Eye Movements and Cognitive Processes in Reading

Keith Rayner
“And so to completely analyze what we do when we read would almost be the acme of a psychologist’s achievements, for it would be to describe very many of the most intricate workings of the human mind, as well as to unravel the tangled story of the most remarkable specific performance that civilization has learned in all its history”.

-- Edmund Burke Huey, 1908
Can Eye Movements be used to Examine On-line Language Processes During Reading?

Is the variability that exists in fixation durations and saccade lengths related to processing ease or difficulty?
Three critical issues:

1. What is the size of the perceptual span (or span of effective vision) during a fixation?
2. What kind of information is integrated across fixations?
3. What determines when we move our eyes and where we look next in reading?
Outline of Talk

1. The perceptual span
2. Integration of information across fixations
3. Eye movement control
4. E-Z Reader model
Investigating the Perceptual Span

T-scope
Control text
Record eye movements
13-CHARACTER WINDOW (SPACES FILLED)

processing of XXXXXXXXXXXX

* 

additional processing of wordXXXXXXXXX

* 

g of words duXXXXXXXXX

*
13-CHARACTER WINDOW (SPACES PRESERVED)

XXX XXXXXXX processing of XXXXX XXXXXXX
  *
XXX XXXXXXX XXXXXssing of wordX XXXXXXX
  *
XXX XXXXXXX XXXXXXXXXXg of words duXXXX
  *
2-WORD WINDOW

Fbc tfvc mf processing of vcnbs hvnrmp
* 
Fbc tfvc mf gnceorrnmp of words hvnrmp
*
Moving window with partial word information

He thought that the pretty bracelet attracted

Kc fbcvqbf fbcaf bfc pretty braectcf cffncfcb

*
MOVING MASK

The pretty bracelet attracted
* 
The pretty bracXlet attracted
* 
The pretty braXxxet attracted
* 
The pretty bXxxxxxxxx attracted
*
Successive Fixations with a 3-character mask

The pretty XXXcelet attracted
    *
The pretty braXXXet attracted
    *
The pretty bracelXXXattracted
    *
BOUNDARY TECHNIQUE

brother has brilliantly composed a new tune for

brother has brilliantly composed a new song for
Each eye movement changes the light pattern

word length

movement changes the light pattern on the

word length

changes the light pattern on the retina

word length
Span of Effective Vision

1. Extends 14-15 spaces to right of fixation
2. Asymmetric 3-4 left
3. No information below the line
4. Word identification span is small
   a. Preview effect
5. The span is not fixed
   a. Word constraint = more information
   b. Fixated word difficult = less information
   c. Word length is important
6. Orthography influences the span
   a. Japanese/Chinese
   b. Hebrew
Integration of Information Across Eye Fixations

Variation of the Boundary Paradigm
Boundary Variation

+ song
  tune

+ chest
  chart

+ chovt
  chart
Integrative Visual Buffer

The reader obtains gross featural information from a parafoveal word and then stores that information in a visual integrative buffer. The information in the buffer is then combined with the information in the fovea following a saccade to that word.
Integration of Information Across Saccades

1. Not purely visual information
2. Not semantic information
3. Letter position effects
4. Abstract letter codes
5. Phonological codes
   beach - beach, beech, bench, house
Control of Eye Movements in Reading

Where to fixate next?
When to move the eyes?
Where to Fixate Next

1. Word length effect
2. Landing position effect
3. Launch site effect
4. No semantic preprocessing
When to Move the Eyes

1. Information gets into the system very early in a fixation

2. Effects of various lexical, discourse, and syntactic factors:
   a. word frequency
   b. contextual constraint
   c. lexically ambiguous words
   d. anaphor and co-reference
   e. syntactic disambiguation
Word Frequency

The slow waltz captured her attention …

music

The exhausted steward left the plane …

student

<table>
<thead>
<tr>
<th></th>
<th>FFD</th>
<th>GAZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>262</td>
<td>330</td>
</tr>
<tr>
<td>High</td>
<td>225</td>
<td>243</td>
</tr>
</tbody>
</table>

Thursday, April 14, 2011
Reading Disappearing Text

The pretty bracelet attracted much attention
The pretty bracelet attracted much attention
The pretty bracelet attracted much attention
# Fixation Times

<table>
<thead>
<tr>
<th></th>
<th>SFD</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FFD</td>
<td>GAZE</td>
<td>FFD</td>
</tr>
<tr>
<td>Normal:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HF</td>
<td>257</td>
<td>256</td>
<td>289</td>
</tr>
<tr>
<td>LF</td>
<td>298</td>
<td>288</td>
<td>328</td>
</tr>
<tr>
<td>Disappearing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HF</td>
<td>277</td>
<td>276</td>
<td>291</td>
</tr>
<tr>
<td>LF</td>
<td>307</td>
<td>301</td>
<td>333</td>
</tr>
</tbody>
</table>
Neutral Context

The port was a great success when she finally served it to her guests.

<table>
<thead>
<tr>
<th></th>
<th>Balanced</th>
<th>Biased</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambiguous</td>
<td>279</td>
<td>261</td>
</tr>
<tr>
<td>Control</td>
<td>261</td>
<td>259</td>
</tr>
</tbody>
</table>
Disambiguating Context

When she finally served it to her guests, the port was a great success.

<table>
<thead>
<tr>
<th></th>
<th>Balanced</th>
<th>Biased</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambiguous</td>
<td>264</td>
<td>277</td>
</tr>
<tr>
<td>Control</td>
<td>264</td>
<td>255</td>
</tr>
</tbody>
</table>
The E-Z Reader Model

Account for how the visual system, the attention system, the language system, and the oculomotor system interact in reading
# E-Z Reader

## Fixation Time Performance

<table>
<thead>
<tr>
<th>Freq</th>
<th>GAZE</th>
<th>FFD</th>
<th>SINGLE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>OB</td>
<td>EZ</td>
<td>OB</td>
</tr>
<tr>
<td></td>
<td>293</td>
<td>291</td>
<td>248</td>
</tr>
<tr>
<td>45</td>
<td>272</td>
<td>271</td>
<td>256</td>
</tr>
<tr>
<td>347</td>
<td>256</td>
<td>257</td>
<td>238</td>
</tr>
<tr>
<td>4889</td>
<td>234</td>
<td>226</td>
<td>223</td>
</tr>
<tr>
<td>40700</td>
<td>214</td>
<td>211</td>
<td>208</td>
</tr>
<tr>
<td>210</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## E-Z Reader
### Fixation Probability Performance

<table>
<thead>
<tr>
<th>Freq</th>
<th>SKIP OB</th>
<th>SKIP EZ</th>
<th>SINGLE OB</th>
<th>SINGLE EZ</th>
<th>TWO OB</th>
<th>TWO EZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.10</td>
<td>0.09</td>
<td>0.68</td>
<td>0.73</td>
<td>0.20</td>
<td>0.17</td>
</tr>
<tr>
<td>45</td>
<td>0.13</td>
<td>0.16</td>
<td>0.70</td>
<td>0.76</td>
<td>0.16</td>
<td>0.09</td>
</tr>
<tr>
<td>347</td>
<td>0.22</td>
<td>0.27</td>
<td>0.68</td>
<td>0.68</td>
<td>0.10</td>
<td>0.04</td>
</tr>
<tr>
<td>4889</td>
<td>0.55</td>
<td>0.49</td>
<td>0.44</td>
<td>0.50</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>40700</td>
<td>0.67</td>
<td>0.68</td>
<td>0.32</td>
<td>0.34</td>
<td>0.01</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Recent Findings with Chinese

1. Frequency effects that are similar to English readers (Yan, Tian, Bai, & Rayner, 2007, British Journal of Psychology)

2. Predictability effects that are similar to English readers (Rayner, Li, Juhasz, & Yan, 2006, Psychonomic Bulletin & Review).

3. Character frequency effects (Yan et al., 2007)

4. E-Z Reader Chinese (Rayner, Li, & Pollatsek, in press)
Gaze Duration

Word Frequency

Gaze Duration (ms)

<table>
<thead>
<tr>
<th>Gaze Duration (ms)</th>
<th>Prd</th>
<th>Obs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Thursday, April 14, 2011
Skip Frequency

Word Frequency

PrS

Prd
Obs

Thursday, April 14, 2011
SUMMARY

The Perceptual Span is Relatively Small
   3-4 left to 14-15 right
Word Identification Span is Even Smaller
   3-4 left to up to 7-8 right
Preview Effects
   Integration – abstract letters/phonological
Eye Movements Influenced by Low Level and Lexical Variables
   Where to look – largely low level
   When to move – lexical effects
Thank you for your attention