The role of eye movement pattern and global-local information processing abilities in isolated English word reading

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Abstract

In isolated word reading, readers have the best performance when fixating between the beginning and center of a word, i.e., the optimal viewing position (OVP). Also, perceptual expertise literature suggests that both global and local processing are important for visual stimulus recognition. Here we showed that in lexical decision, higher similarity to an eye movement pattern that focused at the OVP and better local processing ability predicted faster response time (RT), in addition to verbal working memory and lexical knowledge. Also, this eye movement pattern was associated with longer RT in naming isolated single letters, suggesting conflicting visual abilities required for identifying isolated letters and letter strings. In contrast, word and pseudoword naming RT, and lexical decision and naming accuracy, were predicted by lexical knowledge but not eye movement pattern or global-local processing abilities. Thus, visual processing abilities are important factors accounting for isolated word reading fluency not involving naming.

Keywords: Word recognition; word naming; local processing; eye movements; EMHMM

Introduction

In isolated English word reading, including word recognition (lexical decision) and word pronunciation, lexical knowledge is shown to play an important role in reading performance (Saunders & DeFulio, 2007; Verhagen et al., 2010). Cognitive abilities such as working memory and inhibition are also associated with word reading skills (Knoop-van Campen et al., 2018; Andrews & Lo, 2012). In particular, the ability to rapidly identify an isolated single symbol as measured in the rapid automatized naming (RAN) task, is shown to predict both word and pseudoword reading fluency (Kim et al., 2015; Savage et al., 2018).

In addition to isolated single symbol identification, the ability to efficiently perceive the whole or to selectively attend to a component may be important for recognizing multi-letter words. Indeed, the literature on perceptual expertise has suggested that both global and local information processing are important for the recognition of visual stimuli. For example, although faces are shown to be perceived holistically, recent research has shown that local featural information is also important for face recognition (Cabeza & Kato, 2000; Chuk et al., 2017). Similarly, the development of expertise in Chinese character recognition involves an initial increase in holistic perception, followed by enhanced ability to selectively attend to local components through writing practice (Tso et al., 2014; see also Liu et al., 2016; cf. Hsiao et al., 2021), and reading difficulties in Chinese are associated with impaired ability to selectively attend to local components (Tso et al., 2020). In English word naming, Franceschini et al. (2020) found that global and local perceptual primes led to differential modulation effects on the performance of naming words with irregular and regular letter-sound mappings, which involve phonological access to the lexical and sublexical reading route respectively. This result suggests that global-local perceptual processing abilities may play an important role in isolated English word reading.

Eye movements may also play an important role in isolated word reading. In particular, the optimal viewing position (OVP) phenomenon has been consistently observed in skilled readers, where performance in word naming, lexical decision, or perceptual identification was the best when participants fixated between the beginning and the middle of the words (Brysbaert & Nazir, 2005). Factors that account for this phenomenon include (1) visual acuity drop from center to periphery; (2) information structure of English words, where word beginnings are more informative for identification than word endings (e.g., Chan & Hsiao, 2016; cf. Hsiao & Cheng, 2013; Hsiao & Cheung, 2016); (3) perceptual learning and reading direction, i.e., the enhancement of discrimination sensitivity of a word at the right visual field due to the left-to-right reading direction (Nazir & O'Regan, 1990; Hsiao, 2011; Chung et al., 2017); and (4) a left visual field/right hemisphere advantage in language processing (Hsiao & Lam, 2013; Lam & Hsiao, 2014; cf. Hsiao & Liu, 2012). Consequently, the best word recognition performance can be obtained when the initial fixation is directed to the location that the reader fixates the most often during reading (Brysbaert & Nazir, 2005). Thus, the OVP phenomenon may reflect the development of reading skills through reading experience. Indeed, adult readers are found to have more consistent refixation behavior when reading long words than children (Joseph et al., 2009). This finding suggests that eye fixation behavior reflects word reading expertise, and thus may potentially predict word reading performance. More specifically, individuals who can more accurately fixate at the OVP during word reading may have better recognition performance.

Here we used a novel, machine learning based method, Eye Movement analysis with Hidden Markov Models (EMHMM, Chuk et al., 2014), to provide quantitative measures of individual eye movement patterns in word reading. In EMHMM, each individual' eye movements in a task were summarized using a hidden Markov model (HMM), including person-specific regions of interest (ROIs) and transition probabilities among these ROIs. Individual HMMs can be clustered to discover representative patterns, and similarities among individual patterns can be quantified using data log-likelihoods of the HMMs. Thus, it can help us identify representative eye fixation patterns among readers using a data driven approach and quantify individual differences accordingly. Here we focused on lexical decision, word naming, and pseudoword naming tasks. We hypothesized that better global/local information processing abilities and more focused eye fixation behavior toward the OVP predict better reading performance, in addition to lexical knowledge and potential cognitive ability factors, including working memory, selective attention, and isolated simple symbol identification ability as assessed in RAN. We recruited English as a second language (ESL) learners to ensure sufficient variance in performance for the examination.

Methods

Participants

Participants were 128 ESL learners whose native language was Chinese (38 males). Their ages ranged from 18 to 30 (M = 21.7, SD = 3.03). They had similar college education backgrounds. According to a power analysis, a sample size of 92 was needed for a medium effect size (f^2 = .15) in a linear multiple regression with 5 tested predictors and 14 predictors in total (β = .15; α = .05).

Materials & Tasks

Reading tasks

Lexical decision Stimuli were from the Lexical Test for Advanced Learners of English (LexTALE; Lemhцfer, & Broersma, 2012), designed to assess English proficiency as a second language. Participants judged whether the presented word was a real English word or not.

Word naming Stimuli were selected from Letter-Word Identification of Woodcock-Johnson III Tests of Achievement (Woodcock et al., 2001). Participants were asked to read out the presented word.

Pseudoword naming Stimuli were selected from Word Attack of the Woodcock-Johnson III Tests of Achievement (Woodcock et al., 2001). Participants were asked to pronounce the presented pseudoword.

In all tasks, each trial started with a central solid circle for drift correction. The stimulus was presented at the center of one of the 4 quadrants on the screen until response. Accuracy, RT, and eye movements were recorded. Stimuli were presented in black with a white background with a resolution of 1024 x 768, under a viewing distance of 51cm. An EyeLink 1000 eye tracker (SR Research Ltd., Canada) was used. A chinrest was used to reduce head movement. Recalibration was performed when the gaze position error was larger than 1° visual angle. EyeLink default settings for cognitive research were used in data acquisition. EMHMM was used to analyze eye movement data.

Cognitive Ability Tests

Navon task for global/local attention Participants were presented with a hierarchical letter pattern (Figure 1): a larger letter consisted of smaller letters. They judged whether a target letter was presented regardless of whether it was at the global or local level (Navon, 1977). We measured the accuracy and RT of the trials where there was a target letter at the global and local level separately as the measure of global and local information processing ability respectively.

Rapid Automatized Naming (RAN) for isolated simple symbol identification Participants were presented with a single letter and asked to name it as fast as possible (Denckla, & Rudel, 1974; Siddaiah et al., 2014).

Verbal & visuospatial 2-back for working memory In verbal 2-back, participants judged whether the presented number was the same as the number presented 2 trials back. In visuospatial 2-back task, they judged whether the stimulus was at the same location as the one presented 2 trials back (Lau et al., 2010).

Eriksen flanker task for selective attention It measures the ability to attend to a target while suppressing surrounding incongruent information (Ridderinkhof et al., 1999). Participants judged the direction of an arrow flanked by 2 arrows each on the left and right. The flanking arrow direction may be congruent or incongruent with the target arrow. Flanker effect on accuracy and RT was measured as (Congruent – Incongruent)/(congruent + incongruent).

Accuracy and RT were measured for all tests.

Design & Procedure

We used stepwise multiple regression to examine best predictors for accuracy and RT in reading tasks, including lexical knowledge, eye movement, and cognitive ability measures. For lexical decision, the accuracy of word naming and pseudoword naming were used as lexical knowledge factors. In word and pseudoword naming, the accuracy of lexical decision was used as a lexical knowledge factor. Participants started with lexical decision, followed by word naming and pseudoword naming. Afterwards, they performed the cognitive tests in the following order: Navon task, RAN, verbal and visuospatial 2-back, and Flanker task.

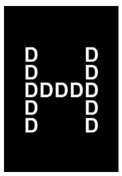


Figure 1: Example for a Navon stimulus.

Eye Movement Data Analysis

In EMHMM, parameters of an HMM were estimated from eye movement data using the Variational Bayesian Expectation Maximization (VBEM) algorithm (Bishop, 2006). When training individual HMMs, we set the range of possible number of ROIs to be 1 to 15. EMHMM uses a variational Bayesian approach to determine the optimal number of ROIs from this preset range for each model. Each model with a different preset number of ROIs was trained for 300 times, and the model with the highest data log-likelihood was used. Then, following previous studies (Chuk et al., 2014), we clustered all individual HMMs in each task to reveal 2 representative patterns, pattern A and pattern B, through the variational hierarchical expectation maximization (VHEM) algorithm (Coviello et al., 2014). The optimal number of ROIs for creating the 2 representative HMMs was decided by the Bayesian method. The clustering algorithm was run for 300 times, and the result with the highest data log-likelihood was used. To quantify an individual' eye movement pattern along the pattern A-pattern B dimension, following previous studies (Chan et al., 2018; Zhang et al., 2019), we defined A-B scale as (A – B)/(|A| + |B|), where A refers to the data log-likelihood given pattern A HMM, and B for that given pattern B HMM. A more positive value indicated higher similarity to pattern A.

Results

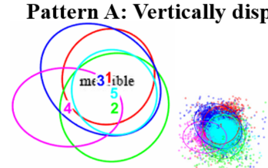
Lexical Decision

Figure 2 shows the two representative eye movement patterns. In Pattern A (vertically dispersed), participants mainly looked at the center of the word (ROI4 captured outlier fixations), with the ROIs vertically dispersed. In Pattern B (vertically focused), the ROIs centered at the typical location of the OVP for skilled readers (between the word beginning and center). Following the method used in Chuk et al. (2014), the two patterns significantly differed, as data from participants adopting Pattern A were more likely to be generated by Pattern A HMM than Pattern B HMM, and vice versa, $F(1, 126) = 20.1$, $p < .001$. Participants using the two patterns did not differ in average number of fixations per trial (4.842). Table 1 shows correlations between lexical decision performance, eye movement pattern, and cognitive abilities.

The average accuracy was .749 (SD = .104). Stepwise multiple regression predicting lexical decision accuracy using A-B scale, word and pseudoword naming accuracy, and performances in the cognitive ability tests showed that verbal 2-back RT, $\beta = .0000554$, $p = .034$, word naming accuracy, $\beta = .259$, $p < .001$, and pseudoword naming accuracy, $\beta = .143$, $p = .005$, were the best predictors, with $R^2 = .473$, F(3, 124) = 36.130, $p < .001$. Thus, lexical decision accuracy was best predicted by working memory and lexical knowledge.

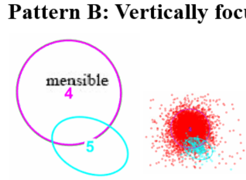
The average RT was 1431 ms (SD = 425 ms). Stepwise multiple regression predicting lexical decision RT using A-B scale, word and pseudoword naming accuracy, and performances in the cognitive ability tests showed that A-B scale, $\beta = 4284.122$, $p = .018$, and Navon task local trial RT were significant predictors, $\beta = .853$, $p < .001$, in addition to word naming accuracy, $\beta = -450.971$, $p = .010$, and visuospatial 2-back accuracy, $\beta = 956.363$, $p = .002$, with $R^2 = .332$, F(4, 124) = 14.881, $p < .001$. Shorter lexical decision RT was associated with higher similarity to eye movement Pattern B and faster local processing time in addition to better lexical knowledge and working memory.

Pattern A: Vertically dispersed



	To Red	To Green	To Blue	To Pink	To Cyan
Prior	.37	.14	.18	.02	.29
To Red	1.0	.00	.00	.00	.00
To Green	.00	.94	.03	.01	.02
To Blue	.00	.01	.97	.01	.00
To Pink	.00	.10	.11	.79	.00
To Cyan	.00	.00	.00	.00	.99

Pattern B: Vertically focused



	To Red	To Green	To Blue	To Pink	To Cyan
Prior	.34	.29	.18	.18	.01
To Red	.36	.23	.22	.18	.00
To Green	.28	.30	.22	.20	.00
To Blue	.28	.24	.26	.22	.00
To Pink	.25	.23	.24	.27	.00
To Cyan	.09	.02	.02	.02	.84

Figure 2: Two representative eye movement patterns in lexical decision. Ellipses show ROIs as 2-D Gaussian emissions. Table on the right shows transition probabilities among the ROIs. Priors show the probabilities that a fixation sequence starts from the ellipse. Small image shows ROI assignment of fixations.

We then performed a follow-up analysis to examine what cognitive abilities best predicted A-B scale (using the performances in the cognitive ability tests). A-B scale was correlated with Flanker effect in accuracy, r(126) = .178, p = .045, RAN RT, r(126) = -.264, p = .003, and Navon global trial RT, r(126) = .185, p = .04. Stepwise multiple regression showed that RAN RT was the only significant predictor, β = -.00002354, p = .004, with R^2 = .067, F(1, 123) = 8.835, p = .004. This suggested that longer RAN RT was associated with Pattern B.

Table 1: Correlations between lexical decision performance, eye movement pattern and cognitive abilities (* p < .05; ** p < .01).

	Lexical decision accuracy	Lexical decision RT
A-B scale	.004	.284**
Word naming accuracy	.646**	-.239**
Pseudoword naming accuracy	.571**	-.211**
Verbal 2-back accuracy	.07	.108
Verbal 2-back RT	.199*	.14
Visuospatial 2-back accuracy	.057	.101
Visuospatial 2-back RT	.179*	.13
Flanker normalized accuracy	.046	.213*
Flanker normalized RT	-.093	.055
Navon global trial accuracy	.051	.152
Navon global trial RT	.044	.088
Navon local trial accuracy	.003	.21*
Navon local trial RT	.108	.428**
RAN accuracy	-.015	-.012
RAN RT	-.12	-.147

Word Naming

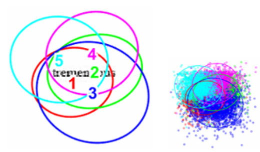
Figure 3 shows the two representative eye movement patterns. Both patterns showed vertical ROI dispersion, with the ROIs in Pattern A more horizontally dispersed than those in Pattern B. The two patterns significantly differed, as data from participants adopting Pattern A were more likely to be generated by Pattern A HMM than Pattern B HMM, and vice versa, F(1, 126) = 10.1, p = .002. The average number of fixations per trial (12.344) did not differ between the two patterns. Table 2 shows correlations between word naming performance, eye movement pattern and cognitive abilities.

The average accuracy of word naming was .760 (SD = .187). Stepwise multiple regression predicting word naming accuracy using A-B scale, lexical decision accuracy, and performances in the cognitive ability tests showed that lexical decision accuracy, β = 1.171, p < .001, and Flanker effect in accuracy were the best predictors, β = -.839, p = .045, with R^2 = .437, F(2, 122) = 47.354, p < .001. Thus, it was best predicted by lexical knowledge and selective attention.

The average RT of word naming was 1957 ms (SD = 833 ms). Stepwise multiple regression predicting word naming RT using A-B scale, lexical decision accuracy, and performances in the cognitive ability tests showed that lexical decision accuracy, β = -1992.205, p = .005, was the only predictor, with R^2 = .062, F(1, 126) = 8.286, p = .005, suggesting that word naming RT was uniquely predicted by lexical knowledge.

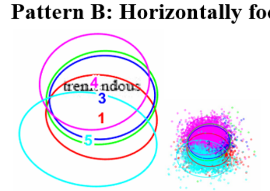
A follow-up stepwise multiple regression predicting A-B scale using performances in the cognitive ability tests showed no predictor for A-B scale.

Pattern A: Horizontally dispersed



	To Red	To Green	To Blue	To Pink	To Cyan
Prior	.29	.24	.27	.11	.09
To Red	.97	.01	.01	.01	.00
To Green	.01	.96	.02	.00	.00
To Blue	.01	.02	.95	.01	.01
To Pink	.02	.01	.03	.91	.02
To Cyan	.01	.01	.02	.03	.92

Pattern B: Horizontally focused



	To Red	To Green	To Blue	To Pink	To Cyan
Prior	.30	.25	.12	.28	.05
To Red	.96	.02	.00	.00	.01
To Green	.04	.35	.58	.01	.01
To Blue	.02	.11	.86	.01	.00
To Pink	.00	.02	.01	.96	.01
To Cyan	.03	.00	.00	.03	.94

Figure 3: Two representative eye movement patterns in word naming.

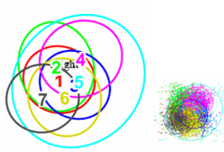
Table 2: Correlation between word naming performance, eye movement pattern and cognitive abilities (* p < .05; ** p < .01).

	Word naming accuracy	Word naming RT
A-B scale	-.029	-.011
Lexical decision accuracy	.646**	-.248**
Verbal 2-back accuracy	-.024	.112
Verbal 2-back RT	.092	.002
Visuospatial 2-back accuracy	-.066	.109
Visuospatial 2-back RT	.148	.116
Flanker normalized accuracy	-.108	.135
Flanker normalized RT	-.047	-.086
Navon global trial accuracy	.017	.049
Navon global trial RT	.025	.035
Navon local trial accuracy	-.029	.054
Navon local trial RT	-.004	.031
RAN accuracy	-.063	-.032
RAN RT	-.132	.012

Pseudoword Naming

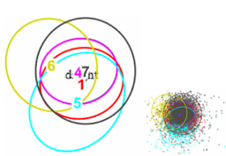
Figure 4 shows the two representative eye movement patterns. Similar to word naming, both patterns showed vertical ROI dispersion, with the ROIs in Pattern A more horizontally dispersed than those in Pattern B. The two patterns significantly differed, as the data from participants adopting Pattern A were more likely to be generated by Pattern A HMM than Pattern B HMM, and vice versa, $F(1, 126) = 6.17$, $p = .014$. The average number of fixations per trial (9.477) did not differ between the two patterns. Table 3 shows the correlations between pseudoword naming performance, eye movement patterns and cognitive abilities.

Pattern A: Horizontally dispersed



	To Red	To Green	To Blue	To Pink	To Cyan	To Yellow	To Brown
Prior	.35	.17	.17	.10	.03	.13	.05
To Red	.97	.01	.00	.00	.00	.01	.00
To Green	.06	.92	.01	.00	.00	.00	.01
To Blue	.00	.01	.97	.01	.00	.00	.00
To Pink	.00	.00	.02	.96	.02	.00	.00
To Cyan	.00	.04	.00	.03	.90	.02	.01
To Yellow	.02	.01	.01	.00	.00	.96	.00
To Brown	.00	.03	.01	.00	.01	.00	.95

Pattern B: Horizontally focused



	To Red	To Green	To Blue	To Pink	To Cyan	To Yellow	To Brown
Prior	.33	.13	.13	.06	.08	.05	.22
To Red	.98	.01	.00	.00	.01	.00	.00
To Green	.02	.42	.41	.14	.00	.00	.00
To Blue	.01	.13	.47	.37	.00	.00	.00
To Pink	.01	.05	.34	.60	.00	.00	.00
To Cyan	.08	.01	.00	.00	.87	.02	.02
To Yellow	.00	.00	.00	.00	.02	.94	.04
To Brown	.00	.00	.00	.00	.01	.01	.98

Figure 4: Two representative eye movement patterns in pseudoword naming.

Table 3: The correlation between pseudoword naming performance, eye movement patterns and cognitive abilities (* p < .05; ** p < .01).

	Pseudoword naming accuracy	Pseudoword naming RT
A-B scale	-.007	-.057
Lexical decision accuracy	.571**	-.189**
Verbal 2-back accuracy	.057	.153
Verbal 2-back RT	.056	-.104
Visuospatial 2-back accuracy	.015	.108
Visuospatial 2-back RT	.137	-.048
Flanker normalized accuracy	-.077	.207*
Flanker normalized RT	-.053	-.09
Navon global trial accuracy	-.011	-.042
Navon global trial RT	.063	.057
Navon local trial accuracy	-.09	.004
Navon local trial RT	-.074	.099
RAN accuracy	-.137	-.11
RAN RT	.012	-.032

The average accuracy of pseudoword naming task was .892 (SD = .183). Stepwise multiple regression predicting pseudoword naming accuracy using A-B scale, lexical decision accuracy, and performances in the cognitive ability tests showed lexical decision accuracy, $\beta = 1.005$, $p < .001$, was the only predictor with $R^2 = .326$, F(1, 126) = 60.940, $p < .001$. The average RT of pseudoword naming task was 2070 ms (SD = 769 ms). Stepwise multiple regression predicting pseudoword naming RT using A-B scale, lexical decision accuracy, and performances in the cognitive ability tests showed that lexical decision accuracy, $\beta = -1567.307$, $p = .015$, Flanker effect in accuracy, $\beta = 5662.997$, $p = .010$, and verbal 2-back accuracy were the best predictors, $\beta = 1512.543$, $p = .039$, with $R^2 = .114$, F(3, 121) = 5.201, $p = .002$. Thus, pseudoword naming RT was best predicted by lexical knowledge, selective attention and working memory.

A follow-up multiple regression predicting A-B scale using performances in the cognitive ability tests showed that Navon task local trial accuracy was the only predictor, $\beta = .042$, $p = .014$, with $R^2 = .047$, F(1, 126) = 6.272, $p = .014$. More horizontally dispersed eye fixation behavior (Pattern A) in pseudoword naming was associated with better local processing ability.

Discussion

Here we tested the hypothesis that global/local information processing abilities and eye movement pattern predict performance in isolated word reading, including lexical decision, word naming, and pseudoword naming, in addition to lexical knowledge and general cognitive abilities. We found that across the 3 tasks, reading accuracy could not be predicted by eye movement pattern or global/local processing abilities. In contrast, lexical knowledge was a unique common predictor for accuracy in all 3 tasks. This result suggests that isolated word reading accuracy mainly depends readers' lexical knowledge. Additionally, lexical decision accuracy was predicted by verbal working memory, whereas word naming accuracy was predicted by selective attention ability. Thus, verbal working memory and the ability to inhibit conflicting surrounding information may also play an important role.

In contrast to reading accuracy, shorter lexical decision RT was predicted by higher eye movement similarity to an eye movement pattern that focused at the area between the beginning and center of a word, which has been shown to be the OVP for word recognition (Brysbaert, & Nazir, 2005). Good local processing ability accounted for additional variance, in addition to working memory and lexical knowledge. These results were consistent with our hypothesis that eye fixation behavior focusing more on the OVP and better local processing ability predict better isolated word reading performance. Indeed, in visual word recognition, word processing time is shown to increase when the initial fixation deviates from the OVP (Liu & Li, 2013). Our finding further suggests that in lexical decision, individuals can differ in their ability to accurately fixate at the OVP, which in turn accounts for individual differences in RT. In addition to eye fixation behavior, local processing but not global processing ability predicted faster RT. The literature on Chinese character recognition expertise has reported an inverted-U trend in perceptual representation development: an increase in holistic processing due to initial visual experience, followed by enhanced sensitivity to local components as a result of writing experience. In particular, Tso et al. (2014) showed that Chinese readers with limited writing experience perceived Chinese characters more holistically and had longer character recognition RT than those who could proficiently read and write Chinese characters. Together these findings suggest that while beginning readers may have developed whole-word perceptual representations from early visual experience, the sensitivity to local components develops later, and thus may reflect word reading expertise and predict individual difference in performance (RT) among ESL learners.

Interestingly, higher similarity to the eye movement pattern focused at the OVP in lexical decision was uniquely predicted by longer RAN RT. This result suggested that the ability to accurately fixate at the OVP for lexical decision may be in conflict with the ability to rapidly identify an isolated familiar symbol. Identifying a multi-letter word may require simultaneously attending to multiple features that distinguish the presented word from its competing orthographic neighbors, in contrast to attending to a single isolated familiar symbol. Consistent with this speculation, local processing ability, but not RAN, predicted lexical decision RT.

In contrast to lexical decision, eye movement pattern or global-local processing abilities did not predict word or pseudoword naming RT. The discovered representative eye movement patterns were both dispersed and did not show concentration at the typical OVP. A common predictor for word and pseudoword naming RT was lexical knowledge. Without the facilitation from word semantic information, pseudoword naming RT additionally depended on selective attention and verbal working memory, suggesting the requirement of identifying and remembering individual letters and sounds. These results showed that naming RT in general does not depend on visual processing abilities as much as lexical decision. Franceschini et al. (2020) showed that local and global perceptual primes modulated RT in naming words with regular and irregular pronunciations differentially. Thus, in a separate analysis, we examined the predictors for naming RTs of regular and irregular words separately, and found that global-local processing abilities did not predict either of them. Thus, while perceptual priming effects may modulate word naming efficiency, individual differences in global-local processing abilities did not significantly predict variance in word naming RT. This phenomenon may be related to the involvement of phonological processing abilities. Future work will examine this possibility.

In conclusion, here we showed that in isolated word reading, an eye movement pattern that focused at the OVP and better local information processing ability predicted faster lexical decision RT, in addition to verbal working memory capacity and lexical knowledge. In addition, we observed an association between a more OVP-focused eye movement pattern and longer RAN RT. This result suggested conflicting visual processing abilities required for identifying isolated letters and letter strings. In contrast, word and pseudoword naming RT, and lexical decision and naming accuracy, were better predicted by lexical knowledge but not eye movement pattern or global-local information processing abilities. Thus, visual processing abilities may be an important factor to consider in isolated word reading fluency that does not involve naming. This finding has important implications for ways to facilitate reading ability development.

Acknowledgments

This research was supported by Seed Fund for Basic Research from University of Hong Kong (#201711159109 to Hsiao). We thank Dr. Kathy Shum for her help and suggestions during the project.

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