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Eye movements of highly skilled and average readers: Differential effects of frequency and predictability

Jane Ashby, Keith Rayner, and Charles Clifton, Jr.
University of Massachusetts, Amherst, USA

This study offers a glimpse of the moment-by-moment processes used by highly skilled and average readers during silent reading. The eye movements of adult readers were monitored while they silently read sentences. Fixation durations and the spatial–temporal patterns of eye movements were examined to see whether the two groups of readers exhibited differential effects of frequency and/or predictability. In Experiment 1, high- and low-frequency target words were embedded in nonconstraining sentence contexts. In Experiment 2, the same participants read high- and low-frequency target words that were either predictable or unpredictable, embedded in highly constraining sentence contexts. Results indicated that when target words appeared in highly constraining sentence contexts, the average readers showed different effects of frequency and predictability from those shown in the highly skilled readers. It appears that reading skill can interact with predictability to affect the word recognition processes used during silent reading.

Since the early days of reading research (Huey, 1908/1968), psychologists have been interested in processing differences due to reading skill (Jackson & McClelland, 1979; Palmer, Macleod, Hunt, & Davidson, 1985; Perfetti, 1985). Interestingly, although eye movement research has served as the basis for much of what is known about reading (Huey, 1908/1968; Rayner & Pollatsek, 1989), there has been little research on differences in reading skill that has utilized eye movement data (see Jared, Levy, & Rayner, 1999, for an exception). We know that reading skill, as measured by reading rate, affects several aspects of the eye movement record. Slower readers have longer fixation durations and make shorter saccades as well as

Correspondence should be addressed to Jane Ashby, Department of Psychology, University of Massachusetts, Amherst, MA 01003, USA. Email: ashby@psych.umass.edu

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more regressions than faster readers (Everatt & Underwood, 1994; Rayner, 1978, 1998; Underwood, Hubbard, & Wilkinson, 1990). In general, these reported differences appear to be ones of degree, rather than type, indicating that less skilled readers use similar reading processes but less efficiently than do the more skilled readers. Likewise, current computational models of eye movement control (Engbert, Longtin, & Kliegl, 2002; Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle, Rayner, & Pollatsek, 2003) basically assume that all readers use similar word recognition processes. However, if there are processing differences associated with reading skill, then models of reading might need to be adjusted in order to account for them.

The present study examined how sentential constraint affected the eye movements of highly skilled and average college readers. We measured the eye movements of readers while they silently read high- and low-frequency words that were embedded in nonconstraining (Experiment 1) and highly constraining (Experiment 2) sentence contexts. The collected data had high spatial and temporal resolution, which was adequate for detecting word-by-word processing differences in the two groups of readers. We then considered data from eight eye movement measures in developing a detailed description of the reading patterns of highly skilled and average readers. This study provides evidence that the cognitive processes used to recognize high- and low-frequency words may vary with the amount of contextual constraint and the level of reading achievement.

Words that appear frequently in written text are read more quickly (i.e., shorter eye fixations) than are low-frequency words (Hyönä & Olson, 1995; Inhoff & Rayner, 1986; Jared et al., 1999; Kennison & Clifton, 1995; Rayner & Duffy, 1986; Rayner & Fischer, 1995; Rayner, Sereno, & Raney, 1996; Vitu, 1991). Similarly, words that are predictable from prior context are read more quickly and are less likely to be directly fixated than are unpredictable words (Ehrlich & Rayner, 1981; Rayner & Well, 1996). There is also some evidence suggesting that frequency and predictability affect different reading processes, since several experiments using various techniques have found additive effects of the two variables (Rayner, Ashby, Pollatsek, & Reichle, 2004; Schuberth & Eimas, 1977; although cf. Cairns & Foss, 1971; Forster, 1981; Stanovich & West, 1983). Although this body of research has increased our understanding of the effects of word frequency and predictability, few online studies have assessed the impact of participants' reading skill on these effects. As a result, most of the literature assumes that frequency and predictability effects hold for the full range of proficient readers. The present research aimed to test that assumption. In particular, it explored the hypothesis that less proficient readers place more reliance on predictability than highly proficient readers do.

This article reports the results from a two-part silent reading experiment, which is referred to as Experiment 1 and Experiment 2. In Experiment 1, highly skilled and average readers read high- and low-frequency words in nonconstraining sentence contexts. In Experiment 2, these same readers read target words of similar length and frequency in highly constraining sentence contexts. In the latter experiment, the sentence contexts contained either an expected (highly predictable) or an unexpected (unpredictable) target word. The same readers participated in the two parts of the experiment concurrently, and the data from Experiment 1 are intended to provide an approximate baseline measure of readers' eye movements when reading nonconstraining sentence contexts. The results from the two experiments are directly compared following Experiment 2. Since eye movement measures record both temporal and spatial information (Rayner, 1998), we report reading times for particular target words, as well as how readers' eyes moved through the text. Readers were divided into two groups based on performance on the Nelson-Denny Reading Test, a timed assessment of vocabulary and comprehension. We examined whether the two groups of readers processed the target words differently in Experiment 1 and in Experiment 2. This comparison of each group's reading patterns lent some insight into how sentential constraint might interact with reading skill to differentially affect reading patterns.

General method

Participants

A total of 44 students at the University of Massachusetts were paid or received credit to participate in the experiment. All were native English speakers with normal vision, and all were naive as to the purpose of the experiment. Two groups of 22 readers were identified based on their composite score on the Nelson-Denny Test. The group of highly skilled readers scored above the 74th percentile with the mean at the 88th percentile, and the scores of the average proficient readers ranged from the 6th percentile to the 70th percentile with the mean at the 40th percentile. A total of 28 of the participants (14 from each group) experienced a longer version of the experimental session, reading the 24 sentences in Experiment 1 interspersed among 32 highly constraining sentences in Experiment 2 and 88 filler items. The remaining 16 participants (8 from each group) read the 24 sentences for Experiment 1 interspersed among 32 highly constraining sentences and 64 filler items. Thus, the participants in the shorter version read the same experimental items as did the other participants, but those items were randomly interspersed with fewer filler sentences.

Apparatus and procedure

The stimuli were presented on a NEC 4FG monitor via a VGA video board that was controlled by a 486 PC. An A to D converter interfaced the computer with a Fourward Technologies Generation V Dual Purkinje eye-tracker. The eye-tracker monitored movements of the right eye, although viewing was binocular. Letters were formed from a 7×8 array of pixels, using the fixed-pitch Borland C default font. Participants sat 61 cm away from a computer screen and silently read single-line sentences while their head position was stabilized by a bite bar. At this viewing distance, 3.8 letters equalled one degree of visual angle. At the beginning of the experiment, the eye-tracking system was calibrated for the participant. At the start of each trial, a check calibration screen appeared, and participants who showed a discrepancy between where their eye fixated and the location of the calibration squares were recalibrated before the next trial.

A trial consisted of the following events. The check calibration screen appeared, and the experimenter determined that the eye-tracker was correctly calibrated. The participant was instructed to look at the calibration square on the far left of the screen, and then the experimenter presented the sentence. The participant read the sentence silently and at his or her own pace, and then clicked a response key to make the sentence disappear. Following a quarter of the trials, a comprehension question appeared on the screen. The participant responded by pressing the response key that corresponded with the position of the correct answer. Then the check calibration screen appeared before the next trial.

Stimuli and design for Experiment 1

A total of 24 high- and low-frequency target words were embedded in sentences. Two of the high-frequency target words were excluded from the data analysis,[1] and the resulting set of targets was composed of 10 high-frequency and 12 low-frequency words (see Appendix A). Each reader saw every target word once in one of two neutral, nonconstraining contexts.

The mean length of the target words was five letters. On average, the high-frequency words (HF) occurred 160 times per million, and the low-frequency words (LF) occurred 4 times per million (Francis & Kucera, 1982). To ensure that the sentence contexts were neutral with respect to the predictability of the target word, norms were gathered from a cloze task performed by 20 participants who were not involved in either experiment. Participants were given the sentence frame up to, but not including, the target word. They were asked to supply the word most likely to appear next in the sentence. The mean probability of completing each sentence with the target word was less than .05 for both the low-frequency and the high-frequency targets.

Stimuli and design for Experiment 2

The target words were 16 pairs of low frequency and high frequency words. Each target word could appear in two sentences: one that predicted that word and one that equally strongly predicted a different word (see Appendix B). Conversely, each sentence served as the context for two possible targets. The sentence in which the high-frequency word was predictable (HFP) was the same context in which the low-frequency word was unpredictable (LFUP). In the other sentence of each pair, the low-frequency word was predictable (LFP) while the high-frequency word was unpredictable (HFUP). One advantage of this design was that it allowed a manipulation of predictability that was independent of the syntax of a specific sentence. However, one consequence was that half of these highly constrained sentences included a target that was different from the word that was expected, given the previous context (i.e., the unpredictable conditions). A review of the materials in Appendix B shows that these unexpected targets are quite plausible, although certainly atypical. Each participant read all of the target words once, half in a predictable context and half in an unpredictable context, resulting in a total of 32 experimental trials. One quarter of the sentences read by each participant contained a predictable high-frequency target, one quarter contained a predictable low-frequency target, one quarter contained an unexpected high-frequency target, and the remaining quarter contained an unexpected low-frequency target.

The members of each stimulus pair were matched for word length within one character, and overall mean length was 5.5 letters. On average, the high-frequency words occurred 150 times per million, and the low-frequency words occurred 5 times per million (Francis & Kucera, 1982). The predictability norms were gathered from a cloze task performed by 20 participants who were not involved in the main experiment. Participants were given the sentence frame up to the target word and asked to fill in what they thought the target word might be. The mean probability of completing each sentence with the predictable target word was .75 for high-frequency targets and .80 for low-frequency targets. The probability of completing each sentence with the unexpected word (i.e., the unpredictable conditions) was less than .01 for both high- and low-frequency words.

Data analysis procedures

To address the question of how frequency effects appeared in the eye movement record of each group of readers, we examined two types of eye movement measure: (a) measures of processing time

[1]The target *frank* received inflated fixation durations. Apparently, the highly frequent usage (*Frank*) interfered with the processing of the appropriate meaning in these sentences. To preserve counterbalancing, the other item in this pair (*moral*) also was excluded from the analyses.

for the target word and (b) measures that describe the spatial–temporal pattern of fixations while reading the sentence.

First-fixation duration is a measure of the mean time spent reading the first time the eye lands on the target word. This includes words processed in a single fixation as well as the first of multiple fixations. We also examined fixation times for words receiving only a *single fixation*. We include the single-fixation data in Table 1 but do not discuss them, since single-fixation time was consistent with first-fixation time. In our analyses, *gaze duration* was calculated as the sum of all consecutive fixations on a word, beginning with the first fixation and including additional fixations up until the eye makes a saccade to another word. Gaze duration is typically assumed to be a measure of the first-pass processing time associated with a fixated word (Rayner, 1998). We also include *spillover time* in our analysis, which measures the duration of the first fixation made after the eye leaves the target word. As such, it can indicate continued or delayed effects in the processing of the target word. All of these measures excluded trials in which the target region was skipped. In Experiment 1 target words were skipped by highly skilled readers 17% of the time and by average readers 15% of the time, and neither frequency nor group differences were significant. In Experiment 2, target words were skipped by highly skilled readers 19% of the time and by average readers 15% of the time.[2]

In addition to these processing time measures, we examined the spatial–temporal pattern of fixations. *Regressions-out* was calculated as the percentage of all trials in which fixations on the target word were followed by a regression to words earlier in the sentence. *Regression path duration* (also referred to as go-past time) is the cumulated fixation durations from when the eyes first enter the target word up until the eyes move on past that word to the right (Konieczny, Hemforth, Scheepers, & Strube, 1997; Liversedge, Patterson, & Pickering, 1998; Rayner & Duffy, 1986). We used a variation of this measure, called *regression path-out*, which included only the time spent re-reading words that preceded the target word. While this measure is largely redundant with regressions-out, it has the advantage of being interpretable as the expected value of the time that a reader would spend re-reading previous material. We also report data from *regressions-in*, which records how often the reader returned to re-read the target word, calculated as the percentage of all trials in which the target word was refixated after the eyes passed the target region to the right.

Consistent with most eye movement research (Rayner, 1998), predetermined cutoffs were used to trim the data. Fixations on the target word that were under 120 ms were eliminated from the analysis since such short fixations do not seem to reflect cognitive processing of the target word (Rayner, 1998; Rayner & Pollatsek, 1987). To eliminate overly long fixations, we excluded fixations over 600 ms from our analysis. Approximately 3% of the data were lost due to these cutoffs and track losses. The remaining data were analysed via analysis of variance (ANOVA) using variability due to participants (F_1) and items (F_2). All participants responded accurately to 80% or more of the comprehension questions.

EXPERIMENT 1

We expected to observe effects of reading skill in the eye movement record. For example, highly skilled readers should have shorter fixation times than poorer readers, as reported by Jared et al. (1999). Highly skilled readers should also regress less often than the average

[2]Since there was no effect of reading group on the probability of fixating on the target word, we do not discuss skipping behaviour. The interaction of frequency and predictability predicted by models such as EZ-Reader did influence skipping rates, $F_1(1, 42) = 7.05$, $p < .05$; $F_2(1, 30) = 6.85$, $p < .05$, in which high-frequency predictable target words were skipped more than any of the other conditions. Skipping rates in the high- and low-frequency predictable conditions were 22% and 13%, respectively. Skipping rates in the high- and low-frequency unpredictable conditions were 14% and 17%, respectively.

readers (Everatt & Underwood, 1994). In addition, we expected to find a somewhat larger frequency effect among the average readers, since Haenggi and Perfetti (1994) reported that average readers were more affected by word frequency than were good readers. Observing such group differences in the eye movement record would confirm that distinguishing highly skilled from average readers based on their Nelson-Denny score was operationally valid. In addition, Experiment 1 offered a baseline observation of the two groups' reading processes as they usually occur in nonconstraining contexts.

Results

Processing time for the target word

First-fixation duration. Table 1 shows the mean first-fixation times on high- and low-frequency words as a function of reading group. The mean first-fixation time for the highly skilled readers (266 ms) was numerically shorter than the mean time for the average readers (277 ms); this difference was significant in the items analysis, $F_2(1, 20) = 4.28$, $p < .05$, but fell short of significance in the participants analysis $F_1(1, 42) = 2.02$, $p < .20$. High-frequency words generally received shorter fixations (262 ms) than low-frequency words (281 ms), $F_1(1, 42) = 13.38$, $p < .001$, and $F_2(1, 20) = 15.54$, $p < .001$. The data show a trend toward smaller frequency effects for the highly skilled readers (11 ms) than for the average readers (26 ms), although this interaction reached significance only in the items analysis, $F_2(1, 20) = 2.09$, $p < .05$, and not by participants, $F_1(1, 42) = 2.45$, $p < .15$.

Gaze duration. Table 1 shows the mean gaze duration times for high- and low-frequency words as a function of group. The mean gaze duration for the highly skilled group

TABLE 1
Mean processing times[a] for the target words in Experiments 1 and 2

		Experiment 1		*Experiment 2*			
	Readers	*HF*	*LF*	*HF-P*	*LF-P*	*HF-U*	*LF-U*
First fixation	skilled	260	271	250	262	257	279
	average	264	290	258	268	266	277
Single fixation	skilled	263	278	250	261	262	280
	average	267	296	261	271	271	287
Gaze duration	skilled	280	291	263	285	282	311
	average	286	326	276	284	303	305
Spillover	skilled	261	271	266	260	268	274
	average	269	283	277	259	259	285

Note: HF = high frequency. LF = low frequency. P = predictable. U = unpredictable.
[a]In ms.

was shorter (286 ms) than that for the average readers (306 ms), $F_1(1, 42) = 5.19$, $p < .05$, and $F_2(1, 20) = 6.33$, $p < .05$. The main effect of frequency was also significant as high-frequency words received shorter gaze durations (283 ms) than did low-frequency words (309 ms), $F_1(1, 42) = 12.43$, $p < .001$, and $F_2(1, 20) = 12.72$, $p < .005$. The size of the frequency effect again appeared smaller for the highly skilled readers (11 ms) than for the average readers (40 ms), and the group by frequency interaction was marginally significant, $F_1(1, 42) = 3.91$, $p = .06$, and $F_2(1, 20) = 3.30$, $p = .08$. Simple effects tests confirmed a significant frequency effect for the average readers, $F_1(1, 20) = 12.94$, $p < .005$, and $F_2(1, 20) = 10.04$, $p < .005$, but not for the highly skilled readers, $F_1(1, 20) = 1.44$, $p < .25$, and $F_2(1, 20) = 2.01$, $p < .20$.

Spillover. The means for spillover appear in Table 1. The main effect of reading group was marginal in the items analysis, $F_2(1, 20) = 3.95$, $p = .06$, and failed to reach significance by participants, $F_1(1, 42) = 1.17$, $p = .29$. The main effect of frequency was marginal by participants, $F_1(1, 42) = 2.87$, $p < .10$, and failed to reach significance in the items analysis, $F_2(1, 20) = 2.48$, $p < .15$. The group by frequency interaction was not significant, $F\text{s} < 1$. It appears that there was little evidence for group differences and/or frequency effects on the duration of fixations immediately after leaving the target word.

The spatial–temporal pattern of fixations

We examined the pattern of fixations before readers went past the target word to read any new text. How often participants regressed out of the target region and how long they spent re-reading prior context are indices of processing difficulty, and so the measures reported here might reveal differential effects of frequency that appear after the first-pass fixation on the target word.

Regressions-out. As the means in Table 2 show, our readers rarely regressed out of the target region. The average readers regressed from the target word more frequently (10% of the time) than did highly skilled readers (5%), $F_1(1, 42) = 3.18$, $p < .10$; $F_2(1, 20) = 12.73$, $p < .005$. Frequency did not have a significant effect on the percentage of regressions-out in either the overall analysis or the interaction with reading group, all $F\text{s} < 1$.

Regression path-out. Table 2 shows the mean regression path-out times for high- and low-frequency words as a function of group. Average readers spent more time re-reading prior context after a regression from the target (30 ms) than did the highly skilled readers (15 ms). This main effect of group was significant in the items analysis, $F_2(1, 20) = 7.21$, $p < .01$, but not in the participants analysis, $F_1(1, 42) = 2.41$, $p = .13$. Frequency did not have a significant effect on the time spent re-reading prior context, in either the overall analysis or the interaction with reading group, all $F\text{s} < 1$.

Regressions-in. The means for percentage of regressions to the target word also appear in Table 2. On average, the highly skilled readers showed a nonsignificant trend toward fewer regressions (10%) than the average readers did (14%), $F_1(1, 42) = 1.32$, $p < .30$, and $F_2(1, 20) = 2.73$, $p < .12$. Frequency did not have a significant effect on how often readers

TABLE 2
Pattern of fixations in Experiments 1 and 2

		Experiment 1		*Experiment 2*			
	Readers	*HF*	*LF*	*HF-P*	*LF-P*	*HF-U*	*LF-U*
Regressions-out[a]	skilled	4.1	5.0	6.5	3.4	2.7	6.9
	average	10.9	8.8	5.4	13.7	5.9	4.0
Regression path-out[b]	skilled	13.8	17.0	14	8	8	29
	average	34.7	27.4	13	45	13	19
Regressions-in[a]	skilled	10.2	10.0	2.2	4.4	3.9	8.6
	average	13.1	14.5	7.8	2.7	9.9	12.0

Note: HF = high frequency. LF = low frequency. P = predictable. U = unpredictable.
[a]In percentages. [b]In ms.

returned to re-read the target word after having left it, either in the overall analysis or in the interaction with reading group, all Fs < 1.

Discussion of Experiment 1

The pattern of data for Experiment 1 generally confirmed the expected differences between highly skilled and average readers. When reading target words embedded in contexts that were not constraining, the highly skilled readers had shorter gaze durations (286 ms) than the average readers did (306 ms). Group differences in reading skill also affected some re-reading patterns. The average readers tended to regress from the target word more often (10%) than did the highly skilled readers (5%). It also appeared that the average group spent more time re-reading prior context (31 ms) than the better readers did (15 ms). Reading skill did not, however, appear to affect the probability of regressing to the target after having moved past it. Both groups read high-frequency words faster than low-frequency words. The size of the frequency effect in gaze duration was smaller for highly skilled readers (11 ms) than for average readers (40 ms). The observation of frequency effects in average readers extends the findings of Jared et al. (1999) that both highly skilled and poor readers take more time to read low-frequency words than high-frequency words (see Hyönä & Olson, 1995, for a demonstration that even very poor readers show such frequency effects). Target word frequency did not appear to influence the spatial–temporal pattern of fixations after readers left the target region, which suggests that frequency effects are tightly linked to the lexical access processes that accompany initial word reading.

In sum, reading skill appeared to influence both word processing time and some re-reading patterns after leaving the target. This supports the validity of distinguishing these two groups of readers based on their Nelson-Denny score. Consistent with Jared et al. (1999), the highly skilled group read the target words faster than did the average readers. However, the two groups had comparable gaze durations on high-frequency words, so the core difference appears to be the processing time for low-frequency words. This difference may stem from the highly skilled readers' greater familiarity with less common words, perhaps because of their increased exposure to text (Stanovich, 1986). Also, the average readers made more regressions from the target word and spent more time re-reading, even when processing these relatively uncomplicated sentences. These data confirm that the commonly observed correlation between reading proficiency and reading speed is attributable to several factors, including word recognition time and re-reading patterns.

EXPERIMENT 2

The primary goal of the present research was to examine the effects of word frequency and word predictability on the reading patterns of each group of readers. To do this, high- and low-frequency targets were embedded in highly constraining sentence contexts:

Subjects read either:
(HFP) He scraped the cold food from his dinner **plate** before washing it. *OR*
(HFUP) John stirred the hot soup with the broken **plate** until it was ready to eat.

Subjects read either:
(LFP) John stirred the hot soup with the broken **spoon** until it was ready to eat. *OR*
(LFUP) He scraped the cold food from his dinner **spoon** before washing it.

In the predictable conditions, the expected high- or low-frequency word appeared in the target region. In the unpredictable conditions, an unexpected high- or low-frequency word appeared in the target region of that same sentence.

In the predictable conditions, orthographic and contextual information should reinforce each other and lead to faster processing times, since the word predicted by prior context and the word that actually appeared as the target were the same (Seidenberg & McClelland, 1989). We expected to find reading time differences for the two groups of readers, given that several studies found that less skilled readers rely more on context for word identification than do more skilled readers (Perfetti & Lesgold, 1979; Schwartz & Stanovich, 1981; Stanovich, 1984). Although the interactive-compensatory model proposed that less skilled readers rely on context more, the effectiveness of these compensatory word identification processes is still an open question. If average readers could use context to efficiently access the target words in the predictable conditions, it is possible that they might benefit more from predictability than would the highly skilled readers. In the unpredictable conditions, however, the word predicted by prior context was *not* the word that actually appeared as the target. Here, the prior context would activate the predicted word, but letter information from the actual target would activate a different lexical entry. In that case, the two lexical items might compete with each other and slow down the word recognition process. If less skilled readers have difficulty suppressing irrelevant context information during word identification task (Gernsbacher, 1993), one might expect that average readers would have very long reading times for unpredictable words, or not fully process some unpredictable words before their eyes leave the target region. We also expected that highly skilled and average readers would differ in their re-reading patterns. The highly skilled readers might spend more time re-reading prior context when the less frequent targets appeared in the unpredictable condition, since these words would be the most difficult to integrate with information from the preceding context. If the average readers were relying on context information to assist word recognition, then they might spend more time re-reading the prior context when a low-frequency target word was predicted by the prior context.

Results

The interaction of the frequency and predictability factors with levels of reading skill is our primary interest in this article. Therefore, we focus primarily on the significant interactions involving reading groups.

Processing time for the target word

First-fixation duration. Table 1 shows the mean first-fixation times on the target word in each of the conditions as a function of reading skill. High-frequency words were read faster (258 ms) than low-frequency words (272 ms), $F_1(1, 42) = 15.63$, $p < .001$; $F_2(1, 30) = 6.92$, $p < .02$. Predictable words were read faster (260 ms) than unpredictable words (270 ms), $F_1(1, 42) = 6.49$, $p < .02$; $F_2(1, 30) = 7.662$, $p < .01$. No significant interactions were found, $F\text{s} < 1$. The main effect of group was not significant, $F_1 < 1$ and $F_2(1, 30) = 1.92$, $p < .20$. Frequency and predictability combined additively to influence the first-fixation times of both groups of readers.

Gaze duration. Table 1 shows the mean gaze duration on the target word in each of the conditions as a function of reading skill. Highly predictable words were read faster (277 ms) than unpredictable words (300 ms), $F_1(1, 42) = 21.23$, $p < .001$; $F_2(1, 30) = 13.94$, $p < .001$. High-frequency words were read faster (281 ms) than low-frequency words (296 ms), with the effect being significant in the participants analysis, $F_1(1, 42) = 10.60$, $p < .003$, and marginal by items, $F_2(1, 30) = 3.51$, $p < .075$. Most importantly, there was an interaction of frequency and reading skill, $F_1(1, 42) = 4.71$, $p < .04$; $F_2(1, 30) = 3.98$, $p < .06$. Highly skilled readers showed a sizeable effect of word frequency (273 vs. 298 ms), $F_1(1, 21) = 14.20$, $p = .001$; $F_2(1, 30) = 5.82$, $p < .05$. Interestingly, there was no frequency effect for the average group (290 vs. 295 ms, $F\text{s} < 1$). The two groups of readers spent similar amounts of time reading low-frequency words. None of the other effects was significant, including interactions involving reading skill or predictability ($F\text{s} < 1$) nor was there any main effect of reading skill ($F\text{s} < 1$).

Spillover. We suggest that one reason that average readers spent relatively little time reading low-frequency words is that, in some cases, they completed identification of the target word after their eyes had moved past it. Such a process can be identified by the spillover measure. The frequency by predictability interaction was significant, $F_1(1, 42) = 7.89$, $p < .01$; $F_2(1, 30) = 5.24$, $p < .05$ (see Table 1). Spillover time was notably longer in the low-frequency unpredictable condition (280 ms vs. an average of 265 ms in the other conditions). Although the three-way interaction was not significant (Fs < 1), the average readers showed a significant frequency by predictability interaction in an analysis of simple effects, $F_1(1, 21) = 10.46$, $p < .005$; $F_2(1, 30) = 9.67$, $p < .005$, while the skilled readers did not, (Fs < 1). In the first fixation after leaving unpredictable target words, the average group's spillover fixation was 26 ms longer when they had read a low-frequency target than when they had read a high-frequency target. In contrast, the highly skilled readers' spillover fixation duration in the unpredictable conditions was only 6 ms longer after low-frequency words than after high-frequency words. This pattern of results suggests that the average readers spent relatively less time looking at low-frequency unpredictable words and often recognized them only after moving to the next word.

The spatial–temporal pattern of fixations

The gaze duration measure indicated that average readers were also unexpectedly fast reading low-frequency predictable words. According to the data just presented, they did not compensate for these fast reading times with long spillover durations on the following word (as they did for low-frequency unpredictable words). However, examining the time participants spent re-reading the sentence context prior to the target proved to shed some light on these short gaze durations.

Regressions-out. The mean percentages for regressions-out of the target region are presented in Table 2. The three-way interaction of frequency, predictability, and reading group was significant, $F_1(1, 42) = 8.16$, $p < .01$, and $F_2(1, 30) = 6.44$, $p < .02$. The nature of this interaction was that the average readers regressed more often from low-frequency targets that were highly predictable from prior context (14%) than from words in the other three conditions (4%–6%), $F_1(1, 21) = 3.98$, $p < .06$, and $F_2(1, 30) = 4.41$, $p < .05$. The low-frequency predictable condition was also one of the conditions in which the average readers showed shortened gaze durations. Thus, the average readers tended to look back to the preceding context after fixating an unfamiliar but predictable word, rather than continue looking at the target until lexical access was completed.

The other condition in which the average readers had shortened gaze durations was the low-frequency unpredictable condition. The average readers did not show an increased percentage of regressions from the target region in this condition, in contrast to the low-frequency predictable condition. However, they did regress more often from the region *after* the target (t + 1) when the target was a low-frequency unpredictable word (14.0%) than in any other condition (a mean of 7.8%). This was not the case for the highly skilled readers (4.0% vs. 3.8%), resulting in a three-way interaction that was significant in the participants analysis, $F_1(1, 42) = 4.35$, $p < .05$, and marginal by items, $F_2(1, 30) = 3.37$, $p < .08$. As the mean spillover duration also was elevated in this condition for the average readers, the observation that they regressed to earlier parts of the sentence late (i.e., after fixating the following word) indicates that average readers' eyes often moved off the target before completing lexical access.

Regression path-out. The means for regression path out are presented in Table 2. Again, there was a three-way interaction of reading skill, predictability, and frequency, $F_1(1, 42) = 8.28$,

$p < .01$, and $F_2(1, 30) = 5.59$, $p < .03$. As in the regressions-out measure, the average readers spent more time re-reading prior context when low-frequency targets were predictable (45 ms) than in the other three conditions (13–19 ms). *T* tests indicated that average readers had longer regression path-out times for low-frequency than for high-frequency targets when they were predictable, $t(21) = 2.46$, $p < .03$, but not when they were unpredictable, $t(21) < 1$. In contrast, the highly skilled readers spent more time re-reading the prior context after landing on unpredictable, low-frequency targets (29 ms) than in the other three conditions (8–14 ms). *T* tests indicated a significant frequency effect for these participants in the unpredictable condition, $t(21) = 2.58$, $p < .02$, but not in the predictable condition, $t(21) < 1$.[3]

Regressions-in. The mean percentage of regressions into the target region appear in Table 2. We found a main effect of predictability in the overall analysis, $F_1(1, 42) = 13.22$, $p = .001$, and $F_2(1, 30) = 8.30$, $p < .001$, indicating that both groups of readers regressed more often to unpredictable than predictable targets. However, there was also a frequency by reading group interaction, $F_1(1, 42) = 3.70$, $p < .07$, and $F_2(1, 30) = 5.11$, $p < .05$. The highly skilled readers regressed more often to low-frequency, unpredictable words (9%) than to words in the other three conditions (2–4%), but a frequency effect appeared for both predictable and unpredictable targets. This is consistent with results of simple effects tests that indicated a frequency effect for highly skilled readers, $F_1(1, 21) = 4.64$, $p < .05$, reaching marginal significance in the items analysis, $F_2(1, 30) = 3.02$, $p < .10$. In other words, the highly skilled readers were more likely to return to a word and have a second look at it when it was more difficult. A different pattern of data appeared for the average readers, however, as frequency effects were not significant in the simple effects tests, *F*s < 1. Although the average group might have regressed slightly more often to low-frequency than to high-frequency unpredictable targets, they appeared to have a sizeable inverse frequency effect in the predictable conditions, such that they regressed less often to low-frequency predictable words (3%) than to high-frequency predictable targets (8%).

Discussion of Experiment 2

Experiment 2 examined the effects of word frequency and predictability on the fixation times and reading patterns of highly skilled and average readers as they read words in highly constraining sentence contexts. Predictability and frequency independently affected processing time, which is consistent with lexical decision experiments conducted by Schuberth

[3]The three-way interaction was statistically examined using simple effects tests, but these yielded marginal significance. We report them here for completeness. An analysis of simple effects in regression path-out for the average readers yielded a main effect of frequency, $F_1(1, 21) = 4.85$, $p < .05$, and $F_2(1, 30) = 4.96$, $p < .05$, significant in both analyses. A main effect of predictability was significant in the items analysis, $F_2(1, 30) = 4.09$, $p < .05$, but not significant by participants, $F_1(1, 21) = 2.52$, $p < .15$. The predictability by frequency interaction reached marginal significance in the participants analysis, $F_1(1, 21) = 2.96$, $p < .10$, but was not significant by items, $F_2(1, 30) = 2.52$, $p < .15$. In the simple effects analysis for the highly skilled readers, however, only the predictability by frequency interaction was significant by participants, $F_1(1, 21) = 6.7$, $p < .05$, and marginal by items $F_2(1, 30) = 3.1$, $p < .09$.

and Eimas (1977) and Schuberth, Spoehr, and Lane (1981; see also Rayner et al., 2004, for eye movement data and theoretical analyses). However, the highly constraining contexts of Experiment 2 seemed to trigger qualitative changes in the reading behaviour of the average readers, which indicates that reading skill interacted with the effects of frequency and predictability.

Group differences in fixation time

Highly skilled readers showed additive main effects of predictability and frequency in all fixation duration measures. The average readers showed predictability effects in these measures, but not frequency effects. We argue that the absence of frequency effects indicates that the average readers did not complete lexical access while fixating low-frequency words, perhaps due to competition effects (Gernsbacher, 1993).

Highly skilled readers read high-frequency targets 17 ms faster on average than did the group of average readers. The finding that better adult readers read high-frequency words substantially faster than less skilled readers is consistent with previous literature (e.g., Haenggi & Perfetti, 1994, in their naming study of short one- and two-syllable words). In contrast, our two groups of readers had similar gaze duration times for low-frequency words (298 ms for the highly skilled readers and 295 ms for the average readers).

The failure to find group differences in reading time for low-frequency words was surprising. However, it is premature to conclude that the average readers recognized low-frequency words as quickly as the skilled readers, for two reasons. First, given that frequency effects did not appear in the average readers' gaze duration, we cannot assume that word recognition occurred. Second, an examination of other measures (spillover and re-reading patterns) revealed that delayed frequency effects sometimes appeared.

Although gaze duration is widely accepted as an indicator of the time needed for lexical access (see Rayner, 1998), it is less clear what the eyes do when lexical access has not been achieved. There are some clues in the eye movement record, suggesting that lexical access was often delayed for average readers when they read low-frequency words in constraining contexts. After the average readers moved their eyes off unpredictable targets, processing seemed to continue during the following fixation until lexical access was completed, resulting in a 26-ms frequency effect in spillover time. In contrast, no reliable frequency effect (6 ms) was observed in spillover for the highly skilled readers. This pattern suggests that, for the average readers, lexical access processes did not always control when the eyes moved. When target words were highly unpredictable, the average readers tended to move their eyes to the next word even though lexical access had not been completed. The frequency effect observed in the average readers' spillover time thus indicates that word recognition was sometimes delayed when they read low-frequency unpredictable words in constraining contexts. Measures of re-reading behaviour, on the other hand, illuminate what the average readers did when they came upon low-frequency predictable words.

Group differences in re-reading patterns

When the percentage of regressions and regression path-out means for the target region were pooled over frequency, the average readers had higher rates of regression (10% vs. 5%) and longer re-reading times (29 ms vs. 16 ms) in the predictable conditions than in the unpredictable conditions, respectively. This surprising pattern of more regressions from the target and more re-reading in the predictable conditions arises specifically in the average readers' re-reading patterns in the low-frequency predictable condition.

The average readers were more likely to regress from low-frequency targets when they were predictable (14%) than when they were unpredictable (4%). They also had longer regression path-out times in the low-frequency predictable condition than in the low-frequency unpredictable condition (45 ms vs. 19 ms). In contrast to this "reverse" predictability effect for the low-frequency words, no predictability effects were observed for high-frequency words. This pattern of eye movements for low-frequency predictable words suggests that the average readers may have anticipated the target word, quickly confirmed that the fixated word matched their prediction (e.g., by using length information or initial letter identity), and then regressed from the target region to use context-based processes to support lexical access of that word. As the percentage of regressions from the target was not inflated in the case of low-frequency unpredictable words, it appears that the average readers either did not realize, or did not immediately act on the realization, that the fixated word was not what they expected in that condition. Instead, the average readers waited until their eyes fixated the following word (t + 1) before they regressed to earlier in the sentence. In comparison, highly skilled readers seemed to become aware of the difficulty integrating low-frequency unpredictable words more quickly. They regressed from the target after completing lexical access and spent the longest time re-reading in that condition (29 ms vs. 8–14 ms). Again, one of the main differences between the highly skilled readers and the average readers is the highly skilled readers' tight coupling of fixations with lexical access and integration processes.

The two groups of readers also had different patterns of regressions back to the target word after leaving it. The highly skilled readers regressed to unpredictable low-frequency words more often (9%) than to words in the other three conditions (2–4%). The average readers tended to regress to the target more frequently (8–12%) than the highly skilled readers did in every condition except for the predictable low-frequency words (3%). The average readers' somewhat higher rates of regression back to unpredictable words in this experiment could indicate a late effort to resolve conflict between context and form-based recognition of low-frequency words, yet these regression rates are slightly lower than those observed when reading the nonconstraining sentences in Experiment 1.

In summary, the two groups of readers displayed distinct patterns of eye movements and re-reading times after leaving the target word. Combined with the differential effects of frequency on word reading time, these differences seem to index some variation in the cognitive processes used for lexical access and integration. For highly skilled readers, frequency effects appeared in all measures of initial reading time, indicating the operation of automatized word recognition processes that efficiently completed lexical access. Re-reading of prior context occurred mainly after low-frequency unpredictable targets and, thus, seemed to signal demands on postlexical integration processes. Average readers, however, often did not complete lexical access by the time their eyes moved off the target word, as indicated by an absence of a frequency effect in gaze duration. Rather, they sometimes completed the lexical access of unpredictable targets during their first fixation after leaving the target word. When the targets were predictable, average readers were more likely to regress from less familiar targets and re-read prior context.

A COMPARISON OF DATA FROM EXPERIMENTS 1 AND 2

We conducted additional analyses between experiments to contrast the fixation time and re-reading data for unpredictable words in nonconstraining (Experiment 1) and highly constrained sentence contexts (Experiment 2). We wanted to confirm that readers were processing the Experiment 2 targets in a natural fashion, despite the use of somewhat unusual materials (e.g., highly constraining sentence contexts that predicted a word other than the target). To test whether the group differences in Experiment 2 were artifacts of our stimulus set, we conducted between-experiment analyses of the eye movement data from Experiment 1 and the unpredictable conditions in Experiment 2. In the participants analysis, experiment and frequency were treated as within factors, and reading group was treated as a between factor. In the items analysis, reading group was treated as within factors, and experiment and frequency were treated as a between factor.

Main effects of frequency were highly significant in the fixation duration measures, all ps $< .001$, which suggests that word frequency influenced fixation times in both experiments, as is commonly observed in the course of normal reading. For percentage of regressions back to the target, a main effect of experiment appeared in the participant analysis, $F_1(1, 42) = 4.73$, $p < .05$, but was not significant by items, $F_2(1, 52) < 1$. Also, a main effect of group appeared in the items analysis, $F_2(1, 52) = 5.19$, $p < .05$, but was only marginal by participants, $F_1(1, 42) = 2.82$, $p < .10$, suggesting that average readers were more likely than highly skilled readers to look back at the target after having read past it. No significant main effects were found in the other re-reading measures.

One interaction did appear significant in gaze duration: a three-way interaction between group, frequency, and experiment, $F_1(1, 42) = 5.74$, $p < .05$; $F_2(1, 52) = 6.87$, $p < .01$. The nature of the interaction was that the average readers showed strong frequency effects in Experiment 1 (40 ms), but not in the unpredictable conditions in Experiment 2 (2 ms). The highly skilled readers, in contrast, showed moderate frequency effects in both experiments. Simple effects tests confirmed that the interaction of frequency and experiment appeared only in the average readers' data, $F_1(1, 20) = 6.17$, $p < .05$; $F_2(1, 52) = 5.07$, $p < .05$, and not in the data for the highly skilled readers, $F_1(1, 20) = 1.03$, $p < .50$; $F_2(1, 52) = 1.49$, $p < .25$.

Overall, these analyses indicate that the reading patterns that appeared in Experiment 2 are unlikely to be artifactual, as the highly skilled readers performed similarly in both experiments. In contrast, the average readers' gaze durations varied substantially between Experiment 1 and the unpredictable conditions of Experiment 2.

GENERAL DISCUSSION

The experiments reported here examined the eye fixation times and eye movement patterns of highly skilled and average college readers in response to two well-known factors that influence silent reading: frequency (Experiment 1) and frequency in combination with predictability (Experiment 2). In the main experiment of interest (Experiment 2), participants read high- and low-frequency target words in highly constraining sentence contexts. Group differences in fixation time data indicated that reading skill influenced the magnitude and time-course of frequency effects. Group differences in re-reading patterns suggested that reading skill also affected the manner in which predictable and unpredictable low-frequency words were processed. Before discussing these differences in more detail, we review the main findings from Experiment 1 in order to provide a vantage point from which to consider the findings of Experiment 2.

In Experiment 1, participants read target words of comparable frequency and length to those targets in Experiment 2. In Experiment 1, however, the target words were embedded in nonconstraining sentence contexts. Both groups read the low-frequency words more slowly than the high-frequency words in Experiment 1. The appearance of frequency effects in measures of fixation time suggests, consistent with models like EZ-Reader (Reichle et al., 1998) and SWIFT (Engbert et al., 2002), that all of our readers usually completed lexical access before their eyes left the target word. Main effects of reading skill were found in fixation duration measures, although the group differences were fully significant only for the low-frequency words. The average readers needed more additional time to process low-frequency words than did the highly skilled readers, yielding stronger frequency effects for the average group. These data are consistent with claims that the clarity and crispness of word representations varies with reading ability (Perfetti, 1985), as well as with other eye movement studies that observed the effect of reading skill on the rate of word recognition processes during silent reading (Jared et al., 1999; Kennison & Clifton, 1995). In addition, our data confirm the relationship between reading skill and re-reading patterns, as the average readers tended to regress and re-read text more often than did the highly skilled readers. In sum, these data suggest that commonly observed differences in reading rate are attributable both to differences in word recognition time and to differences in re-reading patterns.

Given the Experiment 1 data, a similar pattern of frequency and reading skill effects might be expected in Experiment 2, where the same participants read target words of similar length and frequency that were presented in highly constraining sentence contexts. Main effects of frequency and reading skill should appear in the fixation duration measures, and reading skill should inversely affect the percentage of regressions and time spent re-reading the text. Likewise, one might expect additive effects of predictability and frequency (as discussed in the Introduction). This general pattern was observed for the highly skilled readers in Experiment 2, but a different pattern emerged for the average readers.

As the main difference between Experiments 1 and 2 is the constraint of the sentence contexts in which our target words were embedded, it is possible to organize the data from both experiments along a single continuum of predictability. Figure 1 presents the gaze duration data in that way for each group of readers, such that the "high", "neutral", and "low" predictability conditions refer to the predictable conditions in Experiment 2, the nonconstraining contexts of Experiment 1, and the unpredictable conditions of Experiment 2, respectively.

For our highly skilled readers, the eye movement data were remarkably consistent across the two experiments. First-fixation times (see Table 1) were quite similar in Experiment 1 and the unpredictable conditions of Experiment 2, as was the size of the frequency effect. Figure 1, however, shows stronger frequency effects on gaze duration for the highly skilled readers in Experiment 2 than in Experiment 1. It seems, then, that sentential constraint had some effect on the size of the frequency effect, but perhaps not on the nature of the word recognition processes.

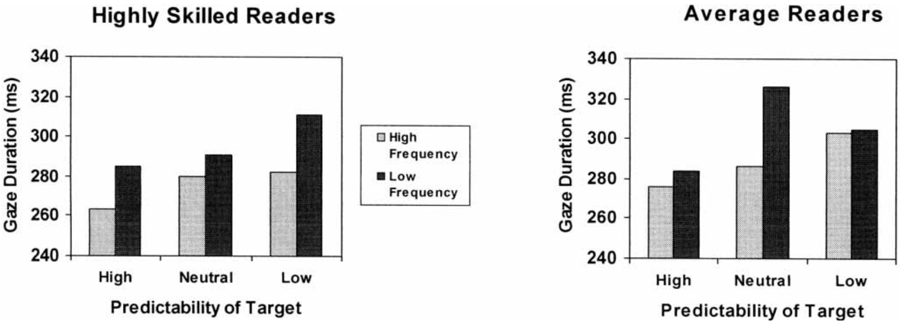

Figure 1. Gaze duration as a function of target word predictability.

In contrast, the eye movements of the average readers indicate that sentential constraint did affect the nature of their reading processes. Figure 1 shows that the average readers spent substantially less time reading both predictable and unpredictable low-frequency words in Experiment 2 than the "neutral" low-frequency words in Experiment 1. Gaze durations on the high-frequency words, however, followed a typical staircase pattern with durations lengthening as predictability decreased. The pattern of shorter fixation times for low-frequency words in Experiment 2 resulted in attenuated or absent frequency effects, relative to Experiment 1, and led us to suspect that the average readers often left the low-frequency targets before they completed lexical access, when the words occurred in constraining sentence contexts.

An examination of additional eye-tracking measures supported this suspicion and further illuminated the effects of sentential constraint on our average readers. Particularly, the average readers' relatively short gaze durations in the low-frequency unpredictable condition were associated with a 26-ms frequency effect in spillover time. Longer spillover times for low-frequency words in the unpredictable conditions suggest that the average readers often completed lexical access after leaving low-frequency unpredictable words. Consistent with the spillover data, they also had a relatively high percentage of regressions from the word that followed low-frequency unpredictable targets. In the predictable conditions, however, a different pattern emerged from the re-reading measures. The average readers were more likely to leave low-frequency predictable targets and re-read the preceding context than they were in the other conditions. These results indicate that in Experiment 2 the average readers were slower to recognize unpredictable, low-frequency words and relied on context to support their recognition of predictable, low-frequency words. In either case, when the sentence context was highly constraining the average readers looked away from low-frequency words before lexical access occurred.

The highly constraining contexts in Experiment 2 had a graded influence on the re-reading patterns of the highly skilled readers. Mainly, they spent more time re-reading the prior context of targets in the low-frequency unpredictable condition than in the other conditions. This difference appeared to be one of degree, as a comparison of the means pooled over predictable and unpredictable conditions indicated that the highly skilled readers had similar regression rates and re-reading times in both Experiments 1 and 2. Given the similar fixation durations, the consistent appearance of frequency effects there, and the similar re-reading patterns, it appears that sentential constraint did not affect how the highly skilled readers processed text. Instead, predictability additively affected their reading times, such that predictable targets were read faster, and unpredictable targets were read slower.

The organization of data in Figure 1 clarifies how an interactive-compensatory model of word recognition might account for some of the differences we observed between the highly skilled and average readers. According to the interactive-compensatory model, better readers rely less on surrounding context to bolster their word recognition skills than do less skilled readers. If our highly skilled readers relied less on context, we would expect that the size of their frequency effects would be more stable across the range of predictability than would that of the average readers. This pattern is apparent in Figure 1. The highly skilled readers' frequency effect was similar in both the high predictable and neutral conditions, while the average readers' frequency effect was clearly modulated by predictability.

An interactive-compensatory view also would predict that the average readers would benefit most from context, and, thus, fixation times should increase as predictability decreases. Two patterns in the gaze duration data fulfil that prediction (see Figure 1). In contrast to the highly skilled readers, the average readers spent more time reading high-frequency words in the low-predictable condition, as compared to the neutral nonconstraining condition. The average readers also took considerably longer to process low-frequency words in the neutral nonconstraining condition than in the high-predictable condition. Notably, the prediction that average readers would read low-frequency unpredictable words more slowly than words in any other condition was not fulfilled, strictly speaking. The average readers' gaze durations on high- and low-frequency unpredictable words were quite comparable, resulting in an absence of frequency effects that indicates a failure to remain on low-frequency, unpredictable words long enough to recognize them. This finding probably reflects the relatively complex properties of eye movements rather than suggesting a failure of the theory.

With respect to our claim that the average readers' relatively short gaze durations on low-frequency words indicate delayed word recognition processes, we must consider one additional possibility. Perhaps our average readers appeared to read low-frequency words quickly simply because they were not carefully attending to the words or comprehending the sentences. This possibility is not consistent, however, with the average readers' processing of low-frequency words in Experiment 1. The appeal of attributing the short reading times to lapses of attention in Experiment 2 is further diminished by the average readers' high accuracy rate on the comprehension questions, which was 85% (compared to a 90% rate for the skilled readers). Although we cannot confidently claim that our average readers were always successful in recognizing low-frequency words, we suggest that their reading behaviour can best be understood in terms of how highly constraining sentence contexts affected their word recognition processes.

In addition to providing support for the interactive-compensatory view of differences in reading skill, the present experiments offer some novel insights. First, it appears that context-based word recognition processes not only differentiate skilled from average readers in childhood, but continue to differentiate readers at the end-point of reading development. Reliance on context-based processes also seems to correlate with relatively subtle differences in reading skill. In terms of the general adult population, our "average" group would rank well above average in reading skill, and our "highly skilled" group would comprise a small minority of extremely good readers. It is somewhat surprising, then, that subtle skill differences affected the recognition of relatively simple words. Second, highly constrained sentence contexts had particular effects on the word recognition processes of the average readers. Primarily, the average readers were unwilling to wait for lexical access to be completed for low-frequency words before looking away from the target. In other words, as they attempted to identify an unfamiliar target word, it was another word in the text that was actually the locus of their eye fixation. Whether the new locus of fixation preceded or followed the target in the sentence seemed to depend on the target's predictability. In the course of years of reading experience, such an eye–mind disjunction could possibly perpetuate a reliance on context-based processes for word recognition and diminish attention to letter information (Stanovich, 1986). A mismatch between the visual information from the locus of fixation and the representation(s) being used for lexical access would, at best, prevent any reinforcement of the representation by the incoming visual information. Any noise from the mismatch might interfere with feedback processes that help form the crisp, stable orthographic and phonological representations needed to access that word efficiently in the future (Perfetti, 1985; Perfetti & Lesgold, 1979). Thus, the recognition of low-frequency words would remain more effortful for less skilled readers, further inducing them to rely on the surrounding context when they suspect it will provide clues to the word's identity. Another insight from this study derives from the observation that the average readers *did* wait and hold their fixation on low-frequency words until lexical access was completed, when the reading material consisted of nonconstraining sentence contexts. If less skilled readers generally coordinate their fixations more closely with lexical access when reading nonconstraining text, then that is the situation in which they are most likely to develop efficient word recognition skills. Further research with young readers is clearly needed to examine the effect of contextual constraint on developing word recognition processes.

In summary, this article identified differences in reading behaviour that manifested as differences in reading skill. Experiments 1 and 2 demonstrate that changes in basic reading processes can be measured in the eye movement record of college-level readers. Those changes indicate that text factors, such as predictability, and lexical properties, such as frequency, interact with reading skill to affect word recognition processes. For example, the highly skilled readers showed comparable frequency effects in both experiments, which suggests that their word recognition processes were relatively unaffected by sentential constraint. Consequently, the highly skilled readers processed even unexpected words efficiently and re-read prior context to integrate these words into a revised representation of the sentence. In contrast, eye movement data from the average readers indicate that they read low-frequency words differently in the nonconstraining sentence contexts than in the highly constraining contexts, and differently in the predictable and unpredictable conditions. Overall, this study offers a glimpse of the moment-by-moment processes used by highly skilled and average readers during silent reading. Finding differential effects of frequency and predictability indicates that group differences in eye movement patterns can help clarify the relationship between reading achievement and differences in word recognition and integration processes.

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APPENDIX A
Materials for Experiment 1

High-frequency targets

The runners will now *stand*|*begin* at the starting blocks.
At the sound of the tone, please *begin*|*stand* to exit the aircraft.
On that day, the *front*|*local* meeting room was full of people.
After bowling, the *local*|*front* bar is always crowded.
Our last dollar was *spent*|*taken* for taxes.
Most of their income was *taken*|*spent* for an expensive car payment.
They liked the new *plant*|*model* better than the old one.
The old *model*|*plant* looked better in the kitchen.
In the evenings, the freshmen would *drink*|*study* together for hours.
The students planned to *study*|*drink* together on Saturday.

Low-frequency targets

After completing an application, the *plump*|*timid* woman waited for an interview.
Over time, the dog became as *timid*|*plump* as its owner.
The doctor checked the child's *scalp*|*navel* to see why it was itchy.

The human *navel*|*scalp* is vulnerable to dermatological diseases.
The carpenter tried to *slant*|*bevel* the new joists.
The unusual *bevel*|*slant* of the frame complemented the painting.
She purchased a *stamp*|*token* at the booth.
He waited in line to buy a *token*|*stamp* during his lunch hour.
Mary hoped the dessert would *tempt*|*amuse* her guests.
He found it surprisingly difficult to *amuse*|*tempt* the customer.
We could go for a walk by the *swamp*|*plaza* sometime tomorrow.
In his first book, monsters roam around the *plaza*|*swamp* at midnight.

APPENDIX B
Materials for Experiment 2

Conditions: High-frequency predictable (HFP) or low-frequency unpredictable (LFUP)

Before warming the milk, the babysitter took the infant's *bottle*|*diaper* out of the travel bag.
Most cowboys know how to ride a *horse*|*camel* if necessary.
June Cleaver always serves meat and *potatoes*|*carrots* for dinner.
He scraped the cold food from his dinner *plate*|*spoon* before washing it.
The cup slipped out of Jim's hand and hit the *floor*|*dryer* when his wife fainted.
The teacher kept the class quiet while she read a short *story*|*diary* at the end of the day.
Wanting children, the newlyweds moved into their first *house*|*igloo* and were excited.
Joey's mother was horrified by his pet *snake*|*shark* even though it was very small.
The friends were not talking because they had a *fight*|*brawl* last semester.
Jenny left her jacket at work and had to return to the *office*|*locker* to pick it up.
We watched the opening night performance at the *theater*|*circus* last night with friends.
The sailor stopped at the deserted *island*|*casino* for a week.
The camera crew finished filming the *movie*|*diver* only after twelve grueling hours.
While away at war, Fred mailed his mother a *letter*|*compass* from China.
He planned to refinish the hardwood *floor*|*shelf* before the holidays.
After cleaning her teeth, Dr. Sam wiped Mary's *mouth*|*cheek* and gave her a toothbrush.

Conditions: Low-frequency predictable (LFP) or high-frequency unpredictable (HFUP)

To prevent a mess, the caregiver checked the baby's *diaper*|*bottle* before leaving.
In the desert, many Arabs ride a *camel*|*horse* to get around.
Bugs Bunny eats lots of *carrots*|*potatoes* to stay healthy.
John stirred the hot soup with the broken *spoon*|*plate* until it was ready to eat.
Bob folded his clean clothes on the warm *dryer*|*floor* before putting everything away.
After writing down her secret thoughts, Sally hides her *diary*|*story* in the closet.
The traditional Eskimo family lived in the *igloo*|*house* built from snow and ice.
The man was in dangerous waters when attacked by the *shark*|*snake* that almost killed him.
John got involved in a bar room *brawl*|*fight* one week ago.
Ed kept gym clothes in his *locker*|*office* because he found it convenient.
We love to watch the clowns at the *circus*|*theater* every summer.
The gambler visited the *casino*|*island* as part of his vacation.
After exploring an underwater cave, the *diver*|*movie* changed direction to examine the coral.
The lost hiker carefully checked his *compass*|*letter* to figure out where he was going.
The librarian returned the books to the appropriate *shelf*|*floor* before leaving for lunch.
She kissed her old friend on the *cheek*|*mouth* when they met again.