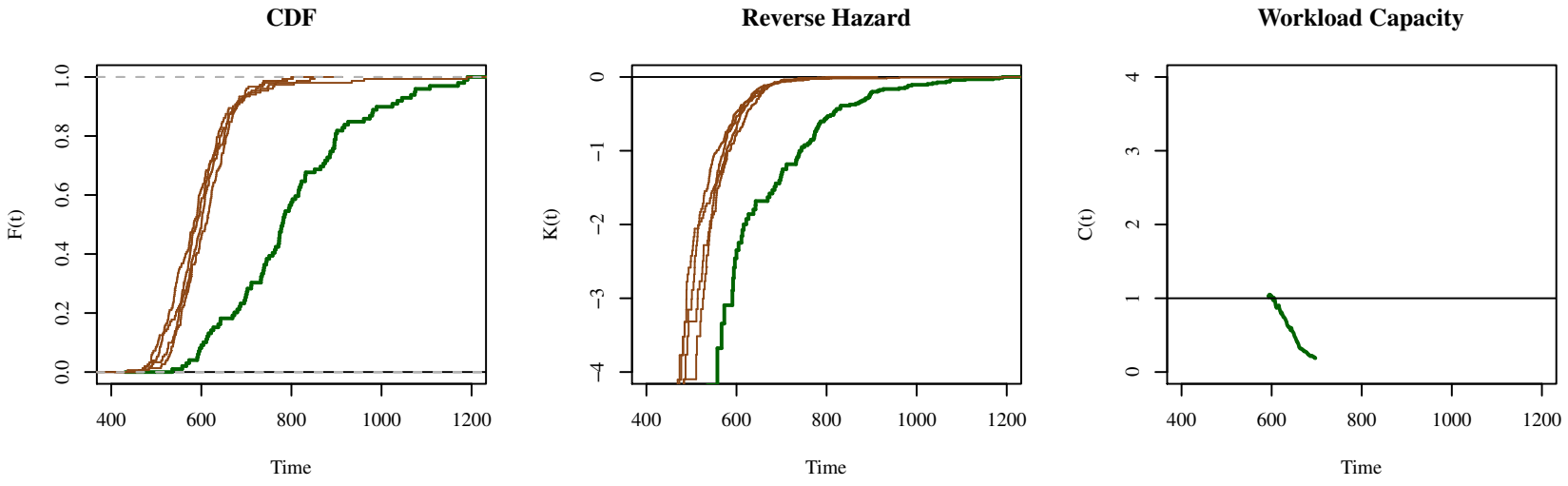
&= \ln(F_c) + \ln(F_a) + \ln(F_r) + \ln(F_e) \\
K_{care} &= K_c + K_a + K_r + K_e \\
C(t) &= \frac{K_c + K_a + K_r + K_e}{K_{care}} = 1
\end{aligned}$$

$$C(t) = \frac{\sum K_{\text{character}}}{K_{\text{string}}}$$

# Example Capacity Data



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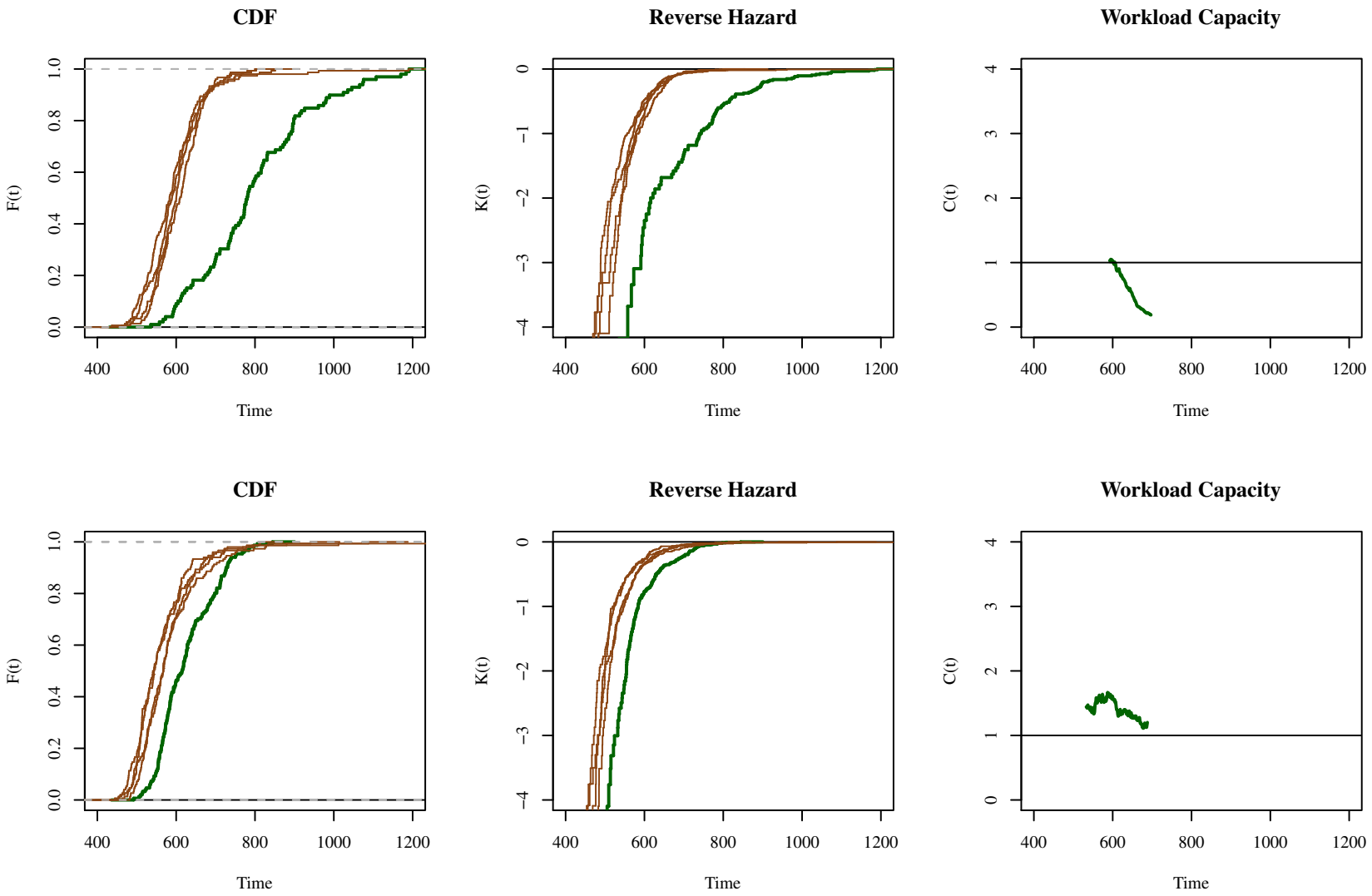

# The Interpretation

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

| | Word | Pseudoword | Random |
|---|---|---|---|
| Target | care | lerb | rlkf |
| Distractors | bare | nerb | vlkf |
| | cure | larb | rtkf |
| | cave | lemb | rlhf |
| | card | lerf | rlkj |
| | c b | l n | r v |
| | a u | e a | l t |
| | r v | r m | k h |
| | e d | b f | f j |

# Mean Level Results

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

| Participant | RT | | | Accuracy | | |
|---|---|---|---|---|---|---|
| 1 | W | (P | R) | W | P | R |
| 2 | W | P | R | (P | W | R) |
| 3 | (W | R | P) | (W | P) | R |
| 4 | (W | P | R) | (W | P | R) |
| 5 | W | P | R | W | P | R |
| 6 | W | P | R | (W | (P) | R) |
| 7 | W | (P | R) | W | P | R |
| 8 | (W | P) | R | (P | W) | R |
| 9 | (P | W) | R | (W | (P) | R) |
| 10 | W | (R | P) | (W | (R) | P) |
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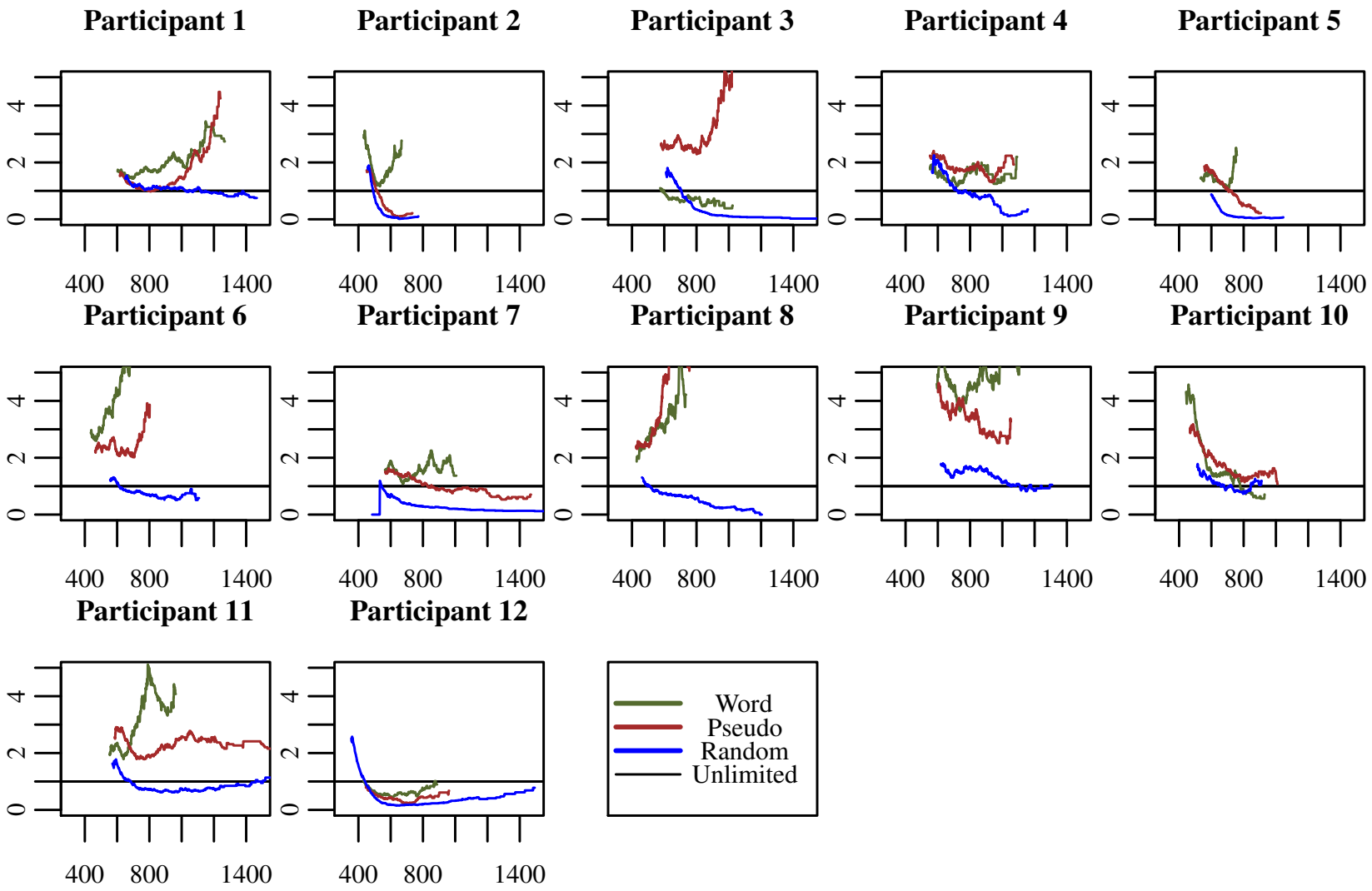
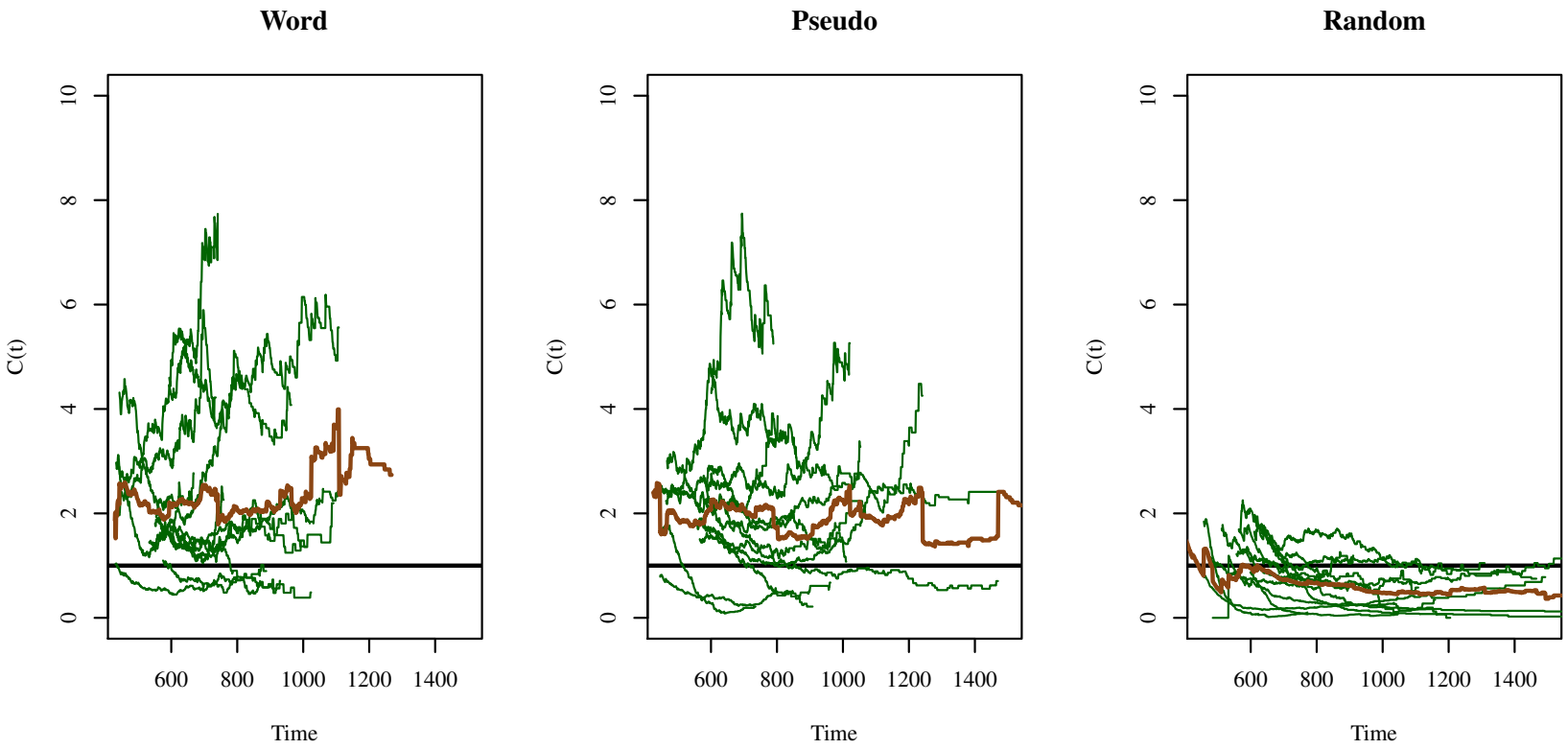
- This does not imply an ordering of efficiency (some letters may be faster than others)

# Individual Data: Graphic



# Group Data: Graphic



# $Z$ Statistic

| Participant | $Z_{\text{Word}}$ | | $Z_{\text{Pseudo}}$ | | $Z_{\text{Random}}$ | |
|---|---|---|---|---|---|---|
| 1 | 5.47 | *** | 2.40 | * | 3.91 | *** |
| 2 | 6.44 | *** | 2.36 | * | -1.77 | |
| 3 | -0.874 | | 10.5 | *** | 4.43 | *** |
| 4 | 3.84 | *** | 8.33 | *** | 3.60 | ** |
| 5 | 4.35 | *** | 5.54 | *** | -3.67 | ** |
| 6 | 13.0 | *** | 8.99 | *** | -0.035 | |
| 7 | 4.62 | *** | 4.38 | *** | -2.68 | ** |
| 8 | 9.98 | *** | 11.0 | *** | 0.779 | |
| 9 | 15.1 | *** | 13.9 | *** | 5.24 | *** |
| 10 | 10.6 | *** | 9.43 | *** | 3.89 | *** |
| 11 | 8.89 | *** | 8.89 | *** | -0.771 | |
| 12 | -1.84 | | -3.70 | *** | -5.33 | *** |

$* < .025; ** < .005; *** < .0005$

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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
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Response Time Word Superiority Effect

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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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- Sensitivity to 'holistic' manipulations
  - Compare capacity for upside words and pseudowords.
  - 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.

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