Crowding, suhstitutirq, and CaPiTaLiZiNg reveal three processes in reading 809

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Introduction.

Can we take reading as serial object recognition, with each word as an object? Are there multiple ways to recognize a word, and do we use them to read? The reading literature includes proposals for three distinct processes of word recognition, which we call **L**, **W**, and **S**, but has little to say about how readers combine them. Educational psychologists led a national debate over the relative importance of letter-by-letter decoding (**L**) and higher level contextual sentence processing (**S**). The current consensus favors letter-by-letter decoding, partly because of the success of early school interventions designed to teach the alphabetic principle (Chall, 1967; Rayner et al. 2002). Even so, Stanovich and Stanovich (1995) estimate that readers can predict the next word in a passage 20 to 35% of the time, depending on reading experience.

The *word superiority effect*, whereby observers can better identify a letter within a word context than alone, has been taken as evidence that the visual system is directly recognizing words by their shape (**W**), without individually identifying the letters. We have shown that this effect is not big enough to warrant that conclusion (Pelli, Farell, and Moore, 2003). In a new approach, work on *crowding* has shown that recognizing an object by parts requires isolation of each part from the rest of the object (Martelli et al. 2005). When the smallest isolation field is larger than the word, the word can only be recognized holistically. We use this — what can be seen holistically — as our definition of word shape and select letter substitutes that do not interfere. You can verify that word shape is preserved by fixating the plus and comparing the two words presented peripherally. Try it. The two words are indistinguishable:

```
Reading        +        Pcedirq
```

Model & Method.

We propose a three-process model of reading to account for reading rate in word/min. The model supposes that there are three independent ways to recognize each word. Each process makes an independent additive contribution to reading rate. To test the model, we distorted text in three ways that selectively knock out each reading process. Operationally, each knock-out defines a process.

L
```
Tbis sartcroa bes lcttan
suhstitutas.
```

• Substituting similar letters knocks out the **Letter process** (**L**), which identifies letters to form the word.

W
```
ThIs TeXt Is WrItTeN iN
aLtErNaTiNg CaSe tO dEsTrOy
WoRd ShApE.
```

• Alternating case knocks out the holistic **Word process** (**W**), which recognizes words by their shape.

S
```
random words is a with the
This in order. sentence
```

• Scrambling word order knocks out the **Sentence process** (**S**), which predicts the word based on context.

Table 1. LWS model of reading rate (word/min) for each reading condition (combination of knock-outs).

	Ordered	Unordered
Plain	$L+W+S = 587$ `at the end of the room a`	$L+W = 462$ `a end of room at the the`
Alternating case	$L+S = 517$ `aT tHe eNd oF ThE RoOm a`	$L = 392$ `a eNd oF RoOm aT tHe tHe`
Substitution	$W+S = 195$ `et tba ard cf tbo neam e`	$W = 70$ `e ard cf neam et tba tba`

Results.

We measured RSVP reading rates for four readers (NYU undergrads), applying every combination of the three knock-outs to passages from a Mary Higgins Clark novel, as shown in Table 1. The LWS model has only 3 degrees of freedom, the rates *L*, *W*, and *S* in Fig. 1, yet provides an excellent fit to the 8 rates in Table 1. The RMS error (for each observer) is about 20 word/min, a mere 3% of the unimpaired reading rate.

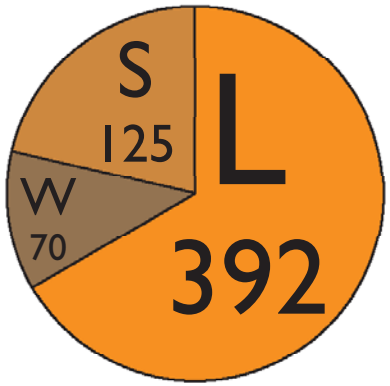

Figure 1. Reading rate (word/min). Mean±SE: *L*=392±59, *W*=70±22, *S*=125±51 across four observers. The unimpaired reading rate for plain text is *L*+*W*+*S*=587±15 word/min.

Conclusions.

As complex as we know reading to be, it is remarkable that reading rate is well-modeled as the sum of three independent word-recognition processes.

L The reading psychologists were right. Mechanistic **letter** decoding accounts for the lion's share (67%) of the fast adult reading rate.

W Holistic **word** recognition accounts for only a small fraction of the reading rate (12%).

S Even in our college-educated readers, the **sentence** process contributes only 21% of reading rate.

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