Use of the Visagraph II to Evaluate Eye Movements During Reading of Japanese Text

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Abstract

Background: *The Visagraph II is used to evaluate eye movements made while a subject silently reads one or more standardized paragraphs. The Visagraph II is not currently available for use with Japanese text. This study was designed to: 1) determine the reliability and repeatability of data obtained while native Japanese readers read texts written in Japanese; 2) identify and quantify eye movements made by our subjects when reading exclusively Kana text versus mixed Kanji/Kana text; 3) compare the eye-movement characteristics of native Japanese subjects reading texts translated into Japanese to published normative data from subjects reading text in English.*

Methods: *Twenty four Japanese foreign students in the United States, who had at least graduated from high school in Japan and currently attended American schools (mainly colleges and English as a Second Language programs), served as subjects. None had ever been diagnosed as reading disabled or dyslexic. Reading material consisted of three Level 1 and three Level 10 paragraphs translated into Japanese by a professional translator.*

Results: *ANOVA comparisons did not show significant differences between paragraphs. There were more fixations, a shorter span of recognition, longer duration of fixation, and slower reading rate when reading mixed Kanji/Kana texts compared to exclusive Kana. There were more fixations and regressions, longer duration of fixation, and shorter span of recognition with Japanese than English.*

Conclusions: *The Visagraph II can be used for Japanese readers to evaluate reading performance in Japanese even though some adjustments might be needed. There are differences in eye movements between reading exclusive Kana text versus mixed Kanji/Kana text as well as between English and Japanese text.*

Key Words

dyslexia, eye movement, Japanese, reading, Visagraph

The Visagraph II is an eye movement monitoring device made by Taylor Associates.[a] It uses infrared emitters and detectors mounted in safety-type goggles to determine eye position. It senses the differential infrared reflections from the cornea, sclera, and other anterior ocular surfaces.[1] Analog information about eye position is converted to digital values and are transferred to a computer that analyzes the data to determine when certain types of eye movements occur.

The Visagraph II is used to evaluate eye movements made while a subject silently reads one or more standard paragraphs. These paragraphs provide content appropriate for readers ranging from primary to adult/college. The recording is turned into an idealized representation with stable fixations and abrupt saccadic movements that are counted by the software. The accuracy of the idealized trace represents actual eye movements, as opposed to electrical noise, eye blinks, etc. and sets limits on the accuracy of numeric data provided by the Visagraph II. These numeric data include the number of fixations made per 100 words, the number of right-to-left regression eye movements, and reading speed in words per minute. The system also calculates several derived values, including the equivalent grade level of the subject's reading eye movements based on normative data collected by Taylor and colleagues (Table 1).[2]

Currently, the Visagraph II is not available for Japanese even though reading difficulties have been documented and eye movement recording during reading could be important to making the diagnosis. No attempt to use the instrument for Japanese text has been reported and no booklet or normative data is commercially available in Japanese.

Reading difficulties can be caused by a number of problems, including those associated with eye movement control.[3-13] With a cross-over research design, Solan reported that eye movement therapy improved eye movements measured by Visagraph II and also resulted in significant gains in reading comprehension.[14] Reading comprehension therapy likewise produced improvement both in eye movement efficiency and in reading comprehension. The results support the notion of a cognitive link between eye movement efficiency and reading comprehension. Interestingly, Solan's study also

Table 1: Names, abbreviations, and definitions of data produced by the Visagraph II

Name and abbreviation	Measurement or calculation
Fixations (FIX)	Number of eye pauses per 100 words read.
Regressions (REG)	Number of significant right-to-left eye movements (excluding return sweeps) per 100 words read.
Span of recognition (SPAN)	Number of words read divided by the number of fixations made.
Duration of fixation (DUR)	Total reading time (in seconds) divided by number of fixations made.
Reading rate with comprehension (RATE)	Reading rate (in words per minute) determined for all lines in the paragraph, excluding the first and last.
Grade level efficiency (GRADE)	An equivalent academic grade (reading from 1 to 18) determined by converting the recorded data to a grade level equivalent using norms provided by Taylor. This is a nonlinear conversion.

demonstrated improvements in reading comprehension secondary to eye movement therapy alone as well as greater improvement when comprehension therapy was followed by eye movement therapy. The ability to accurately and objectively monitor eye movements during reading can be of significant diagnostic value when evaluating native English readers.

We believe this same type of reading eye movement information would be valuable in patients with reading problems in other languages as well. If the Visagraph II provides reliable and repeatable data while native Japanese readers read paragraphs written in Japanese, the diagnostic results could in turn contribute to more effective remedial approaches. A special challenge is the difference between Japanese and English in grammar, syntax, symbols, reading direction/orientation, information density of a character, different learning process/development, and complicity of decoding/encoding. There are many factors that have not yet been clarified in terms of the correlation between eye movement skills and reading comprehension. It is hoped that this study can be the first step toward this clarification.

Introduction to Japanese

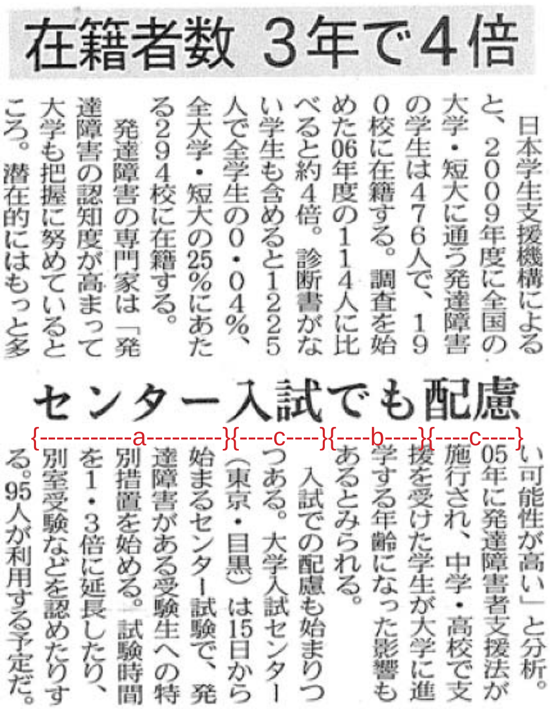
Unlike English, the Japanese language is composed mainly of two kinds of characters: Kanji and Kana. Kanji are logographic or symbolic characters developed from pictures used by the Chinese several thousand years ago to represent the world around them. Each Kanji has a meaning by itself. Kanji also can be combined in Kanji to form new meanings, much as root words, prefixes, and suffixes are combined in English.[15] Approximately 4,500 Kanji are generally used in Japanese newspapers and other printed material. The official list maintained by the Japanese ministry of education contains all the characters that every Japanese student should know. It has been increased to 2136. The ministry of education in Japan requires that 1,006 Kanji are taught by the end of sixth grade in all elementary schools.[16]

In addition to Kanji, Japanese contains phonetic syllabaries called Kana, which can be divided into two subtypes: Hiragana and Katakana. Each syllabary of 46 characters represents the same sounds. The cursive Hiragana is used to write words not normally written in Kanji, for verb endings and parts of speech. The angular Katakana is used for emphasis and to write words and names not of Japanese or Chinese origin. However, it is also possible to write Japanese sentences in Kana characters alone. Exclusive Kana is customarily used in telegrams and for primer text in reading materials for beginning readers. Thus, the initial task of Japanese children is to relate the Kana characters to the syllables of Japanese speech. Kanji characters are gradually assimilated and mastered as students advance to higher grades. Written English requires space between words because of the simplified characters and a highly abstracted code system. Written Japanese doesn't have spaces between the words because the mixture of Kanji and Kana provides good visual guidance without spaces (Figures 1 and 2). In English, the 26 characters of the alphabet are used to describe most things in the world. This limited set of symbols is more easily mastered than the approximately 5000 basic Kanji and 92 Kana (46 Katakana and 46 Hiragana). The evolution of this limited set of phonetic symbols (alphabets) was as significant an advance in literacy as was the introduction of the Arabic decimal system of 10 numbers, which allowed mathematics to flourish. Most formerly logographic (non-phonetic) languages have converted to phonetic alphabets (e.g., Korean and several other languages). However, the Japanese language is unique, because even though it converted logographic (Kanji) to phonetic language (Kana), they still use logographic characters by mixing them with phonetic letters.

English, Spanish, and French are phonetic languages. They all have phonetic spelling irregularities, such as the silent "h" in herb. Japanese Kana is very regular phonetically. Chinese and the Japanese Kanji are the principal examples of a non-phonetic logographic language. A non-phonetic logographic written language has some advantage over phonetically written ones. The reader does not need to know how to speak the language. It has often been reported that the many diverse regions of the Chinese nation have been held together by the common written language even though the many spoken dialects are incomprehensible from one region to another.[17] The Japanese language incorporates both phonetic and logographic features, rendering it efficient, yet difficult to master.

The process of learning to read most likely varies from one language to another. The process of learning to read in English is an amalgamation between recognizing familiar words (eidetic decoding) and using phonic analysis on those words that are insufficiently familiar (phonetic decoding).[18] Because Japanese sentences are written in Kana characters for beginning readers, the initial task of Japanese children is to relate the Kana characters to the syllables of Japanese speech. This is most parallel to phonetic decoding. Later they must learn

Figure 1: Sample from newspaper in Japanese
a: Katakana b: Hiragana c: Kanji



在籍者数 ３年で４倍

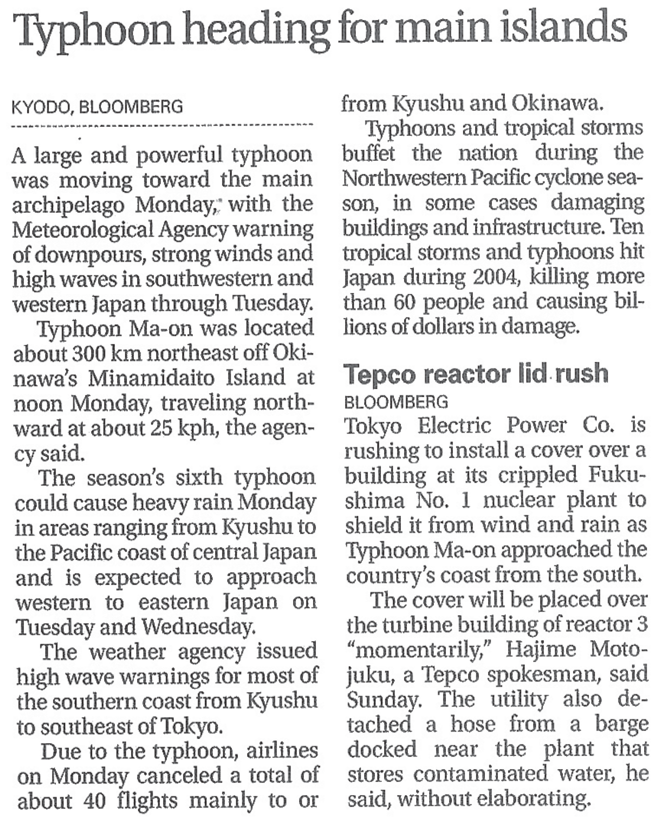
日本学生支援機構によると、２００９年度に全国の大学・短大に通う発達障害の学生は４７６人で、１９０校に在籍する。調査を始めた06年度の１１４人に比べると約４倍。診断書がない学生も含めると１２２５人で全学生の０・０４％、全大学・短大の25％にあたる２９４校に在籍する。

発達障害の専門家は「発達障害の認知度が高まって大学も把握に努めているところ。潜在的にはもっと多い可能性が高い」と分析。05年に発達障害者支援法が施行され、中学・高校で支援を受けた学生が大学に進学する年齢になった影響もあるとみられる。

センター入試でも配慮

入試での配慮も始まりつつある。大学入試センター（東京・目黒）は15日から始まるセンター試験で、発達障害がある受験生への特別措置を始める。試験時間を1・3倍に延長したり、別室受験などを認めたりする。95人が利用する予定だ。

Figure 2: Sample from newspaper in English



Typhoon heading for main islands

KYODO, BLOOMBERG

A large and powerful typhoon was moving toward the main archipelago Monday, with the Meteorological Agency warning of downpours, strong winds and high waves in southwestern and western Japan through Tuesday.

Typhoon Ma-on was located about 300 km northeast off Okinawa's Minamidaito Island at noon Monday, traveling northward at about 25 kph, the agency said.

The season's sixth typhoon could cause heavy rain Monday in areas ranging from Kyushu to the Pacific coast of central Japan and is expected to approach western to eastern Japan on Tuesday and Wednesday.

The weather agency issued high wave warnings for most of the southern coast from Kyushu to southeast of Tokyo.

Due to the typhoon, airlines on Monday canceled a total of about 40 flights mainly to or from Kyushu and Okinawa.

Typhoons and tropical storms buffet the nation during the Northwestern Pacific cyclone season, in some cases damaging buildings and infrastructure. Ten tropical storms and typhoons hit Japan during 2004, killing more than 60 people and causing billions of dollars in damage.

Tepco reactor lid rush

BLOOMBERG

Tokyo Electric Power Co. is rushing to install a cover over a building at its crippled Fukushima No. 1 nuclear plant to shield it from wind and rain as Typhoon Ma-on approached the country's coast from the south.

The cover will be placed over the turbine building of reactor 3 "momentarily," Hajime Motojuku, a Tepco spokesman, said Sunday. The utility also detached a hose from a barge docked near the plant that stores contaminated water, he said, without elaborating.

greater amounts of Kanji characters for morphemes and substitute them for Kana syllabic symbols. Once a Kana symbol is replaced with a Kanji character, there is no cue to phonetically decode it. Phonetic and eidetic process apparently take place separately for Kanji and Kana in the ontology of Japanese language processing. These processes are used more in parallel in the development of English language decoding.[5]

A 10-15% probability for reading disability has been documented. The Japanese Ministry of Education, Culture, Sports, Science and Technology reported that the incidence of children who were mentally normal but showed difficulties in reading and writing in elementary and junior high schools was 2.5%.[19] The percentage of dyslexia is uniquely less than one fifth of that reported in most countries. If the percentage is accurate, it is probably related to the Japanese language structure.

To better understand Japanese reading eye movements, it is helpful to review selected investigations from the past. Using infrared reflectometry, Osaka studied the eye movements of native Japanese subjects reading both Kana and Kanji symbols. Osaka's study found a shorter duration of fixation and longer saccade length when reading mixed Kanji/Kana texts than exclusive Kana texts.[20] The mean saccade lengths were 5.2 and 7.8 characters for exclusive Kana and mixed Kanji text. He suggests that Kanji components facilitate processing efficiency due to Kanji's direct lexical access property as compared with Kana. In contrast, in English, it has been reported that 14-16 characters are processed during an average fixation in normal reading. The range of perceptual span (effective visual field size) for skilled readers of English, extends 3-4 character spaces to the left of fixation and about 15-16 character spaces to right of fixation.[21] In contrast, the perceptual span among readers of Japanese is 5.5 characters.[20] Even though these studies cannot be compared directly because the methods of measurement varied, for the Japanese writing system, the span of recognition is considerably smaller than that for English if one equates a Japanese character with a letter.[22]

Project Goals

The current study was designed to: 1) determine the reliability and repeatability of data obtained while native Japanese readers read texts written in Japanese; 2) identify and quantify eye movements made by our subjects when reading exclusively Kana text versus mixed Kanji/Kana text; 3) compare the eye-movement characteristics of native Japanese subjects reading texts translated into Japanese to published normative data from U.S. subjects reading text in English.

Subjects

Twenty-four Japanese foreign students in the U.S., who had graduated from high school in Japan and were currently attending American school (mainly colleges and English as a Second Language programs) served as subjects: 10 were males (mean age, 26.7 years; SD, 6.0) and 14 were females (mean age, 22.0 years; SD, 1.9). None had ever been diagnosed as reading disabled or dyslexic. Each subject demonstrated at least 20/30 near Snellen equivalent at 40 cm (with correction if required) and gave informed consent for participation in this project.

Methods

The procedures used in this study follow those described in the Visagraph II user's manual. After an orientation, the subject was comfortably seated and asked to hold the paragraph text 40 cm from the eyes at an angle of approximately

Figure 3: Exclusive Kana text (half spaces every few words)

あるひ、みほさんは へやの まどを あけました。みどりの とりが まどに とまっていました。その とりは みほさんの てのうえに とびのりました。おかあさんは「きっと だれかのペットね」といいました。みほさんは「いえを さがしてあげなきゃ」といいました。よにんの こどもが そのとりを みにきました。でも、そのとりは そのこどもたちの みどりの とりでは ありませんでした。みほさんは「とりさん うちに おいてあげてもいい？」とききました。おかあさんは「いいわよ、とりかごをかわなきゃね」といいました。

Figure 4: Mixed Kanji/Kana text (no extra spaces between Kana/Kanji

フランス人のルイ・ブレイユは、盲目の教師でした。三歳の時、事故がもとで視力を失ったのです。ブレイユはパリにある盲人のための学校に通い、十九歳の時にそこの講師になりました。当時、視力を失った人たちに読みを教えるのに彫って浮き上がらせた文字が使われていましたが、ブレイユはより簡単な方法を工夫しました。フランス軍の将校によって考案された点字による読み書きのシステムを改良したのです。ブレイユのアルファベットは六つの点のいろいろな組み合わせから成り立っています。このシステムは文学と同様、音楽にも取り入れられました。ブレイユは１８２９年にはじめてこの点字を発表しましたが、あまりにも急進的だったため、反発を招きました。彼の点字が広く認められるようになったのはブレイユの死後のことでした。

30 degrees down from vertical. Goggles were placed over the subject's near correction (when indicated) and adjusted for interpupillary distance by centering the pupils through the apertures as the subject viewed a near target.

Reading material consisted of three Level 1 and three Level 10 paragraphs translated into Japanese by a professional translator. Level 1 and Level 10 paragraphs were chosen because we wanted to demonstrate the repeatability of Visagraph II results with the easiest and most difficult level of texts, and compare mixed Kanji/Kana text to exclusive Kana text. Japanese primary level text equivalent to Level 1 paragraphs is exclusively composed with Kana characters. In contrast, Japanese college level text equivalent to a Level 10 paragraph is composed of both Kanji and Kana text. The other reason we chose Level 1 and Level 10 paragraphs is that it is easier to translate because we did not have to consider how much Kanji we should include for the paragraph. Text number 3 (Green Bird), 4 (Little Rabbit), and 5 (Yellow Ducks) were chosen from Level 1 paragraphs and used for all subjects. Text number 89 (Braille), 90 (Roebling), and 93 (Paganini) were also chosen from Level 10 paragraphs and used for all subjects. These six paragraphs were chosen by considering the equal familiarity between Japanese and American students, equal difficulty between Japanese and American students after translation, and avoidance of words difficult to smoothly translate from English to Japanese. These six paragraphs were exactly translated from Taylor paragraphs in the booklet, except for the names of main characters in Level 1 paragraphs. Most native Japanese are not familiar with those particular common American names, which in turn may influence eye movement during reading. American names were changed to common Japanese names for this reason. For example, "Jack" in paragraph 5 was changed to "Tatuya." In addition, a few paragraphs were adjusted by the professional translator in order to make the translated Japanese expressions more natural and readable.

The Level 1 Japanese paragraphs used for this project were each nine lines long, typed with 23-point spaces between lines on white bond paper using 13-point Times font (approximately 20/80 near Snellen equivalent). This made the Japanese paragraphs equal with the original Level 1 paragraphs relative to the number of lines and the height and width of the paragraphs. We added half spaces every few words to promote readability. Even though this modified spacing is not the official grammar rule in Japanese, half spaces for exclusive Kana texts are used as a common convention (mainly for elementary reading). Similarly, the Level 10 Japanese paragraphs were each 12 lines long, typed single-spaced on white bond paper using 12-point Times font (approximately 20/70 near Snellen equivalent). This made the Japanese paragraphs equal with the original Level 10 paragraphs in the same manner as mentioned earlier. No extra spaces were added for Level 10 mixed Kanji/Kana texts to accurately mimic natural mixed Kanji/Kana text. The paragraphs were presented in a random order for each subject (Figures 3 and 4).

Instructions to each subject followed the protocol listed in the Visagraph II manual and Taylor paragraph booklet.[23] Subjects were allowed to read each paragraph silently, with no time limit. After reading the paragraph, the subject answered 10 standard Yes/No comprehension questions (translated to Japanese) concerning the content of the paragraph.

RESULTS

Operation of Visagraph II:

The Visagraph II produced usable analysis for 141 of the 144 trials (24 subjects X six paragraphs/per subject). The three analysis failures were caused by operator error. Data from 21 subjects were therefore used.

1. Reliability of Paragraph-by-Paragraph Data

To assess equivalency of the three translated Level 1 and three translated Level 10 paragraphs, repeated measures analyses of variance (ANOVA) was used to compare Visagraph II data across paragraphs for all 21 subjects. Means, standard deviations, and ANOVA probability values are shown in Tables 2 and 3. ANOVA comparisons did not show significant differences between paragraphs. This indicates that the Visagraph II data is reliable across translated English paragraphs.

2. Differences Between Exclusive Kana and Mixed Kanji/Kana Texts

To demonstrate the differences, the averages of each Visagraph value were calculated for Kana, Mixed Kanji/Kana and all texts (Table 4). This data indicates that more fixations and regressions were made and a shorter span of recognition

Table 2. Mean values, standard deviations, and ANOVA probability values across each category data from Visagraph II of 21 subjects for exclusive Kana texts Level 1

Text #		3	4	5	Overall	ANOVA
FIX	Left	132.28 (40.61)	135.38 (55.38)	122.66 (38.19)	130.48 (44.33)	0.3898
	Right	132.76 (42.02)	136.19 (56.03)	123.71 (39.12)	131.4 (45.62)	0.3940
REG	Left	18.47 (12.80)	19.23 (18.93)	15.14 (11.03)	17.87 (14.38)	0.4561
	Right	20.61 (14.22)	21.61 (20.82)	17.38 (12.96)	20.13 (16.14)	0.5395
SPAN	Left	0.84 (0.33)	0.84 (0.29)	0.90 (0.31)	0.86 (0.3)	0.4217
	Right	0.84 (0.35)	0.84 (0.29)	0.89 (0.31)	0.85 (0.3)	0.4852
DUR	Left	0.259 (0.02)	0.259 (0.03)	0.261 (0.02)	0.260 (0.03)	0.8808
	Right	0.261 (0.02)	0.259 (0.03)	0.261 (0.02)	0.260 (0.03)	0.7508
RATE		195.95 (83.79)	195.23 (71.45)	208.90 (76.26)	195.71 (72.78)	0.4315
GRADE		6.73 (4.74)	7.22 (4.83)	7.69 (4.77)	7.14 (4.65)	0.3976

Table 3. Mean values, standard deviations, and ANOVA probability values across each category data from Visagraph II of 21 subjects for Mixed Kanji/Kana Level 10

Text #		89	90	93	Overall	ANOVA
FIX	Left	110.66 (39.16)	108.23 (37.07)	109.19 (38.11)	109.37 (37.52)	0.7564
	Right	110.47 (39.16)	108.47 (37.50)	109.81 (38.75)	109.59 (37.82)	0.8499
REG	Left	14.14 (12.41)	13.14 (11.79)	13.90 (10.34)	13.73 (11.37)	0.6905
	Right	15.04 (10.87)	14.47 (11.48)	16.14 (11.04)	15.22 (10.98)	0.2279
SPAN	Left	1.02 (0.40)	1.02 (0.32)	1.05 (0.47)	1.03 (0.40)	0.7014
	Right	1.03 (0.40)	1.02 (0.33)	1.04 (0.48)	1.03 (0.4)	0.7771
DUR	Left	0.276 (0.03)	0.272 (0.03)	0.268 (0.02)	0.272 (0.03)	0.5115
	Right	0.275 (0.03)	0.272 (0.03)	0.267 (0.02)	0.271 (0.03)	0.3985
RATE		223.61 (99.51)	222.90 (80.27)	238.47 (125.45)	228.33 (101.99)	0.2003
GRADE		8.84 (4.80)	9.43 (4.35)	8.86 (4.74)	9.05 (4.57)	0.2467

Table 4. Results of eye movement data comparing exclusive Kana versus mixed Kanji/Kana Texts (Raw scores)

	Overall	Exclusive Kana	Mix Kanji/ Kana
FIX Left	121.43	130.48	109.37
FIX Right	122.05	131.4	109.59
REG Left	16.1	17.87	13.73
REG Right	18.03	20.13	15.22
SPAN Left	0.93	0.86	1.03
SPAN Right	0.93	0.85	1.03
DUR Left	0.266	0.260	0.272
DUR Right	0.265	0.260	0.271
RATE	209.69	195.71	228.33
GRADE	7.96	7.14	9.05

Table 5. The ratio (the number of characters in paragraph/translated paragraph)

Text No.	The title of paragraph	Level	Characters		Ratio
			English	Japanese	(E/J)
3	GREEN BIRD	1	193	190	1.02
4	LITTLE RABBIT	1	207	190	1.09
5	YELLOW DUCKS	1	192	190	1.01
89	BRAILLE	10	481	290	1.65
90	ROEBLING	10	510	290	1.75
93	PAGANINI	10	484	292	1.66

occurred when reading exclusive Kana text. Similar duration of fixation was found. A faster reading rate with comprehension when reading mixed Kanji/Kana text was documented. However, because of the ratio between the numbers of characters in original paragraphs in English and translated Japanese paragraphs (Table 5), the data on Table 4 is subject to further analysis.

To adjust the difference between Japanese and English texts for the number of words per paragraph, the averages from Table 4 were converted to calculated scores (Table 6). The data in Table 7 shows the number of words and characters in each paragraph used toward this purpose. We used characters, instead of words, per paragraph for the adjusted data for several reasons. After translation, we realized that the number of characters tended to be the same across the same level of texts. Unlike English, space between words in Japanese is not used. Kanji was used that demonstrates one meaning with one character; therefore, we thought that characters were more important units in Japanese rather than words. Also, in this study, the word “character,” is differentiated from “letter” to commonly describe the alphabet, Kanji, and Kana. “Letter” is used for only the alphabet and Kana, but not Kanji.

The p-values (Table 6) indicate that eye movement characteristics between exclusive Kana and mixed Kanji/Kana are statistically different for all measurements except for regressions. This calculated data indicates that more fixations are needed when reading mixed Kanji/Kana texts. The span of

Table 6. Differences between exclusive Kana and mixed Kanji/Kana Texts Calculated scores and p-value

	Converted value	Exclusive Kana	Mix Kanji/ Kana	p-value
FIX Left	fixation/ 100 characters	34.33(1)	37.71(2)	0.0229
FIX Right	fixation/ 100 characters	34.57	37.78	0.0234
REG Left	regression/100 characters	4.70(3)	4.73(4)	0.8469
REG right	regression/100 characters	5.29	5.24	0.9712
SPAN Left	characters/ fixation	3.26(5)	2.98(6)	0.0330
SPAN Right	characters / fixation	3.23	2.98	0.0442
DUR Left		0.260	0.272	0.0028
DUR Right		0.260	0.271	0.0010
RATE	characters /min	743.69(7)	662.15(8)	0.0143

(1)(Raw score x (50/100)) x (100/190)
(2)(Raw score x (100/100)) x (100/290)
(3)(Raw score x (50/100)) x (100/190)
(4)(Raw score x (100/100)) x (100/290)
(5)Raw score x (190/50)
(6)Raw score x (290/100)
(7)Raw score x (190/50)
(8)Raw score x (290/100)

recognition is shorter but the duration of fixation is longer with mixed Kanji/Kana text. Reading rate with comprehension is faster for reading exclusive Kana texts.

3. The Characteristics of Eye Movement When Reading Japanese Compared to Reading English

To demonstrate the difference in eye movements between reading Japanese and English at the college level, the data from the Taylor National Norms for college level[2] (Table 8) was used for English data and converted to character-based numbers to compare to Japanese data. The adjusted data is shown in Table 9. For this comparison, we used only mixed Kanji/Kana text data because there is no normative data for the Visagraph when college students read low level paragraphs in English. The number of fixations and regressions are much greater, the duration of fixation is longer and span of recognition is shorter in Japanese than in English. Reading rate with comprehension is faster in English than in Japanese.

DISCUSSION

1. Reliability of Paragraph-by-Paragraph Data

The Visagraph II performed properly over a large number of trials and produced data that was reliable and repeatable. It was also possible to assess reading skills of Japanese reading using both exclusive Kana and mixed Kana/Kanji text. This indicates that there is a high possibility of using the Visagraph II for Japanese readers to evaluate reading performance in Japanese. However, we realized that some adjustments might be needed before practically using the Visagraph II for Japanese. First, the scores might need to be character- instead of word-based because no space between words is used in Japanese. This is because Japanese uses a lot of post-positions, which is equivalent to the preposition in English, making the number of words irregular. Second, we should consider the text used for recording eye movement with the Visagraph II. The translated Japanese texts from the Level 1 and Level 10 Taylor booklet were very usable for this project, but for real world application, we have to consider how many and what level of Kanji are used for the texts depending on the grade level. In this project, no Kanji was used for Level 1 and Kanji, commonly used by adults, was used for Level 10. Further research for determining what level of Kanji should be used for the texts in addition to the ratio of Kanji and Kana across same level texts needs to be investigated.

Table 7. The number of words and characters in each text (in 7 lines analyzed for data)

Text No.	The title of paragraph	Level	English		Japanese
			Words	Characters	Characters
3	GREEN BIRD	1	50	193	190
4	LITTLE RABBIT	1	50	207	190
5	YELLOW DUCKS	1	50	192	190
89	BRAILLE	10	100	481	290
90	ROEBLING	10	99	510	290
93	PAGANINI	10	100	484	292

Table 8. Taylor National Norms[2]

	College level
Fixations/100 words	90
Regressions/100 words	15
Span of recognition	1.11
Duration of fixation	0.24
Rate with comprehension (words/min)	280

Table 9. Character-basis calculated Taylor national norms for English and average scores in this study for Japanese (Level 10, college level)

	Japanese	English
Fixations/100 characters	37.75	18(9)
Regressions/100 characters	4.99	3(10)
Span of recognition (characters/fixation)	2.98	5.55(11)
Duration of fixation	0.272	0.24
Rate with comprehension (characters /min)	662.15	1400(12)

2. Differences Between Exclusive Kana and Mixed Kanji/Kana Texts

Osaka's study previously showed shorter fixations and longer saccades when reading mixed Kanji/Kana texts than exclusively Kana texts.[20] In Osaka's study, using an eye-mark recording system (NAC Corporation, type V eye-mark recorder), 7.8 characters of mixed Kanji/Kana text and 5.2 characters of exclusively Kana text were processed in one fixation. Osaka suggests that Kanji components facilitate processing efficiency due to Kanji's direct lexical access property as compared with Kana.[20] In contrast, this study demonstrated longer duration of fixation and shorter saccades with mixed Kanji/Kana texts than found with exclusive Kana texts. Also, reading rate with comprehension is faster for reading exclusive Kana texts probably because of shorter span of recognition or fewer fixations. Regressions are basically the same between the two types of texts. This indicates that the total number of regressions made during reading is about the same, regardless of the level of difficulty or the kind of Japanese characters.

However, there are several factors that can influence the data of this study compared with others. First, we need to consider the difference between mixed Kanji/Kana texts and Kana texts in terms of level of difficulty. We can't directly compare the data because mixed Kanji/Kana text was used in Level 10 (college level) and exclusive Kana text was used in Level 1 (first grade level). The subjects, who are college students, read first grade level contents with exclusive Kana in this project because the main purpose of this project was to demonstrate repeatability and usability of the Visagraph II. Studies have shown that eye movements during reading can be influenced by cognitive processing depending on the level of content.[24] The content of Level 1 paragraphs is much easier than Level 10 paragraphs, which possibly caused the different results in this project from Osaka's study.

Secondly, it is possible that psychological pressure was different between this work and Osaka's. In this study, the subjects were informed that they would have ten comprehensive questions to answer after each reading passage. This might have unconsciously encouraged the subjects to read the passage more carefully during testing, causing a greater duration of fixation, more fixations and regressions, a longer span of recognition, and a slower rate of reading. Other studies probably did not have this control factor so that subjects were psychologically free to read without comprehension concerns. This could possibly explain why this study showed a shorter span of recognition and longer duration of fixation in comparison to Osaka's study. Thirdly, it should be noted that this data was simply converted to a character basis by using general information (i.e., the number of characters, average length of words) rather than actual measurements. Even though the Visagraph II data is shown to be repeatable, the validity of the data on a character basis is questionable in comparison to data from other studies. Even though several factors need to be controlled, the use of Visagraph II with an adjustment for Japanese provides many opportunities to reveal the Japanese reading process.

In spite of the disagreement of the data in this study with Osaka's results, there appear to be differences in eye movements between reading Kana text versus mixed Kanji/Kana text. A study of language impairment in Japanese dyslexia patients showed that these patients have some unique symptomatology, including selective impairment in the use of one of the two kinds of written symbol (Kanji or Kana).[17] This suggests that these symbols are independently processed. If Kanji and Kana were processed in same way, the study results should not show a significant difference.

According to Osaka's dual-processing model, Japanese is a hybrid written language. Access can be gained to the same lexical property in different ways, i.e., through ideograms or through phonograms.[20] As mentioned earlier, Kana are phonetic symbols for syllables, whereas Kanji are essentially non-phonetic symbols, or ideograms, representing lexical morphemes. Kanji characters are more complex patterns that involve relatively higher spatial frequency components and are more iconic in form.[20] Even though Osaka recognized that symptoms in Japanese dyslexia patients are clearly different from the symptoms exhibited by aphasic native speakers of Indo-European languages, there seem to be some common characteristics between Japanese dyslexia and English dyslexia in terms of the dual-processing model (ideogram and phonogram). Previous work has identified two major types of dyslexia in English, dyseidesia and dysphonesia. Dyslexia has been linked to specific cortical locations, principally in the left hemisphere of the brain (for right-handed and most left-handed individuals). These locations appear to be primarily responsible for the two fundamental linguistic-cognitive processes. These processes have been described as (1) phonetic (syllabic) word analysis and (2) eidetic (whole-word) analysis. The dynamics of the two processes become evident in the explanation of how words are decoded based on the neurologic-behavioral model of Griffin and Walton.[18]

The visual configuration of a word, represented by a grouping of letters, is processed through primarily the visual pathway and associated areas. Impulses are then transmitted to the angular gyrus of the left parietal lobe, where a sight-sound match may be made if the word is one with which the patient is sufficiently familiar. If such a match is made within 1-2 seconds, the word is said to have been in the individual's sight-word vocabulary and believe to be processed eidetically. For unfamiliar words, more extensive analysis is required; Wernicke's area mediates the phonetic analysis (word attack). This generally requires more than two seconds because the word must be syllabicated; each syllable is sounded out and then the sounds for each syllable are blended.[25] Based on the neuroanatomic model described, two types of previously identified dyslexia (in English) fit this model, dyseidesia, and dysphonesia.[25-28] Dyseidesia is related to minimal brain dysfunction or differential brain function in the angular gyrus. Individuals with dyseidesia have poor sight-word recognition and rely on time-consuming word-attack skills (phonetic approach) to decode most words. In contrast, individuals with dysphonesia have impairments in phonetic ability to decode unfamiliar words.[25-30] An individual with dysphonesia either knows a word as a part of his or her sight-word lexicon or does not. When presented with an unfamiliar written word, even if it is a phonetically regular word (e.g., stop, kid, back), an individual with dysphonesia may have great difficulty syllabicating, sounding out, and blending the sounds together to decode the word.

It is interesting that the dual-processing reading model for Japanese that Osaka[20] described is remarkably similar to the neurologic-behavioral model for English described by Griffin and Walton.[18] If the neurologic-behavioral model is very similar to the dual-processing model, it is conceivable that the grouping of Kana symbols might be processed eidetically, similar to "sight words" (ideogram or sight-word). If a "Kana word" is sufficiently familiar, it is processed in a similar manner to how Kanji are processed, or in other words, eidetically. Osaka stated that Kana is processed only phonetically.[20] Based upon our understanding of the dual-processing model, Kana could also be processed eidetically as well. It is our belief that Kana symbols are processed primarily phonetically when a "Kana word" is relatively unfamiliar to the individual. Following repeated exposure the Kana symbols are increasingly processed eidetically as a "Kana word" after the individual becomes familiar with it.

Based upon this hypothesis, the subject's familiarity with exclusively Kana needs to considered. Japanese adults don't usually read in Kana only as it is generally for children who have not yet learned Kanji. It is likely that our subjects read the Kana text phonetically. This might have influenced the results of eye movement in this and Osaka's studies.

In summary, there seem to be two kinds of processing for reading regardless of whether in Japanese, English, or possibly other languages: eidetic and phonetic. These two types of processing seem responsible for the variation of eye movements (saccade length, the number of fixation, span of fixation, and duration of fixation) depending on what kind of characters are read (in Japanese) and the familiarity of the word.

3. The Characteristics of Eye Movement When Reading Japanese Compared to Reading English

Significant differences between Japanese and English readers in eye movements were found in this study. The number of fixations and regressions is much greater with Japanese than with English. Duration of fixation is longer with Japanese than English probably because of the existence of Kanji. For the same reason, the span of recognition in Japanese is shorter. Duration of fixation is also much longer when reading Japanese than English probably because the alphabet in English is simpler compared to Kanji characters. Our results indicate that Japanese readers fixate longer while reading Japanese text than Americans do while reading a standard English text. This occurs whether reading exclusively Kana text or mixed Kana/Kanji text.

Only adult subjects participated in this project. Although elementary Level 1 paragraphs were read by the college level Japanese readers, it is unlikely that their reading eye movements mirror the characteristics of elementary level Japanese readers. Because Japanese involves different characters and grammar compared to English, we expect the characteristic patterns of eye movements needed for the development of reading to be different. Alphabets are the most used characters in the world. Languages from Latin, including English, seem to demand more phonetic processing to read because combinations of letters represent sounds. On the other hand, Japanese would seem to demand more eidetic processing to read because Kanji characters made from pictures are used. Although phonetic processing is necessary with Kana, the Japanese alphabet is phonetically more consistent. Unlike English, Kana symbols always represent the same sounds in the same manner. The phonological structure and principles are more simple than English. It is our contention that these characteristic differences most likely produce a difference in the development of reading eye movements between Japanese and English. Further research and experimentation is needed to explore and confirm this concept.

The measurement of perceptual span is one interesting way to characterize information processing in reading. The size of the perceptual span is measured as the useful visual field in one fixation. Previous research has demonstrated that in English, the range of perceptual span for skilled readers of English extends 3-4 character spaces to the left of fixation and about 15-16 character spaces to right of fixation.[31] Of the 19-character span, word identification occurs within a 9-character zone. In contrast, the effective visual field size among readers of Japanese (oriented either horizontally or vertically) is 5.5 character spaces.[20,22] The data in this project and reading eye movement norms[2] revealed a smaller perceptual span than that of previous studies. In Japanese, 2.98 characters (mixed Kanji/Kana text) are processed in one fixation in reading, whereas, in English, 5.55 characters are processed in the average fixation. Even though these studies cannot be compared directly because the methods for measuring perceptual span are different, the effective size of the perceptual span for reading of English seems consistently longer than that with Japanese. The average ratio of the number of characters in the original untranslated Taylor paragraphs (alphabet) compared to the translated paragraphs (mixed Kanji/Kana) was 1.69. This suggests that the concentration of linguistic information in Japanese mixed Kanji/Kana text is denser than that in English text (Table 5). In this study, by considering the difference in density between English and Japanese (Mixed Kanji/Kana text), the span of recognition in English is identical with that in Japanese in the amount of information in one fixation (instead of the number of characters in fixation). Essentially, the difference in the span of recognition may not actually be present if the density of information is equal.

Another potentially fruitful area of study between reading eye movement characteristics of Japanese and English readers is vertical eye movement. One of the most notable characteristics of Japanese reading is that texts can be oriented both vertically and horizontally while English is always oriented horizontally from left to right. Although written Japanese has became more horizontally oriented than it used to be, Japanese students still learn to first read vertically. Japanese newspapers and paperback books are printed vertically. Nakano[32] demonstrated a significant difference ($p<0.01$) between Americans and Japanese in the horizontal-vertical ratio for visual search tasks with numbers. Using a hand counter, Americans searched and counted the designated number horizontally faster than vertically. Japanese searched and counted the numbers vertically faster than horizontally. Vertical eye movement seems to be more important to read Japanese than English and is probably reflected early on in the "learning to read" process. Exploration of these potential differences would require different instrumentation because the current Visagraph II system is unable to measure vertical eye movements.

CONCLUSION

1. The Visagraph II performed properly over a large number of trials and produced data that was reliable and repeatable with Japanese texts. This indicates that there is a high possibility of using the Visagraph II for Japanese readers to evaluate reading performance in Japanese even though some adjustments might be needed.

2. The calculated data indicates more fixations, shorter span of recognition, longer duration of fixation, and slower reading rate when reading mixed Kanji/Kana texts probably because the complexity of Kanji requires careful analysis. There appear to be differences in eye movements between reading Kana text exclusively versus mixed Kanji/Kana text. Since differences exist between mixed Kanji/Kana texts and exclusively Kana text in the level of difficulty, the difference in eye movements might be caused by several factors. Further investigation will be needed to clarify the differences.

3. There were more fixations and regressions, longer duration of fixation, and a shorter span of recognition with Japanese than English. This is probably because word parts in English are simpler compared to Kanji characters. However, by considering the difference in density between English and Japanese (mixed Kanji/Kana text), the span of recognition in English is identical with that in Japanese in the amount of information in one fixation.

Acknowledgement

We would like to thank retired Pacific University professors Paul Kohl, Robert Yolton, and Anita McClain for their contributions to the success of our research.

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Neither of the authors has any financial interest in this product.

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Date accepted for publication: 17 March 2011.