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VERTICAL-HORIZONTAL DIFFERENCES IN VISUAL SPACE RECOGNITION OF AMERICANS AND JAPANESE

By
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Biography

The author, Ikuko Nakano, graduated from Kikuchi College of Optometry in Japan in 1983. After teaching assistant at the school for one year, she worked for the Kikuchi Optical Company for six years. She came to Pacific University in 1989, and earned the visual science degree in 1992 and the doctor of optometry degree in 1994. She is accepted for a residency program in pediatric optometry and vision therapy at Southern California College of Optometry. She was involved with voluntary eye care service in Amigos club, which includes two trips to Colombia and Mexico. She continues to improve her knowledge and skills of optometry. In the future, she is hoping to help establishing optometry system in Japan.

Abstract

This study compared two different written language groups, Americans and Japanese. Interestingly, Japanese can be written and read ether vertically or horizontally, but English can be done only horizontally. Since vision is a learned process, especially skilled reading is highly automated process, we suspected that Japanese would have more effective vertical visual recognition process than would Americans. In order to examine our hypothesis, three tasks were designed as follows. Card task 1 was oral reading task. Card task 2 was searching and counting task without vocalization process. Computer task was letter recognition on a computer monitor. All three tasks had two types of trials, vertical and horizontal. 25 American and 28 Japanese subjects were involved in this study. The results of card task 2 supported our assumption that Japanese had more effectiveness in vertical task and Americans had more effectiveness in horizontal task with significant difference.

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Introduction

There have been many studies of visual processing related to reading skill. Most of the research has been limited to English and European languages that are written only horizontally using Roman characters. Interestingly, Japanese can be written and read either vertically or horizontally. Since skilled reading requires highly automatic abilities, the difference in written language may differentially affect the development of visual information processing abilities for Japanese vs. American or European readers.

Alphabets are the most used characters in the world. Since the alphabets are based on a segmentation of the sound stream in terms of highly abstract units, they are represented only indirectly in the acoustic wave. Learning to read English is learning to use predominantly phonological principles[1]. Written Japanese uses two types of characters based upon phonology, and a third type based upon ideograms. Hiragana and katakana characters represent sounds. The kanji, based upon ideograms, has at least two different pronunciations, because it is represented with original Chinese characters and Japanese native words[2]. One of the kanji characters has as many as nine different pronunciations. In spite of the complication of reading kanji, it can imply meaning easier by showing the basic figure component of the character without knowing exact pronunciation.

English is written with only 26 characters. Written Japanese uses 70 hiragana and 70 katakana, and 1850 official listed kanji characters (the number of common use kanji is about 4500). Because of the simplified characters and highly abstracted code system in English, written English requires space between the words. Written Japanese doesn't have space between the words.

Fig. 1: Sample from Japanese newspaper

寸言

モータリゼーションが飽和状態に達したという時代認識を背景に、両者とも、陸上交通機関の中で高速鉄道を優先整備する意義を強調した。

が、手法については国債発行や公的資金の投入にこだわらず、列島の基軸鉄道としての新幹線整備を積極推進する立場と、国の財源難という限られた可能性や整備後のＪＲの経営赤字化の回避を考慮し、在来線の高速化も活用して、鉄道を需要に対応させ近代化する立場に分かれた。

私鉄整備政策にも波及

その違いは、公共機関だが民営でもあるＪＲ鉄道について、公共性か民間企業性のどちらに比重を置くか、という点から生まれているようにも見える。

となると、ＪＲ以外の私鉄の整備を国がどうバックアップして進めるかという点にも共通する問題になる。それだけに国会、行政側ともに、この機会に明確な見方を確立しておく必要があろう。

鉄道整備 — Kanji

こうした — Hiragana

モータリゼーション — Katakana

Fig. 2: Sample from American newspaper

Our eighth annual search for the nation's best and brightest high school students is under way again.

Nominations are being accepted for the 1994 All-USA High School Academic Team, which honors students who excel in scholarship, leadership and creativity. Forms were mailed this month to principals and guidance offices of every high school, public and private. Deadline: March 12.

Forms can be requested by calling 703-558-5613.

Twenty students selected for the All-USA First Team will earn $2,500 and a trip to an awards ceremony in Washington, D.C., in May. Twenty each also will be named to the second and third teams.

Judges, all educators, look at a student's grades, test scores, leadership roles in and out of school and an ability to use academic talent beyond the classroom.

The All-USA high school team is one of three honored each year by USA TODAY. The 1994 college team will be announced Feb. 4, the two-year college team in April.

The mixture of kanji and kana provides good visual guidance without space (see Figures 1 and 2). A recent study shows kanji-hiragana mixed text, which has picture-like symbols, elicits shorter eye fixations and longer saccades than those seen when reading hiragana text[3]. Also, subjects use different strategies as evidenced by saccade size and speed, when reading the phonogram-based kana components and ideogram-based kanji components[4]. Osaka[3] suggests that kanji components facilitate processing efficiency due to kanji's direct lexical access property as compared with kana. The difference in scripts between English and Japanese probably affects how visual information is processed during reading.

Measurement of perceptual span is one interesting way to characterize information processing in reading. The size of the perceptual span is measured as the size of useful visual field in one fixation. In English, 14-16 letter spaces (about 5^{o} visual angle) are processed during a fixation in normal reading, and up to 8 letters (about 2.5^{o} visual angle) can be consciously identified in one fixation[5]. The range of visual span for skilled readers of English extends 3-4 letter spaces to the left of fixation and about 15-16 letter spaces to the right of fixation[6]. In contrast the effective visual field size for vertical reading among readers of Japanese is 5.5 character spaces (about 5^{o} visual angle). The size of effective visual field during reading seems to be similar between horizontal and vertical reading in Japanese[7]. Seven characters of kanji-kana mixed text (about 5.6^{o} visual angle) and 5 characters of hiragana text (about 4^{o} visual angle) are processed in one fixation in horizontal reading[3]. Even though these studies cannot be compared directly, the effective size of the perceptual span for reading seems similar in each case, about $4\text{-}6^{o}$ for English and for Japanese (oriented either horizontally or vertically). However, a study of vertical and horizontal reading in Chinese showed the span for vertical Chinese text is about half of the span for horizontal Chinese text or for English[8].

Japanese text studies have not shown a similar difference of perceptual span between vertical and horizontal directions[3,7]. The Chinese text study showed the broader perceptual span in horizontal reading pattern[8]. Some physiological data indicate that the horizontal span may be larger because of a visual resolution difference. Klein, *et al.'s* 1990 study showed that the decline in performance for identifying a briefly presented letter with increasing retinal eccentricity is steeper in the vertical direction than the horizontal direction in both normal and dyslexic readers[9]. They presented target letters briefly at 16 randomly intermixed positions away from fixation (above, below, right, left) and the results were analyzed with direction and eccentricity as within-subject factors.

In reading, not only visual perception but also cognitive language processes are involved. Also, in the early stage of information processing during reading, eye movements play an essential role[8]. The quality of reading performance can be affected by many different factors in the information processing system.

Although written Japanese has become more horizontally oriented than it used to be, Japanese students still learn how to first read vertically. Also Japanese newspapers and paperback books are printed vertically. Because of these factors, Japanese may develop more efficient vertical saccadic ability than will English readers. How to walk, how to speak, and how to interact with the external world are learned, developmental process as are the eye movements in reading[13]. It may be that the guidance mechanisms responsible for eye movements during reading are influenced by learning and experience.

Peripheral search guidance and cognitive search guidance are two sub-mechanisms in the visual information sampling system[1]. Peripheral search guidance would guide the next saccade (eye movement) to the most informative part of the page based upon information from peripheral vision. Cognitive search guidance allows selective hypothesis formation to operate on the material in view at any glance. When targets are easy to detect in peripheral vision and visual span is relatively large, a cognitive event becomes the trigger of a saccade. If the mental process requires more time, the fixation duration will become longer and timing of the saccade will depend on the cognitive process at that time.

Recent studies develop some models of eye movement in reading[5,10,11]. These studies have focused upon measurable factors related to temporal and spatial decisions in generating saccadic eye movements. The idea of simultaneous 'when' and 'where' systems, two independent and parallel saccade control sub-systems, explains the character of the saccadic eye movements more clearly than earlier ideas such as two different visual field functions, central and peripheral, or cognitive search guidance and peripheral search guidance. Jacobs proposes a model which uses two independent sub-systems for "when" and "where" control. In his model, both the "when" and the "where" system have two types of information: visual information and non-visual information. Once the "when" decision is achieved a saccade will be elicited, whether the amplitude computation is already accomplished or not[10].

In order to decide where to move the eyes, peripheral visual awareness plays a role in search guidance as processing both visual and non-visual information.

By using peripheral vision, the computation occurs to determine where to move the eyes. Not only the location of the next target subject, but also the information related to familiarity or difficulty of that subject may be computed simultaneously. In other words, the cognitive processing related to memorized visual properties probably also contributes to the decision of not only when but also where to move the eyes.

So far, visual information processing during reading has been discussed primarily from a psychological point of view. The theory from this point of view involving "when" and "where" systems as parallel information processes supporting saccadic eye movements is also supported by physiological data. Studies of the neural basis of saccades show the saccade-related response present within these structures: motor nuclei, supranuclear region of brainstem, NRTP (nucleus reticularis tegmenti pontis), cerebellum, superior colliculus, substantia nigra, caudate nucleus, thalamus, and cortex[12]. These structures are richly interconnected and widely distributed as a complex neuronal network. Like a super computer network, this neuronal network can send multiple representations of information to multiple locations. Because this information is processed simultaneously in parallel pathways, the network can use many sources of input to effect a single output. Since saccadic eye movements in reading interact with continuous cognitive information processing, the effectiveness of a saccade is dependent upon previous information processing. The analyses of the complex visual world are also filtered by attention to control overflow information[12].

This study was designed to test the hypothesis that vertical-horizontal differences in visual recognition exist between Americans and Japanese[1].

Specifically, it was postulated that Americans would demonstrate better performance with horizontally-oriented written material, and Japanese better performance with vertically-oriented material.

Methods

Subjects

After screening, 25 Americans and 28 Japanese who were born and raised in Japan were entered in the study. The screening criteria and tests used are listed in Table 1. American subjects ranged in age from 19 to 38 years (mean 24.3 ± 4.8). Japanese subjects ranged from 18 to 43 years (mean 23.5 ± 5.5). Eight (32%) of the American and twelve (42.9%) of the Japanese subjects were male. All subjects provided informed consent and were given compensation in the form of extra class credit for American subjects and a certificate redeemable for free vision care for Japanese subjects.

Table 1: Inclusion criteria

Astigmatism: < -2.00 D: Current prescription
Phoria at distance and near: < 12 prism diopters: Alternate cover test with prism neutralization
Stereo acuity: better than 60 seconds arc : Random Dot stereo Butterfly
Habitual visual acuity of OD,OS,OU at distance and near better than 20/30: Snellen chart
General and ocular health: no pathological condition: Case history
No medications which affect vision: Case history
Smooth and accurate eye movements: bead skills

Procedure

This study utilized three different tasks. The first task was reading aloud numbers printed vertically and horizontally. Since the subject read the numbers aloud in his/her own language, this task was influenced by the vocalized difference of each language. The second task was counting a target number vertically and horizontally. This task didn't require the vocalization process. The third task was identifying a target letter on the computer monitor. This task didn't require the vocalization process directly.

During the procedures, each subject was seated on an adjustable height stool and used a chin rest to maintain the viewing distance of 60 cm (forehead to target). The room illumination was kept constant at approximately 55 cf. During the two card tasks, a diffused 60 watt nearpoint lamp was directed onto the stimulus materials to yield incident light at 50 ± 3 cf.

Pages of random numbers were used for both card tasks. Card task 1 had 100 single-digit numbers vertically or horizontally aligned on the card. The numbers on the vertical card (Fig. 3) were spaced as four columns of 25 numbers each in an area of 15.5 x 2.9 cm^2. The numbers on the horizontal card (Fig. 4) were spaced as four rows of 25 numbers each in 3.0 x 15.5 cm^2. The visual demand for the numbers of card task 1 was approximately 20/80. The numbers were printed in 10 point Courier font. Each subject was asked to call the numbers as quickly and accurately as possible in his/her own language. The subject called down the numbers from upper right to lower left when the vertical card was shown; this direction was the same reading direction of Japanese vertical reading. When the horizontal card was shown, the subject called across from upper left to lower right; this direction was the same as English reading as well as Japanese horizontal reading. The order of presentation of the cards was alternated for each subject. The time required to call all the numbers on the card and any errors were recorded.

Fig. 3: Vertical presentation (Card task 1)

The subject called down each column aloud from the upper right (3*) to the lower left (2**) as quickly and accurately as possible.

6	7	8	3*
4	3	7	0
1	1	3	8
9	2	8	1
9	2	9	3
4	3	6	8
8	7	0	1
3	3	8	1
1	5	1	4
1	6	0	2
4	9	6	8
2	1	3	4
5	2	2	0
6	6	2	2
6	9	6	0
0	1	8	6
9	3	5	4
9	8	1	9
0	0	8	6
8	5	7	0
3	4	4	4
4	7	6	0
7	4	3	2
2	7	6	4
2**	2	5	7

Fig. 4: Horizontal presentation (Card task 1)

The subject called across each number aloud from upper left (6*) to the lower right (7**) as quickly and accurately as possible.

6* 7 8 3 4 3 7 0 1 1 3 8 9 2 8 1 9 2 9 3 4 3 6 8 8

7 0 1 3 3 8 1 1 5 1 4 1 6 0 2 4 9 6 8 2 1 3 4 5 2

2 0 6 6 2 2 6 9 6 0 0 1 8 6 9 3 5 4 9 8 1 9 0 0 8

6 8 5 7 0 3 4 4 4 4 7 6 0 7 4 3 2 2 7 6 4 2 2 5 7**

Card task 2 had two cards, A and B (see Fig. 5), which presented two different orders of 391 single-digit numbers arranged in 23 rows and 17 columns in an area of 8.8 x 9.1 cm^2. The visual acuity demand for the numbers of card task 2 was approximately 20/60. The numbers were printed in 9 point Monaco font. Each subject was asked to count a target number on the card as quickly and accurately as possible by using a hand counter. The subject first used vertical eye movements, searching from the top number in the right column to the bottom number in the left column silently. The task was then repeated for the same target number on the other card using horizontal eye movements, searching from the top left number to the bottom right number. The subject was also instructed not to look at the number on the counter during or after counting the target number. The order of eye movement direction was alternated each subject. The time required to count the target number on each card and the number on the counter were recorded. The difference between the counted number and the correct number was recorded as error.

Fig. 5: Single-digit card for Card task 2

<Card A> The subject searched for the target number, 2, by using a vertical eye movement search, and recording occurrences of the target number by means of a hand counter. The search progressed vertically down each column from upper right to lower left using the same eye movement direction as card task 1, but without verbalization.

1	3	2	8	4	2	1	2	2	4	9	9	0	5	2	0	0
1	9	9	6	0	5	7	8	9	1	2	4	0	9	7	4	5
8	3	5	2	4	9	3	8	9	8	0	1	0	7	5	3	6
2	3	7	7	0	9	9	4	9	9	6	3	8	7	2	0	5
5	2	4	0	3	8	7	4	9	7	6	3	5	5	5	3	3
5	6	7	6	7	4	8	1	5	4	5	2	4	6	7	6	5
0	9	1	9	6	8	9	4	2	7	5	1	1	1	9	4	6
9	6	5	1	8	3	5	7	2	6	3	9	7	3	7	9	7
0	2	5	6	2	8	1	4	2	5	5	7	8	6	8	7	6
3	1	7	9	0	0	7	1	9	4	4	5	4	6	8	4	2
5	9	4	6	0	1	3	5	3	9	9	0	8	3	5	2	0
2	1	7	8	7	5	5	2	5	4	9	4	6	0	1	3	5
3	9	9	0	8	3	5	2	0	2	1	7	8	7	5	5	2
5	2	8	2	1	1	9	5	9	1	1	6	4	4	0	6	3
0	7	7	6	2	8	5	5	5	3	2	2	7	8	0	1	7
4	4	7	6	8	2	5	1	0	8	3	6	1	2	4	1	3
4	7	1	6	4	0	8	1	8	6	2	9	7	3	1	1	5
5	7	4	9	1	3	0	4	0	5	1	6	6	3	1	9	6
7	7	3	3	8	9	3	5	3	1	6	2	4	7	8	9	1
9	0	3	9	3	1	7	4	4	2	6	0	9	0	6	6	4
2	2	3	8	1	6	1	5	3	2	1	4	5	7	2	1	5
8	1	5	5	6	1	2	4	4	6	5	7	9	1	3	4	0
9	1	2	2	7	5	0	0	0	1	6	5	3	9	0	2	7

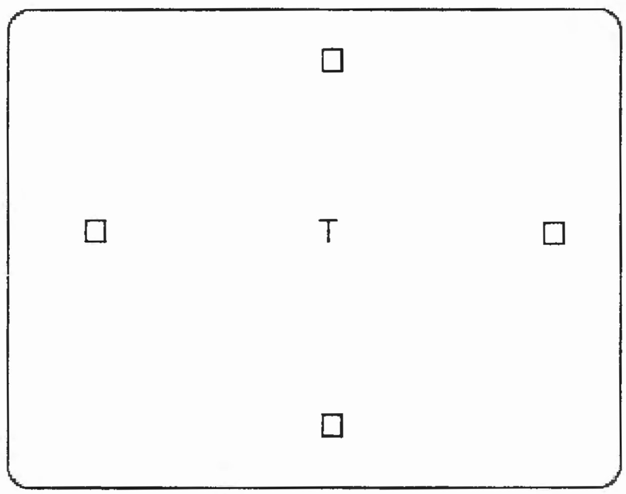
<Card B> The subject searched for the target number, 2, by using a horizontal eye movement search, and recording occurrences of the target number by means of a hand counter. The search progressed horizontally across each row from upper left to lower right using the same eye movement direction as card task 1, but without verbalization.

3	9	9	0	8	3	5	2	0	2	1	7	8	7	5	5	2
5	2	8	2	1	1	9	5	9	1	1	6	4	4	0	6	3
0	7	7	6	2	8	5	5	5	3	2	2	7	8	0	1	7
4	4	7	6	8	2	5	1	0	8	3	6	1	2	4	1	3
4	7	1	6	4	0	8	1	8	6	2	9	7	3	1	1	5
5	7	4	9	1	3	0	4	0	5	1	6	6	3	1	9	6
7	7	3	3	8	9	3	5	3	1	6	2	4	7	8	9	1
9	0	3	9	3	1	7	4	4	2	6	0	9	0	6	6	4
2	2	3	8	1	6	1	5	3	2	1	4	5	7	2	1	5
8	1	5	5	6	1	2	4	4	6	5	7	9	1	3	4	0
9	1	2	2	7	5	0	0	0	1	6	5	3	9	0	2	7
1	3	2	8	4	2	1	2	2	4	9	9	0	5	2	0	0
1	9	9	6	0	5	7	8	9	1	2	4	0	9	7	4	5
8	3	5	2	4	9	3	8	9	8	0	1	0	7	5	3	6
2	3	7	7	0	9	9	4	9	9	6	3	8	7	2	0	5
5	2	4	0	3	8	7	4	9	7	6	3	5	5	5	3	3
5	6	7	6	7	4	8	1	5	4	5	2	4	6	7	6	5
0	9	1	9	6	8	9	4	2	7	5	1	1	1	9	4	6
9	6	5	1	8	3	5	7	2	6	3	9	7	3	7	9	7
0	2	5	6	2	8	1	4	2	5	5	7	8	6	8	7	6
3	1	7	9	0	0	7	1	9	4	4	5	4	6	8	4	2
5	9	4	6	0	1	3	5	3	9	9	0	8	3	5	2	0
2	1	7	8	7	5	5	2	5	4	9	4	6	0	1	3	5

The Rolodex™ program, developed by Alan LeRoy, O.D., was used for the computer task. The Rolodex program was run on a Macintosh Quadra computer. In this task, the subject saw initially a target letter at the center of the monitor. After an approximate 5-second presentation of the initial target letter, two series of different letters were scrolled at high speed in different locations on the screen. One of the scrolling series always appeared at the center of the monitor as stimulus letters, and the other set appeared at one of the offset positions (above, right, left, and below) as response letters (Fig. 6). The subject had five practice trials before experimental data were taken. The position of the offset response letters was 9.0^{o} from the stimulus letters in each of the four directions. The visual acuity demand of all the letters was 20/81 at 60 cm (font was 20 point Helvetica).

Fig. 6. Rolodex stimulus presentation

The target letter initially appeared at the center of the monitor, and the subject noted which letter it was. The response letters appeared at one of the offset positions. The offset position is 9.0^{o} angular distance from the center of the monitor at 60 cm.



T : A target letter and/or stimulus letters

□ : Response letter locations

The display time and off time of each stimulus and response letter could be set independently using two control lists in the program. List 1 specified the display and off times of stimulus and response letters until the target letter appeared on the screen. List 2 specified the speed of scrolling letters after the target letter appeared. For the five practice trials, both the stimulus and response letters were displayed 40 msec with a 100 msec inter-stimulus blank interval on list 1 and 2 (see Table 2a). After the practice trials, the speed of scrolling letters on list 1 was changed from 40 msec display to 25 msec. List 1 off time remained at 100 msec. The speed of list 2 was changed to reduce the off time from 100 msec to 40 msec; the display time was kept at 40 msec during data collection. During trials, when the subject saw the target letter again in the scrolling stimulus letters, s/he looked immediately to the response position and identified the first letter seen there (see Table 2b). The letter that the subject identified was correlated with the time for recognition. In the recording form, only the maximum time was recorded, not the time interval during which recognition occurred. The offset position was alternated every five trials, and totally 40 trials were measured for each subject, ten trials for each direction.

Table 2a :
Sample of the time sequence of the scrolling letters

<Practice trial>

If the subject identifies the response letter as "G", the time for this trial is recorded as 500 msec. If s/he called "S", the datum for this trial is 920 msec. The minus times in this table show the relative time to the point when the target appears in the scrolling stimulus letters.

	Time (msec)	Stimulus letter T (target letter)	Response letter
(List 1)	-980--940 (display)	U	P
	-940--840 (off)		
	-840--800 (display)	H	W
	-800--700 (off)		
	-700--660 (display)	O	Q
	-660--560 (off)		
	-560--520 (display)	C	E
	-520--420 (off)		
	-420--380 (display)	N	D
	-380--280 (off)		
	-280--240 (display)	B	X
	-240--140 (off)		
	-140---100 (display)	R	U
	-100-0 (off)		
(List 2)	0-40 (display)	T	O
	40-140 (off)		
	140-180 (display)	S	K
	180-220 (off)		
	220-260 (display)	W	J
	260-360 (off)		
	360-400 (display)	H	G
	400-500 (off)		
	500-540 (display)	P	V
	540-640 (off)		
	640-680 (display)	K	A
	680-780 (off)		
	780-820 (display)	Y	S
	820-920 (off)		
	920-960 (display)	G	W

Table 2-b
The sample of the time sequence and the scrolling letters

<Actual trial>

If the subject identifies the response letter as "T", the time for this trial is recorded as 365 msec. If s/he called "G", the datum for this trial is 605 msec. The minus times in this table show the relative time to the point when the target appears in the scrolling stimulus letters.

	Time (msec)	Stimulus letter S (target letter)	Response letter
(List 1)			
	-525--500 (display)	Y	P
	-500--400 (off)		
	-400--375 (display)	B	A
	-375-275 (off)		
	-275--250 (display)	G	Z
	-250--150 (off)		
	-150--125 (display)	M	X
	-125-0 (off)		
(List 2)			
	0-25 (display)	S	R
	25-125 (off)		
	125-165 (display)	P	L
	165-205 (off)		
	205-245 (display)	V	W
	245-285 (off)		
	285-325 (display)	Q	T
	325-365 (off)		
	365-405 (display)	F	I
	405-445 (off)		
	445-485 (display)	H	U
	485-525 (off)		
	525-565 (display)	C	G
	565-605 (off)		
	605-645 (display)	B	J
	645-685 (off)		

Data analysis

Data of Card Task 1

Time: the actual time required by each subject to complete the trial

Error: the total number of errors

Error value: the adjusted time considering errors

= the number of adding errors + (-1) x the number of skipping errors + (0) x the number of replacing errors

<example>

printed numbers 678343701

called numbers (5)7()3437(3)(7)0 1

Total errors = 4 (replacing error 6 to 5, skipping error 8, adding error 3 and 7)

error value = 2 + (-1) x 1 + (0) x 1 = 1

Ratio of horizontal/vertical:

the ratio of the calibrated horizontal and vertical times

$$= \frac{\text{the time of horizontal/(100 + error value)}}{\text{the time of vertical/(100+ error value)}}$$

$$= \frac{\text{the time for each number called out horizontally}}{\text{the time for each number called out vertically}}$$

100: the total number of digits on each card in card task 1

Data of Card Task 2

Time: the actual time required by each subject to complete the trial

Error: the difference between correct number and the counted number (more counted number as plus, fewer counted number as minus)

Ratio of horizontal/vertical:

the ratio of the adjusted horizontal and vertical time

$$= \frac{\text{the time for each number counted horizontally}}{\text{the time for each number counted vertically}}$$

<example>

row horizontal time = 55 sec

counted number horizontally = 40

row vertical time = 51 sec

counted number vertically = 39

$$\text{the ratio} = \frac{55/40}{51/39} = 1.0514$$

Data of computer task

Time:	the maximum response time for each trial the second to the sixth fastest response times were used as valid trial times: ten data taken at each position. The one fastest and four slowest times were discarded.
Mean of horizontal (H Mn):	mean time of right and left response trials
Mean of vertical (V Mn):	mean time of up and down response trials
Mean of up (V- Mn):	mean time of upward response trials
Mean of down (V+ Mn):	mean time of downward response trials
Mean of left (H- Mn):	mean time of leftward response trials
Mean of right (H+ Mn):	mean time of rightward response trials

Data analysis

Differences in performance between Japanese and American subjects were analyzed for each task using two-tailed t-tests for independent groups. The ratio of horizontal and vertical performance on each task was calculated for each subject in order to eliminate variable factors of individual capability.

Result

The results of the card task 1, task 2 and computer task are shown below (see Table 3 a and b). In card task 1, both horizontal and vertical time showed significant difference between Americans and Japanese ($p < 0.05$), with the Japanese subjects showing faster performance in both directions. The vertical error value also showed significant difference, even though vertical error itself was minimal. When we exclude outliers (more than 2 s.d.), the difference in vertical error value disappeared. In card task 2, the horizontal and vertical search speeds did not show significant difference between groups, despite the presence of trends in the predicted direction. When the search speeds were analyzed as a ratio, the trends became significant.. The horizontal and vertical ratio showed significant difference ($p < 0.01$) between the experimental groups in the direction predicted by the initial hypotheses. In the computer task, the results showed no significant difference between groups on any variable studied.

Table 3a: Include all data

All data were used in the results in this table. Significant differences were shown between Americans and Japanese in horizontal and vertical time in card task 1, vertical error value in card task 1, and the horizontal and vertical ratio in card task 2.

	American	Japanese	t- value	probability
Card task 1	Mean ± s.d.	Mean ± s.d.		
H sec	33.10±4.69	29.40±5.86	2.52	.015
H error	1.08±1.08	0.93±1.02	0.53	.60
H error val.	0.68±1.14	0.89±1.03	-0.71	.48
V sec	36.05±5.44	31.34±5.63	3.09	.003
V error	0.76±1.05	1.39±1.83	-1.52	.14
V error val.	0.32±0.85	1.04±1.45	-2.13	.038
H'/V'	0.92±0.06	0.94±0.07	-1.24	.22
Card task 2				
H sec	60.39±10.24	65.14±18.64	-1.13	.26
H #	38.68±1.93	36.64±5.22	1.84	.07
H error	-2.32±1.93	-4.36±5.22	1.84	.07
V sec	68.25±11.56	64.93±19.72	0.74	.46
V #	36.52±3.22	36.11±3.80	0.42	.67
V error	-4.48±3.22	-4.89±3.80	0.42	.67
H'/V'	0.84±0.09	1.03±0.23	-3.84	0.0003
Computer task				
H+ Mn	475.72±93.40	489±81.77	-0.55	.58
H- Mn	481.48±93.13	505.57±66.24	-1.09	.28
V+ Mn	514.76±81.04	523.29±81.04	-0.38	.70
V- Mn	489.16±91.71	510.14±68.84	-0.95	.35
H Mn	478.6±87.36	497.29±63.35	-0.90	.37
V Mn	501.96±83.34	516.71±64.46	-0.73	.47
H+Mn/V+Mn	0.93±0.12	0.95±0.17	-0.46	.65
H-Mn/V-Mn	1.00±0.23	1.00±0.09	0.17	.87
H Mn/V Mn	0.96±0.14	0.96±0.07	-0.16	.88

Table 3b: Exclude outliers (2 s.d.)

The data fall in exceeding 2 s.d. from the mean were excluded for these results. In these results, vertical error value for card task 1 did not show significant difference. Also in card task 2, American subjects counted the target number more accurately with probability less than 5 %.

	American	Japanese	t-value	probability
Card task 1	Mean ± s.d.	Mean ± s.d.		
H sec	32.32±3.69	28.38±5.44	2.63	.012
H error	0.56±0.65	0.65±0.71	-0.46	.65
H error val.	0.22±0.55	0.61±0.72	-1.88	.07
V sec	35.36±4.38	30.13±4.81	3.59	.0009
V error	0.5±0.62	1.00±1.24	-1.56	.13
V error val.	0.28±0.57	0.83±1.30	-1.66	.10
H'/V'	0.92±0.07	0.94±0.06	-1.14	.26
Card task 2				
H sec	58.93±8.24	60.95±10.67	-0.71	.48
H #	39.09±1.60	37.43±3.29	2.13	.04
H error	-1.91±1.60	-3.57±3.29	2.13	.04
V sec	67.16±10.86	61.15±14.12	1.59	.12
V #	36.63±3.36	36.91±2.50	-0.31	.75
V error	-4.36±3.36	-4.09±2.50	-0.31	.75
H'/V'	0.83±0.07	1.01±0.19	-4.20	0.0001
Computer task				
H+ Mn	470.26±75.86	491.22±56.74	-0.95	.35
H- Mn	469.42±61.59	497.44±53.44	-1.47	.15
V+ Mn	507.32±58.64	522.33±57.62	-0.79	.44
V- Mn	487.95±56.20	500.11±58.14	-0.65	.52
H Mn	469.84±62.76	494.33±50.54	-1.30	.20
V Mn	497.63±52.21	511.22±52.91	-0.79	.44
H+Mn/V+Mn	0.93±0.12	0.95±0.11	-0.45	.65
H-Mn/V-Mn	0.97±0.10	1.00±0.07	-1.14	.26
H Mn/V Mn	0.95±0.08	0.97±0.06	-0.99	.33

Only card task 2 showed significant difference ($p < 0.01$) between Americans and Japanese in the horizontal-vertical ratio (see Figure 7). The ratio in card task 1 didn't show significant difference between Americans and Japanese, still Japanese showed slightly higher number in the ratio than that of Americans. The computer task showed that the ratios of American and Japanese were identical. Since the horizontal time was divided by the vertical time in order to calculate each ratio, a ratio greater than 1.0 means the horizontal time was slower than vertical time. A ratio smaller than 1.0 means horizontal time was faster than vertical time. Card task 1 and the computer task indicated that both American and Japanese subjects responded to the horizontal task faster than the vertical task.

Figure 7: The horizontal and vertical ratio in each task.

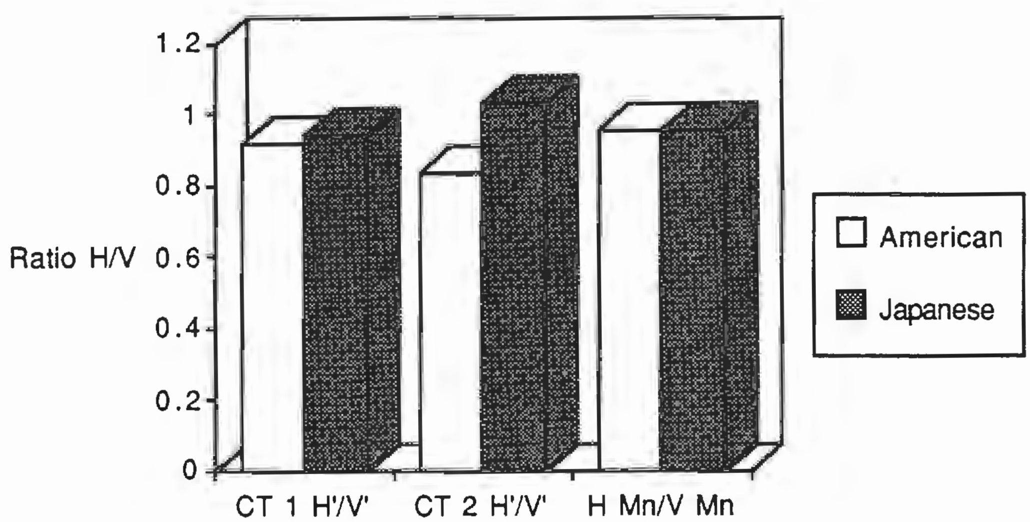


Figure 8: The time in card task 1 and 2

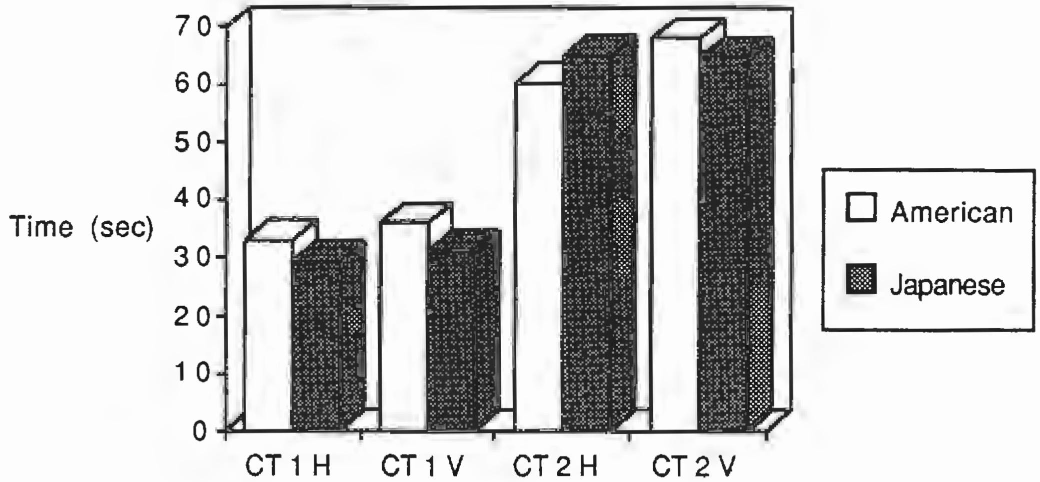
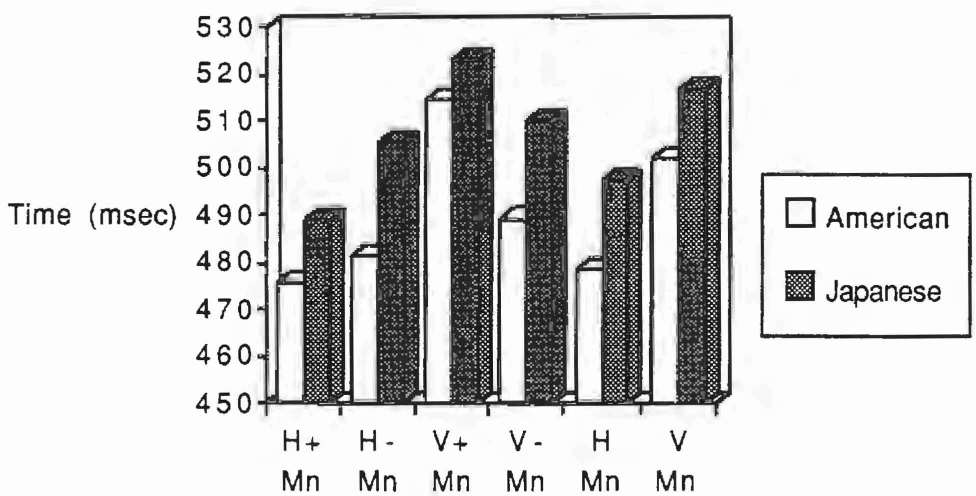
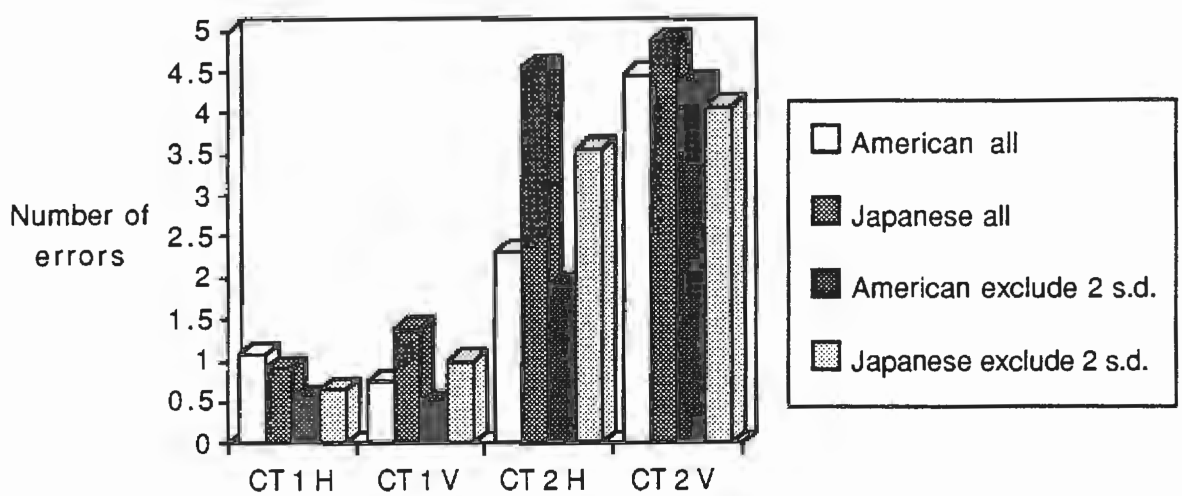


Figure 9: The time in computer task



Japanese subjects read numbers faster both horizontally and vertically than did American subjects in card task 1. On card task 2, the Japanese subjects counted the target number vertically slightly faster, and the American subjects counted the target number horizontally slightly faster (see Figure 8). The difference in card task 1 was significant ($p < 0.05$). Americans responded insignificantly faster than did Japanese to all four directions in the computer task (see Figure 9). The mean error values of each vertical and horizontal task in both card task 1 and 2 are shown in Figure 10. Error values generally did not differ between groups with the exception of horizontal error value in card task 2 (see Figure 10).

Figure 10: Error in card task 1 and 2



Discussion

Based upon the results of this study, visual information processing abilities in different languages seem to be different. The results of card task 1 showed significant differences between Americans and Japanese in oral reading speed. This difference is most likely due to differences in the vocalization process. Reading numbers in Japanese and English seems very similar (see Table 4), however Japanese has generally shorter vowels that are usually clipped in spoken Japanese. Also, English uses the diphthong. Not only does reading numbers in English take longer than in Japanese, the Japanese examiner in this study might have affected American subjects. They might not have read numbers as quickly as they could, because subconsciously they might defer to the researcher who was not a native speaker. There was not that kind of factor for Japanese subjects. In this task directional effects were not different. One possible reason could be that the vocalization process limited the performance speed more than did the visual process. In order to assess the directional ratio, each raw time was adjusted as described in the methods section. Since the targets were Arabic numbers, they are commonly read only horizontally for both subject groups. This familiarity of reading might have affected the result. The ratio of H'/V' in card task 1 showed both groups called the numbers horizontally faster than vertically. The vertical error value differed between the two groups with the Japanese subjects showing the greater error score.

Table 4: Reading numbers in Japanese and English

Number	0	1	2	3	4	5	6	7	8	9
Japanese	zero	ichi	ni	san	shi	go	roku	nana	hachi	ku
English	zero	one	two	three	four	five	six	seven	eight	nine

The results of card task 2 did not show a significant difference in speed. Instead of the difference in speed, the result showed a significant difference in the direction ratio (H'/V'). Using the hand counter, Americans counted the target number horizontally faster than vertically. Japanese counted the number vertically faster than horizontally. Since this task didn't involve vocalization like card task 1, the significant difference in direction ratio between Americans and Japanese seems related to visual information processing. After excluding outliers, the horizontally counted number error showed significant difference between Americans and Japanese. Americans counted more accurately horizontally than did Japanese.

The results from the computer task didn't show significant difference between Americans and Japanese in any condition. Compared to the other tasks, this task involved a single letter rather than continuous text. This would suggest that the visual information process might be different from that in reading tasks. Probably card task 2 was most close to reading task in these experiments. Also the results suggest that automated reading skill develops relative to environmental demands since Americans counted more accurately and quickly on the horizontal task than did Japanese.

Previous studies have discussed a model of visual information processing involving 'when' and 'where' systems in saccadic eye movement function. In order to recognize the next target, its location and familiarity play important roles. In continuous text like card task 1 and 2, the information processing of the next target may occur simultaneously with the previous fixation. In the computer task, the location of the response letter is more defined than the task of searching for target number in card task 2. Instead of making easier the location of the response letters by scrolling, the simultaneous process for the response letter itself becomes more difficult because of the short presentation period of the target. The visual information processing of either continuous stabilized text or scrolling text may use different levels of sub-system control in order to decide 'where' and 'when to move the eyes. Though the subjects in this study used saccadic eye movement in both card task 2 and the computer task, they might use different levels of visual information processing at each task. To understand these processes, further investigation will be required.

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