

Stroke Density Effect on Sentence Written in Latin Letters

라틴문자로 작성된 문장에서의 획밀도효과

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Keyword

획밀도효과, 라틴문자, 단어인지과정
 Stroke Density Effect, Latin letters, word
 recognition process

After the discovery that the whole image of words is involved in the cognitive process of words, various experiments have been conducted to prove the Word Shape Effect on sentences written in Latin letters, but there have been no successful cases. On the other hand, in the experiments conducted under the expectation that the change of the stroke density between Hangul characters also determines the whole image of the word, the Stroke Density Effect (SDE) was confirmed several times. Then this study noted that the sentences written in Latin letters also show the change of stroke densities and an experiment was conducted to verify the SDE. The experiment was carried out by measuring the reading speeds of two types of documents : the SDE enhanced document that the visual brightness change caused by the different stroke density is enhanced and the SDE weakened document that the visual brightness change is weakened. As a result, the reading speed of the SDE enhanced document was higher, but it was insignificant. On the other hand, in the subjects with high reading ability, the reading speed of the SDE enhanced document was significantly faster than the SDE weakened document whereas in the subjects with poor reading ability, the reading speed of the SDE weakened document was insignificantly faster than the SDE enhanced document. These results show that the Stroke Density Effect is based on sufficient reading experiences.

논문요약

단어의 인지과정에서 단어의 전체적인 이미지가 개입한다는 사실이 밝혀진 이래 라틴문자로 작성된 문장의 단어운곽효과를 증명하기 위한 실험이 꾸준히 진행되어왔지만, 증명에 성공한 사례는 없다. 한편, 한글의 낱글자 간 획밀도 변화역시 단어의 전체적인 이미지를 결정하는 요소라는 판단 하에 실시된 획밀도 인지실험에서는 독서과정에 획밀도효과가 나타남이 여러 차례 확인되었다. 이에 본 연구에서는 라틴문자로 작성된 문장에도 획밀도 변화가 나타난다는 사실에 주목

하고, 획밀도효과 검증 실험을 실시하였다. 실험은 획 밀도 차이에 의해 나타나는 시각적 명도변화를 강화한 문서와 시각적 명도변화를 약화한 문서의 독서속도를 측정하는 방식으로 실시되었다. 그 결과 획밀도효과 강화형 문서의 독서속도가 높게 나타났으나 유의한 결과는 아니었다. 한편, 독서능력이 높은 피험자그룹에서는 획밀도효과 강화형 문장의 독서속도가 약화형 문장에 비해 뚜렷하게 빠른 것으로 나타난 반면, 독서능력이 떨어지는 그룹에서는 오히려 획밀도효과 약화형 문장의 독서속도가 유의하지 않은 수준으로 빠르게 나타났다. 이러한 결과는 획밀도효과가 많은 독서경험을 바탕으로 나타나는 것임을 보여준다.

1. Introduction

The purpose of this study is to investigate whether the Stroke Density Effect(SDE)¹⁾ works in the word written in Latin letters. Various studies have been conducted on the letter or word recognition factors that act during the reading process. In 1886, Cattell's study found that the time it takes to recognize a word is shorter than the time it takes to recognize the letters that constitutes the word.²⁾ Reicher(1969) found Word Superiority Effect³⁾ and the inference that the word recognition process is not caused by the sequential perception of the letters constituting the word, but the word is recognized through the perception of the whole image of the word. The word shape of Latin words has been judged as a representative element that defines the

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- 1) In this study, the Stroke Density Effect means that the change in the stroke density acts as a cognitive factor for words in the reading process. Stroke density does not mean a density change in the stroke thickness but refers to the density of strokes relative to the space represented by the length and the number of strokes. For example, in the case of the word 'density', stroke density is low in the area of 'den' but high in the area of 'ity'.
- 2) Cattell, J. (1886) "The time taken up by cerebral operations". *Mind*, 11, pp.385-387 ; *Classics in the History of Psychology*, Republished by Christopher D. G. at <http://psychclassics.yorku.ca/Cattell/Time/part3.htm>
- 3) Reicher, G.M. (1969) "Perceptual recognition as a function of meaningfulness of stimulus material". *Journal of Experimental Psychology*, 81, pp.275-280.

whole image of the word, and various studies have been conducted to verify Word Shape Effect, but no successful verification has been made yet.

In the case of Hangeul, Korean writing system, Bonyoung Koo(2008) pointed out that there is a large difference in the stroke density between the characters that made of several Korean Alphabets and express syllables and proved that the difference affects the legibility positively⁴⁾ as an important factor defining the whole image of a word.

This study also notes that there are differences in stroke densities between words even in the sentences written in Latin letters, and tests whether the stroke density affects the word recognition in sentences written in Latin letters.

2. Case Study

2.1. Familiarity and legibility

In Latin letters, lowercase sentences are easier to read than uppercase letters. One of the certain reasons is familiarity. Most sentences written in Latin letters are written in lower case letters. Therefore, people become familiarized to sentences written in lowercase letters. Tinker & Goodenough (1931) proved that familiarity affects legibility by mirror-reading experiment.⁵⁾

2.2 Word Superiority Effect

Gerald M. Reicher (1969) found the Word

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- 4) Koo, Bonyoung. (2008) Effect on Readability by Various Stroke Densities Hangeul has, *Journal of Korean Society of Design Science*, Vol.21 No.3 279-287
- 5) Tinker, M.A. & Goodenough, F.L. (1931) "Mirror Reading as a Method of Analyzing Factors Involved in Word Perception". *Journal of Educational Psychology*, Vol 22(7), Oct., pp.493-502.

Superiority Effect that an alphabet in a word is recognized most easily by experimenting with the recognition of the alphabets existing in a single alphabet, a word, and a non-word.⁶⁾

The cause can be found in the research of Cattell (1886). His study found that reading was not a process of perceiving the order of the spellings forming a word, but of recognizing the word through the whole image of the word.⁷⁾

2.3 Word Shape Effect

Many researchers thought that the whole image of a word means word shape, built the Word Shape Effect hypothesis, and have tried to prove the hypothesis with various experiments (Beech & Mayall, 2005; Haber & Schindler, 1981; McConkie & Rayner, 1975 etc.).⁸⁾ However most experiments have failed to prove. Although some studies argued that they succeeded in verifying Word Shape Effect, Bonyoung Koo (2009) asserted that the researches have serious errors in the preconditions of the factors that determine the word shape.⁹⁾ Bonyoung Koo (2018) conducted an experiment that complemented the problems, but failed to prove the Word Shape Effect.¹⁰⁾

6) Reicher, *ibid.*

7) Cattell, *ibid.*

8) Beech, J.R. & Mayall, K.A. (2005). The word shape hypothesis re-examined: evidence for an external feature advantage in visual word recognition, *Journal of Research in Reading*, Vol. 28, Issue 3, pp.306-311. ; Haber R.N. & Schindler, R.M. (1981) "Errors in proofreading: Evidence of syntactic control of letter processing?". *Journal of Experimental Psychology: Human Perception and Performance*, 7, pp.573-579. ; McConkie, G.W. & Rayner, K. (1975) "The span of the effective stimulus during a fixation in reading". *Perception and Psychophysics*, 17, pp.578-586.

9) Koo, Bonyoung. (2009). Causes That Hypothesis about Word Shape Could Not Be Fixed, *Conference of Communication Design Society*, Vol.2009 16-21

10) Koo, Bonyoung. (2018) Examination of Word Shape Effect by Adjusting the Strength of the Word Shape Determinants of Latin Characters, *Bulletin of Korean Society of Basic Design & Art*, 2018 Vol.19 No.4, 29-40

2.4 Stroke Density Effect

Bonyoung Koo pointed out that there is a large difference in stroke density between the Hangeul characters, and conducted various experiments with the SDE hypothesis, that the stroke density difference would intervene in the reading process.

He pointed out that a character composed of many strokes looks darker than composed of few strokes and prepared two kind of documents written in Hangeul for an experiment : applying bolder fonts with more strokes to enhance the effect of stroke density and applying lighter fonts with more strokes to weaken the effect of stroke density. As a result, it was confirmed that the legibility of the sentence enhancing the effect of stroke density was higher (Koo, 2008).¹¹⁾

He proved SDE through several other experiments : an experiment applying dark or light background around high stroke density area (Koo, 2010a)¹²⁾ and an experiment applying light strokes in the part of high or low stroke density area (Koo, 2010b).¹³⁾

In addition, there are several researches about stroke density of letters such as study of Jonathan et. al. (2016).¹⁴⁾ However they are not about SDE that made of the number and length of strokes but thickness of stroke but about thickness of fonts.

11) Koo, Bonyoung. (2008) *ibid*

12) Koo, Bonyoung. (2010a) Associations between The Structures of Hangeul Fonts for Text and The Factors of Recognition, *Doctoral Dissertation of Dankook University*, 118-123.

13) Koo, Bonyoung. (2010b) The Test of Hypotheses about Stroke Density Effect, *Journal of Communication Design*, Vol.34 16-24

14) Jonathan Dobres, Nadine Chahine, Bryan Reimer, David Gould, Nan Zhao, (2016) The effects of Chinese typeface design, stroke weight, and contrast polarity on glance legibility, *Displays* 41, 42-49.

2.5 Inference of SDE written in Latin Letters

In the case of Latin Letter, the differences of stroke density between each letter is smaller than the case of Hangeul. However in word units, there are differences in stroke density depending on the areas. This study assumed that these differences would also serve as cognitive factors for the word and designed an experiment to verify the SDE.

To design the experiment, the experimental methods to verify the SDE of Hangeul were referred to. The experiment applying fonts of different thickness was considered inappropriate because of different situation Latin letters have.

Consequently for the experimental method, experimental documents that the background of high density areas were darkened or brightened were chosen ; darkened to enhance and brightened to weaken the SDE.

3. Experiment Design

3.1 Precondition

Where the strokes are dense, it looks visually dark, while where it is not, it looks relatively bright. Therefore if the surroundings with dense strokes are darkened, the SDE will be enhanced and if the surroundings with dense strokes are brightened, the SDE will be weakened

3.2 Subject

The subjects were 108 persons aged between 18 to 40 years old who live in Georgia, United States and whose first language is English. Demographic statistics such as sex or occupation was not considered because the SDE does not seem to be different depending on the tendency

of subjects. However persons who speak English as the second language or who are under the age of 18 were excluded from the subjects because the SDE must be based on familiarity with sufficient reading experience. In addition, persons more than 40 years old were also excluded from the subjects because of presbyopia.

The experiment was conducted on staffs at various shops and offices and on undergraduate and graduate students.

3.3 Materials

10 articles were selected from news paper web sites of United States. The selected articles did not have complex numbers, special characters, or abbreviations and consisted of between 400 and 500 words. In addition, all of them were published more than 10 years before. If a recent article had been used as an experimental material, some subjects would have experienced the articles and the experience would have affected the experiment.

The American Studies Specialist selected two articles with the lowest reading difficulty (articles A and B) out of 10 articles and modified the hard words among the words used in the articles to be easy words at the level of 9th grade students.

Each selected article was typed on A4 paper with Helvetica Neue 45 Light 12pt size, 18pt line spacing, and 130mm line length.

To extract the areas that strokes are dense, the articles were imported into Adobe Photoshop and applied blur filter. Then the areas where the strokes were dense were extracted, using the level command and channel.

Two types of backgrounds were prepared : background type D (dark) that dark gray (black30%) was applied to the extracted

area on the light gray (black 15%) background and background type L (light) that white was applied to the extracted area on the light gray (black 15%) background.

With two articles and two background types, four kind of documents were made : document AD that applied article A on the background type D, document AL that applied article A on the background type L, document BD that applied article B on the background type D, and document BL that applied article B on the background type L.

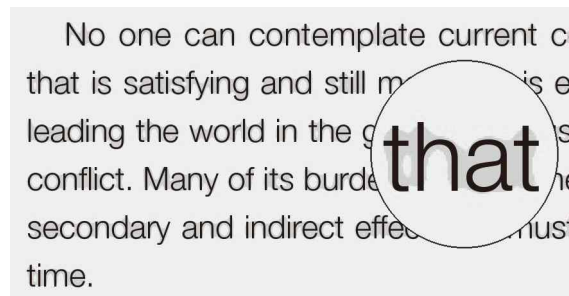


Fig. 1 Example of a document Applied Background Type D

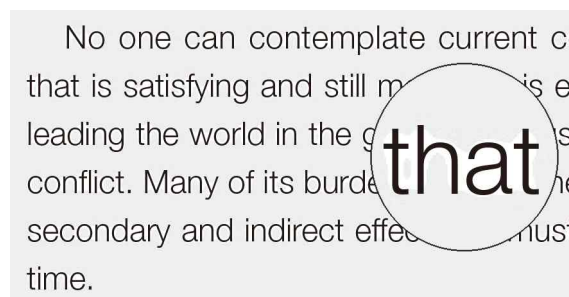


Fig. 2 Example of a document Applied Background Type L

Table 2 Four Documents by Applied Article & Background

	Article A	Article B
Background Type D	document AD	document BD
Background Type L	document AL	document BL

Two kinds of handouts were made : Handout ADBL that composed with a cover, document AD, and document BL and Handout ALBD composed with a cover, document AL, and document BD.

Table 3 Composition of Each Handout

	page 1	page 2	page 3
Handout ADBL	cover	document AD	document BL
		Article A	Article B
		that	that
Handout ALBD	cover	document AL	document BD
		Article A	Article B
		that	that

3.4 Procedure

The experiment was conducted in small groups of 2 to 10 persons. The number of subjects in the group proceeded as evenly as possible, and the number of handouts ADBL and ALBD was distributed in equal numbers. In the case of an odd number of group units, the next experimental unit was adjusted to an odd number to maintain the same number of handouts ADBL and ALBD used for the whole experiment.

Handout ADBL or ALBD was distributed to each subject. After the experimenter explained how to take the experiment and gave the start signal, the subject was asked to read the example sentence on the cover. After 30 seconds, when the experimenter gave a stop signal, the subject stopped reading and marked the last word read. The experimenter confirmed if there was an error a subject made in the experiment or not. If an error was found, the experimenter further explained in order to participate correctly.

When the experimenter signaled the start again, the subject turned the page and started reading article A (experimental document AD or AL depending on the subject). One minute after the start of reading article A, when the experimenter gave a stop signal, the subject was asked to mark the last word read by the previous method.

When the experimenter signaled the start

again, the subject turned the page and participated in the same manner as the previous method for article B (experimental document BL or BD depending on the subject).

4. Results of Experiment

A total of 100 handouts were analyzed, except for the cases where all on the article A or B was read and where the last word read was not displayed or was ambiguous among 108.

Among them the analysis was performed on 92 handouts, except that 8 handouts whose proportions read words or letters through each document by same subjects were more than twice the standard deviation from the mean value.

As a result, the average number of words read by the subject for 1 minute was 304.03 for document AD, 321.39 for document BL, 283.33 for document AL, and 305.21 for document BD. The average number of letters read by the subject for 1 minute was 1495.34 for document AD, 1534.95 for document BL, 1400.00 for document AL, and 1460.13 for document BD.

Table 4 Average Number of Reading Words and Letters

Handout	Article	Bg.	Stroke Density	Word	Letter
ADBL	A	D	enhance	304.03	1495.34
	B	L	weaken	321.39	1534.95
ALBD	A	L	weaken	283.33	1400.00
	B	D	enhance	305.21	1460.13

Based on this comparison, subjects who read handout ALBD read less than subjects who read handout ADBL in all cases. When comparing the reading volume by articles, Article B showed a large number of reading words and letters.

In the comparison according to the types of

backgrounds, the article that SDE was enhanced was read more in the case of handout ADBL, while the article that SDE was weakened was read more in the case of handout ALBD. These results show that there were differences in reading ability between subjects and sentence difficulty between articles.

In order to remove the interference caused by the difficulty of sentence, all subjects' reading word indexes WAD/A, WAL/A, WBL/B, and WBD/B were calculated using the following equation.

$$WAD/A = \frac{\text{number of words read from docu. AD}}{\text{avg. number of words read from docu. AD \& AL}} \times 100$$

$$WAL/A = \frac{\text{number of words read from docu. AL}}{\text{avg. number of words read from docu. AD \& AL}} \times 100$$

$$WBL/B = \frac{\text{number of words read from docu. BL}}{\text{avg. number of words read from docu. BD \& BL}} \times 100$$

$$WBD/B = \frac{\text{number of words read from docu. BD}}{\text{avg. number of words read from docu. BD \& BL}} \times 100$$

In addition, the reading letter index LAD/A, LAL/A, LBL/B, and LBD/B of all subjects were also calculated using the following equation.

$$LAD/A = \frac{\text{number of letters read from docu. AD}}{\text{avg. number of letters read from docu. AD \& AL}} \times 100$$

$$LAL/A = \frac{\text{number of letters read from docu. AL}}{\text{avg. number of letters read from docu. AD \& AL}} \times 100$$

$$LBL/B = \frac{\text{number of letters read from docu. BL}}{\text{avg. number of letters read from docu. BD \& BL}} \times 100$$

$$LBD/B = \frac{\text{number of letters read from docu. BD}}{\text{avg. number of letters read from docu. BD \& BL}} \times 100$$

Table 5 Reading Word Index for Each Article

Article	Index	Stroke Density	Word Index		
			Avg.	SD	difference
A	WAD/A	enhance	103.68	22.10	7.06
	WAL/A	weaken	96.62	27.01	
B	WBD/B	enhance	97.53	29.66	5.17
	WBL/B	weaken	102.70	21.84	

Table 6 Reading Letter Index for Each Article

Article	Index	Stroke Density	Letter Index		
			Avg.	SD	Difference
A	LAD/A	강화	103.44	20.84	6.60
	LAL/A	약화	96.85	25.59	
B	LBD/B	강화	97.61	28.50	5.00
	LBL/B	약화	102.61	20.96	

In case of reading letter index average, LAD/A 103.44, LAL/A 96.85, LBL/B 102.61, LBD/B 97.61 showed the same result as word index.

The why the comparison of reading indices according to background types showed opposite results between each article was caused from the different reading abilities each subject group had.

Table 7 Reading Word Index for Each Handout

Handout	Index	ADBL		ALBD	
		WAD/A	WBL/B	WBD/B	WAL/A
Word Index	Stroke Density	Enhance	Weaken	Enhance	Weaken
	Average	103.68	102.70	97.53	96.62
	SD	22.10	21.84	29.66	27.01
	Avg. Difference	0.99		0.90	
	Paired T	0.53		0.55	
P value	0.60		0.59		

Table 8 Reading Letter Index for Each Handout

Handout	Index	ADBL		ALBD	
		LAD/A	LBL/B	LBD/B	LAL/A
Letter Index	Stroke Density	Enhance	Weaken	Enhance	Weaken
	Average	103.44	102.61	97.61	96.85
	SD	20.84	20.96	28.50	25.59
	Avg. Difference	0.83		0.76	
	Paired T	0.47		0.47	
P value	0.64		0.64		

comparing the reading word or letter index between SDE enhanced and weakened for each subject group who used same handout, the SDE enhanced type was higher in both group but insignificant ($P>0.05$).

Table 9 Reading Word Index with SDE Enhanced and Weakened for All Subjects

Word Index		Enhance	Weaken
		Average	100.47
	SD	26.50	24.86
	Avg. Difference	0.94	
	Paired T	0.769	
	P value	0.44	

Table 10 Reading Letter Index with SDE Enhanced and Weakened for All Subjects

Letter Index		Enhance	Weaken
		Average	100.40
	SD	25.29	23.67
	Avg. Difference	0.79	
	Paired T	0.67	
	P value	0.50	

All subjects reading indexes between SDE enhanced and SDE weakened type was also compared, and then the SDE enhanced type was also read easily. However, paired samples T test resulted in insignificant ($P>0.05$).

It is noteworthy that the SDE depends on the reading ability of subjects. Regardless of the types of handouts, the top 30 and bottom 30 persons of reading abilities based on the number of letters read within a given time was analyzed. As a result, the subjects who read SDE enhanced type more than SDE weakened type were 19 persons among 30 persons of the top reading competencies. In contrast, only 12 persons among 30 persons of the bottom reading competencies read SDE enhanced article more.

Table 11 Reading Word Index of the Top 30 and Bottom 30 Persons in Reading Ability

Reading Ability	Top 30		Bottom 30	
	Enhance	Weaken	Enhance	Weaken
Stroke Density				
Average	129.35	125.49	69.18	70.03
SD	5.48	7.20	11.95	10.31
Avg. Difference	3.86		0.85	
Paired T	2.17		0.45	
P value	0.04		0.66	

Table 12 Reading Letter Index of the Top 30 and Bottom 30 Persons in Reading Ability

Reading Ability Stroke Density	상위 30명		하위 30명	
	Enhance	Weaken	Enhance	Weaken
Average	127.96	124.26	70.48	71.53
SD	5.04	6.95	11.75	10.15
Avg. Difference	3.70		1.05	
Paired T	2.19		0.54	
P value	0.04		0.59	

In the average of reading word index, the top 30 persons showed 129.35 for SDE enhanced type and 125.49 for SDE weakened type (3.86 higher for SDE enhanced type ; $P < 0.05$), while the bottom 30 persons showed 69.18 for SDE enhanced type and 70.03 for SDE weakened type (0.85 higher for SDE weakened type ; $P > 0.05$). Similar difference were found for the reading letter index.

5. Discussion

Many studies have been conducted on the factors that determine the overall image of a word. Despite stroke density act as factors that determine the whole image of a word, there was no study on the Stroke Density Effect.

As a result of this experiment, a clue that stroke density might be involved in the reading process of Latin text was found but it was not significant.

However, in the group with relatively high reading ability, the reading efficiency of the SDE enhanced type was significantly higher, whereas in the group with poor reading ability, the reading efficiency of the SDE enhanced type was low insignificantly. This shows the possibility that the SDE actually exists, considering that the effect is based on sufficient reading experiences.

The reason that the reading efficiency of the SDE enhanced type was lower in the

group with low reading ability was that the surroundings of the stroke were darkened in the SDE enhanced type, making it difficult to distinguish between letters and background. In contrasted the periphery of the stroke is brightened in the SDE weakend type so that the distinction between the letters and the background appears clearly.

In this study, the Stroke Density Effect was verified in people with excellent reading ability, but it was not investigated how high level of reading ability was required for the Stroke Density Effect.

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