A Research on Readable Japanese Typography
for Dyslexic Children and Students:

Creating Japanese Typefaces for Dyslexic Readers

Shohei Yamada and Xinru Zhu

The University of Tokyo

Abstract

A line of evidence shows that 3–5% of the population in Japan have developmental dyslexia. Hence, providing them with assistive environment is essential. While it is supported by previous studies that typefaces have impacts on dyslexic readers, Japanese typefaces for dyslexic readers have not been created because (1) the characteristics of typefaces specially designed for dyslexic readers have not been clarified, (2) Japanese typefaces contain a large number of complicated characters which makes them more difficult to create, and (3) it is not easy to create a typeface that fits everyone with dyslexia due to the wide variation of symptoms.

Against this backdrop, the present study aims to develop (i) Japanese typefaces for dyslexic readers and (ii) a typeface customization system for dyslexic readers.

In this paper, we proposed the framework of the research and we conducted three studies which make up a part of the research.

In Study 1, we extracted the characteristics of Latin typefaces for dyslexic readers by both objectively and subjectively comparing the elements of dyslexia typefaces to those of standard typefaces.

In Study 2, we defined the desiderata for Japanese typefaces for dyslexic readers by mapping the characteristics extracted in Study 1 to Japanese typefaces. Previous research reporting the similarity of the character recognition process across the languages and the similar visual symptoms of dyslexia in English and Japanese provides basis for the mapping.

In Study 3, we create two prototypes of Japanese typefaces for dyslexic readers—*LiS Font walnut* and *LiS Font cashew*—by applying the desiderata defined in Study 2 both programmatically and manually to an open source font Source Han Sans. We also propose methods for the preliminary evaluation of the prototypes based on previous studies.

Keywords: developmental dyslexia, Latin typefaces, Japanese typefaces, readability, legibility

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1. Introduction

1.1. Background

Developmental dyslexia is defined as below according to the International Dyslexia Association.

"Dyslexia is a specific learning disability that is neurobiological in origin. It is characterized by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities. These difficulties typically result from a deficit in the phonological component of language that is often unexpected in relation to other cognitive abilities and the provision of effective classroom instruction. Secondary consequences may include problems in reading comprehension and reduced reading experience that can impede growth of vocabulary and background knowledge." (International Dyslexia Association, 2002)

Evidence shows that 5–17% of the population in English-speaking countries and 3–5% of the population in Japan have developmental dyslexia (Shaywitz & Shaywitz, 2007; Karita et al., 2010). As is stated in its definition, children and adults with dyslexia may suffer from difficulties in reading comprehension, a reduced reading experience, and a shortage of vocabulary and background knowledge, which may lead to a lack of self-esteem. Therefore it is essential to provide sufferers of dyslexia with an assistive environment.

Since the symptoms of dyslexia vary from person to person, a wide range of assistive tools have been adopted to help dyslexic readers (Smythe, 2010; Kato, 2016). These tools can be divided into two categories: (1) auditory assistive tools (e.g. text-to-speech software and hardware, audio books, multimedia books), and (2) visual assistive tools (e.g. rulers, colored overlays, adjustments to typographic elements) (Iizuka, 2007; Smythe, 2010).

In this research, we focus on adjustments to typographic elements, especially typefaces, as a visual assistive tool for dyslexic readers.

During the past few years, several Latin typefaces have been created for dyslexic readers. These are Dyslexie, Lexie Readable, OpenDyslexic, Read Regular, and Sylexiad. Studies indicate that typefaces have significant impacts on dyslexic readers in countries using the Latin alphabet (Rello & Baeza-Yates, 2013). With specially designed typefaces, dyslexic readers are able to read with fewer errors (De Leeuw, 2010; Pijpker, 2013) or they simply prefer the specially designed typefaces compared to standard typefaces (Hillier, 2006).

A recent study indicates that typefaces also affect Japanese dyslexic readers (Tani et al., 2016), which implies that Japanese typefaces specially designed for dyslexic readers would also be effective; however, these are yet to be created.

1.2. Problems

Japanese typefaces for dyslexic readers have not been created mainly because: (1) the characteristics

of typefaces (both Latin and Japanese) for dyslexic readers have not been clarified, (2) Japanese typefaces contain a large number of complicated characters which makes them more difficult to create, and (3) it is not easy to create a typeface that fits everyone with dyslexia due to their wide variation of symptoms.

1.3. Research Objectives

This research proposes prototypes of Japanese typefaces for dyslexic readers by solving the first and second problems stated above.

In this research, we aim to solve the first problem by (i) clarifying the characteristics of Latin typefaces for dyslexic readers and (ii) mapping them to Japanese typefaces to define the desiderata for Japanese typefaces for dyslexic readers, and to solve the second problem by (iii) creating Japanese typefaces for dyslexic readers by programmatically manipulating glyphs of open source typefaces.

This research, therefore, consists of the following three studies:

Study 1: The extraction of the characteristics of Latin typefaces for dyslexic readers,

Study 2: The definition of the desiderata for Japanese typefaces for dyslexic readers based on the characteristics extracted in Study 1,

Study 3: The creation of the Japanese typefaces for dyslexic readers based on the desiderata defined in Study 2 and an evaluation of the typefaces created.

We intend to solve the third problem mentioned above by developing a typeface customization system in future research.

2. Characteristics of Latin Typefaces for Dyslexic Readers
2.1 Methods

Since a typeface is the visual design of the letterforms (Lupton, 2010), its function is related to readability—the ease in reading text without strain or difficulty (Tracy, 1986)—and legibility—the ease in distinguishing one letter from another (Tracy, 1986)—these qualities result from a typeface's visual characteristics.

Thus, the Latin typeface characteristics that are more readable and legible for dyslexic readers can be extracted by describing and comparing the visual features of typefaces for dyslexic readers to those of standard typefaces that are less readable and legible for dyslexic readers. Since visual features of typefaces exist as features of their graphic elements (Koizumi, 2012), comparing characteristics of typefaces means comparing the graphic elements of typefaces.

From over 40 elements of typefaces listed in Koizumi (2012), Kobayashi (2005), Middendorp (2012) and Beier (2012), we selected 15 chief elements to examine in this research because they are mentioned by all the four authors. These elements are shown in *Figure 1*.
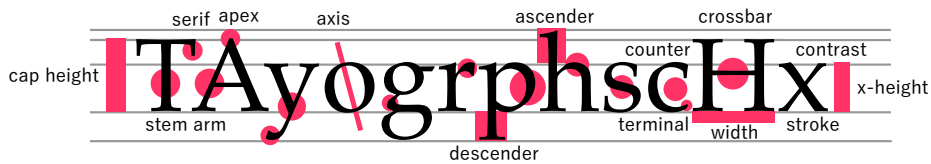
Figure 1 Elements of typefaces

Table 1 PANOSE classification

PANOSE No.	Characteristics of Typefaces
1	Family Kind
2	Serif Style
3	Weight
4	Proportion
5	Contrast
6	Stroke Variation
7	Arm Style and Termination of Open Curves
8	Slant and Shape of the Letter
9	Midlines and Apexes
10	X-height and Behavior of Uppercase Letters Relative to Accents

In order to describe the characteristics of typefaces, we adopted three methods: (i) measuring the elements related to size of the glyphs, (ii) calculating the PANOSE values—PANOSE "is a system for describing characteristics of Latin fonts that is based on calculable quantities: dimensions, angles, shapes, etc." (Haralambous, 2009)—of typefaces by measuring the elements related to details of the glyphs, and (iii) visually comparing and identifying details of the elements related identifying similar letterforms.

The first and third methods are commonly adopted by scholars and practitioners of typography to extract the characteristics of typefaces either objectively or subjectively (Smeijers, 1996; Pohlen, 2015). The second method, however, has not been adopted in the research of typography to the best of our knowledge. In the second method, we use the PANOSE classification of typefaces—a classification system built in the CSS (Cascading Style Sheets) specification, the SVG (Scalable Vector Graphics) specification, and the OpenType font specification—

Figure 2 Dyslexia typefaces and standard typefaces

Dyslexie
Lexie Readable
OpenDyslexic

Arial
Calibri
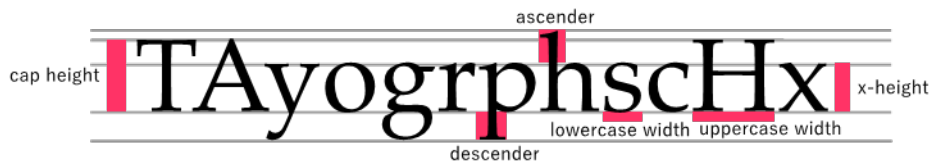Century Gothic
Comic Sans
Trebuchet
Verdana

Figure 3 Elements related to the size of glyphs

to describe the characteristics of typefaces by labeling the characteristics from 1–10. *Table 1* shows the characteristics of typefaces represented by numeric labels. PANOSE values are calculated based on the measurements of the elements of typefaces, and can be used to describe the detailed characteristics of typefaces objectively, which fills a gap between the first and third methods.

We chose to work with two groups of typefaces: dyslexia typefaces and standard typefaces. We selected Dyslexie, Lexie Readable, and OpenDyslexic to be included in the group of dyslexia typefaces because they are widely used and have been evaluated in several studies; we selected Arial, Calibri, Century Gothic, Comic Sans, Trebuchet, and Verdana to be included in the group of standard

typefaces, as they are recommended by the British Dyslexia Association (2015). These typefaces are shown in *Figure 2*.

We conducted our research using the OpenType fonts of these 9 typefaces, the font editor RoboFont, and Python scripts, and the research is conducted within the scope of the licenses of the fonts.

2.2. Results
2.2.1 Size of Glyphs

We measured 6 elements (illustrated in Figure 3) related to the size of the glyphs of 9 typefaces. The result is shown in Figure 4.

In order to obtain the general characteristics of the dyslexia typefaces and the standard typefaces, we calculated the average values of each group. The

results are shown in Table 2 and Figure 5, and the
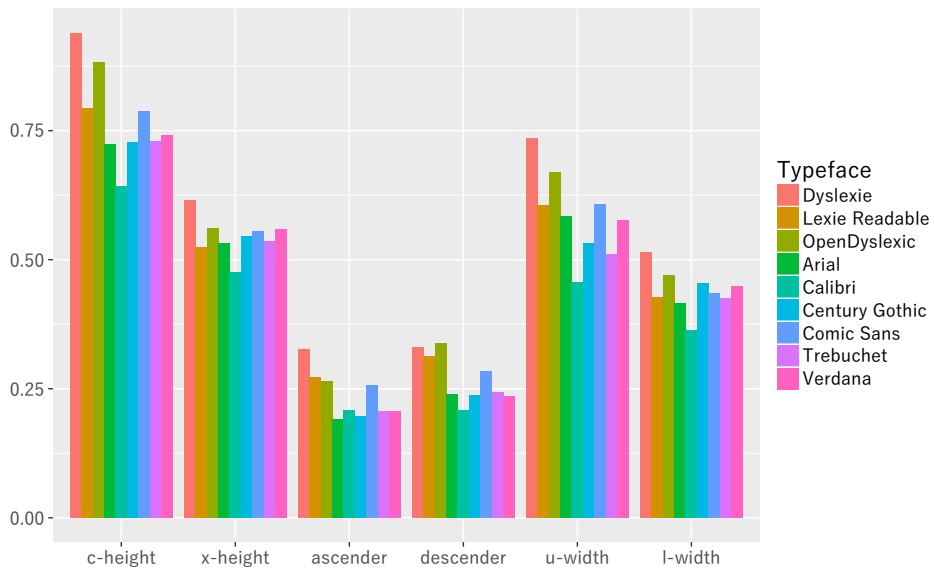visualization of the results is illustrated in Figure 6.

Figure 4 Size of 6 elements

From the measurements and comparison conducted
here, the following characteristics of dyslexia
typefaces are extracted:

a) Letters in a certain font size are larger
than standard letters in the same font size,
b) Extremely tall cap height,
c) Larger gap between cap height and x-
height.

Table 2 Average size of 6 elements of two groups

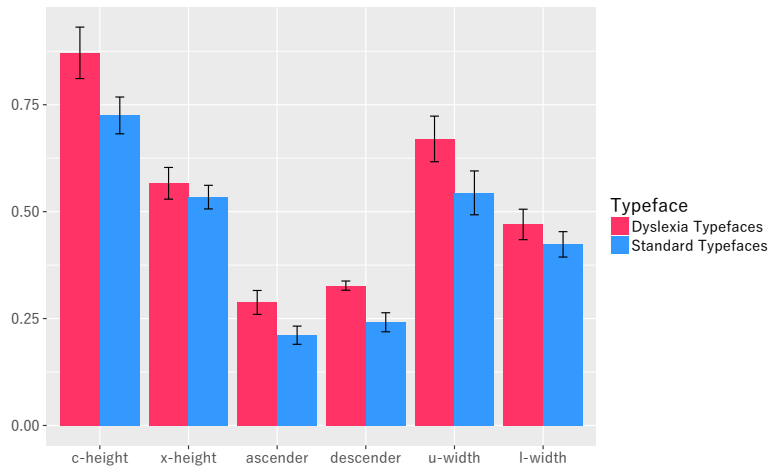| Typeface	c-height	x-height	ascender	descender	u-width	l-width
Dyslexia Typefaces	0.871	0.566	0.288	0.327	0.670	0.470
Standard Typefaces	0.725	0.534	0.211	0.241	0.544	0.424

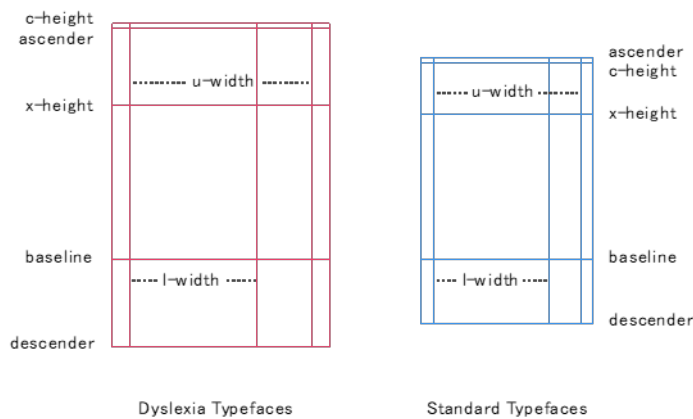Figure 2 Average size of 6 elements of two groups

Figure 3 Visualization of the size of glyphs

2.2.2. Details of Glyphs

We calculated the PANOSE values of each typeface by measuring the elements related to details of the glyphs. The measurement and calculation is conducted based on calculation methods described by Haralambous (2009). The results of our calculations are shown in *Table 3*. The most frequent values are calculated to obtain the general characteristics of each group of typefaces and the results are shown in *Table 4*.

Table 4 shows that two groups of typefaces share the same values only in PANOSE No. 1, No. 8, and No. 9. For those PANOSE values which are different in the two groups, we translated the differencese as characteristics of the typefaces The results are shown in *Table 5*.

Table 1 PANOSE values of 9 typefaces

Typeface	1	2	3	4	5	6	7	8	9	10
Dyslexie	2	11	6	3	3	5	7	2	2	3
Lexie Readable	2	15	5	9	2	2	2	2	2	4
OpenDyslexic	2	15	6	3	5	5	8	2	2	3
Arial	2	11	5	4	2	2	3	2	2	4
Calibri	2	15	5	2	2	2	4	2	2	4
Century Gothic	2	11	4	2	2	2	3	2	3	4
Comic Sans	2	15	5	3	2	2	9	2	9	4
Trebuchet	2	11	6	3	2	2	3	2	3	4
Verdana	2	11	5	2	2	2	4	2	2	4

Table 2 Most frequent PANOSE values of the two groups

Typeface	1	2	3	4	5	6	7	8	9	10
Dyslexia Typefaces	2	15	6	3	NA	5	NA	2	2	3
Standard Typefaces	2	11	5	2	2	2	3	2	2	4

Table 3 Characteristics represented by PANOSE values of the two groups

PANOSE No.	Dyslexia Typefaces	Standard Typefaces
2	15: rounded sans serif	11: normal sans serif
3	6: medium	5: book
4	3: modern	2: old style
5	NA: low contrast	2: no contrast
6	5: gradual/vertical	2: no variation
7	NA: nonstraight arms/horizontal terminations	3: straight arms/wedge terminations
10	3: constant letters/standard x-height	4: constant letters/large x-height

From the measurements, calculation, and comparison conducted here, the following characteristics of dyslexia typefaces are extracted:

Rounded sans serif typefaces,

Bolder strokes,

Larger height/width ratio,

Contrast in stroke width,

Larger gap between cap height and x-height.

2.2.3. Details Related to Similar Letterforms

We examined details of the elements which contribute to the ease of distinguishing similar letterforms in dyslexia typefaces by visually comparing letters of Dyslexie, Lexie Readable and OpenDyslexic to those of Arial.

Before making the comparison, we determined which letterforms in the Latin writing system are similar, based on Koizumi (2012), Samara (2011) and Beier (2012), mapped in

Table 4. During the process, several groups of characters including "I, l, and 1", "O, o, and 0", "b and d", "n and u", "p and q", and "6 and 9" are accorded special attention.

After listing all the details related to distinguishing similar letterforms in each typeface, we extracted the following characteristics of dyslexia typefaces:

As for characters with similar letterforms:

Larger counters,

Manipulated shapes of letterforms,

Slanted or rotated to the opposite direction,

One character of a similar set replaced with an alternative letterform.

Figure 7, *Figure 8*, and *Figure 9* show the comparison of characters in the three dyslexia typefaces to Arial.

Table 4 Similar characters in Latin writing system

Uppercase	Lowercase	Numbers
E, F, H, I, L, T	f, i, j, l, t	1
K, N, Y	k	
M, V, W, X	v, w, x, y	
A, Z	z	4, 7
C, O, Q, S	c, o, s	0, 3, 8
B, D, J, P, U	a, b, d, g, h,	6, 9
	m, n, p, q, r, u	
G, R	e	2, 5

Figure 4 Comparing Dyslexie to Arial

Figure 5 Comparing Lexie Readable to Arial

Figure 6 Comparing OpenDyslexic to Arial

2.2.4 Characteristics of Latin Typefaces for Dyslexic Readers

From the research conducted in this section, we extracted the following characteristics of Latin typefaces for dyslexic readers:

Letters in a certain font size are larger than standard letters in the same font size,

Extremely tall cap height,

Larger gap between cap height and x-height,

Rounded sans serif typefaces,

Bolder strokes,

Larger height/width ratio,

Contrast in stroke width,

As for characters with similar letterforms:

Larger counters,

Manipulated shapes of letterforms,

Slanted or rotated to the opposite direction,

One character of a similar set replaced with an alternative letterform.

3. Desiderata for Japanese Typefaces for Dyslexic Readers

3.1 Methods

In this section, the characteristics of Latin typefaces for dyslexic readers are mapped to Japanese typefaces so that we are able to obtain the desiderata for Japanese typefaces for dyslexic readers.

Although Japanese writing systems are different from languages using the Latin alphabet, the character recognition process across the languages is similar (Dehaene, 2009). Moreover, the visual symptoms of dyslexia such as letter reversals, distortion and blurring, and superimposition (Stein &

Walsh, 1997; Stein, 2008; Kato, 2016), are similar between English and Japanese as well.

Therefore, it is reasonable to assume that the general characteristics of Latin typefaces for dyslexic readers can be mapped to Japanese typefaces.

In the mapping process, we first listed the elements of Japanese typefaces based on Sato (1964, 1965, 1966, 1973, 1976) and associated them with those of Latin typefaces based on their definitions (TR X 0003:2000, 2000). Next we reviewed research in the field of graphic design as well as psychology

to determine the characters with similar forms in the Japanese writing system.

3.2 Results
3.2.1 Elements of Latin and Japanese Typefaces

As stated above, we associated the elements of Japanese typefaces with those of Latin typefaces based on their definitions. The result of this association is shown in *Table 7*. *Figure 10* illustrates these elements of Japanese typefaces.

Table 5 The association of elements of Latin and Japanese typefaces

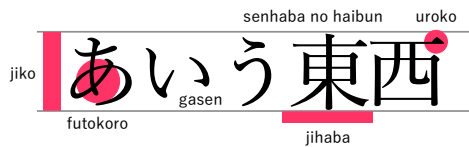| Elements of Latin typefaces	Definitions	Elements of Japanese typefaces
cap height/x-height	the height of a glyph	*jiko* (字高)
width	the width of a glyph	*jihaba* (字幅)
stroke	lines which make up a glyph	*gasen* (画線)
contrast	the amount of variation in between thick and thin strokes	*senhaba no haibun* (線幅の配分)
counter	the empty space inside a glyph	*futokoro* (ふところ)
serif	tapered corners on the ends of strokes	*uroko* (うろこ)

Figure 7 Elements of Japanese typefaces

3.2.2 Characters with Similar Shapes

In Sato (1965, 1966) and Kuwayama (1969), the similarity in shapes of hiragana and katakana characters are discussed in the context of designing typefaces. Matsubara and Kobayashi (1967) and Okada (1970) reported hiragana and katakana characters with similar shapes based on empirical research in the field of psychology.

We compiled a list of hiragana and katakana characters which share similar shapes from this previous research. This list is shown in *Table 8*.

As for kanji characters, Sato (1976), Imada and Yodogawa (1983) looked at the cause of confusion of kanji characters due to the similarity in shape. Kato (2016) suggested the strategy of focusing on kanji radicals to help avoid confusion when teaching kanji characters to dyslexic children.

criteria to determine the similarity of kanji characters from Imada and Yodogawa (1983), as quoted below.

Table 6 Kana characters with similar shapes

Hiragana	Katakana
い, こ	リ, ハ, ソ, ン
へ, く	ウ, ワ, フ, サ
は, ほ	ユ, エ
ろ, る	マ, ア
め, ぬ	テ, チ
わ, ね	ツ, シ
わ, れ	ソ, ン
め, あ	ム, マ
あ, お	ニ, リ
ろ, ら, う	フ, レ

Due to the enormous numbers of kanji characters, it is difficult to list all the kanji characters with similar shapes. In this research we adopt the

"1-A: Kanji characters that share the same radical and the rest of the strokes are very simple (e.g. '方 and 万', '王 and 玉', '体 and 休', '太 and 大', and '貨 and 貸'),

1-B: Kanji characters that share the same radical and the rest of the strokes are very similar (e.g. '官 and 宮', '校 and 枝', '動 and 勤', '陛 and 陸', and '種 and 積'),

2　: Kanji characters that have similar outlines (e.g. '支 and 友', '草 and 革', '銅 and 飼', '丈 and 文', and '専 and 車')" (Imada & Yodogawa, 1983)

3.2.3 Desiderata for Japanese Typefaces for Dyslexic Readers

Based on the research and discussion conducted in 0 and 0, we mapped the characteristics of Latin typefaces for dyslexic readers listed in 0 and obtained the desiderata for Japanese typefaces for dyslexic readers:

Characters in a certain font size are larger than standard characters in the same font size,

Maru gothic (rounded sans serif) typefaces,

Bolder *gasen* (strokes),

Larger height/width ratio,

Contrast in the width of *gasen* (strokes),

As for hiragana and katakana characters with similar shapes:

Larger *futokoro* (counters),

Manipulated shapes of characters,

Slanted or rotated to the opposite direction,

One character of a similar set replaced with an alternative character.

As for kanji characters with similar shapes:

Larger *futokoro* (counters),

Manipulated shapes of characters,

Slanted or rotated to the opposite direction,

One character of a similar set replaced with an alternative character.

An option to frame the structure of kanji characters to illustrate radicals.

4. Creation and Evaluation of Japanese Typefaces for Dyslexic Readers
4.1 Creation
4.1.1 Methods

To create Japanese typefaces which fulfill the desiderata defined in 0, we combined the programmatic method of manipulating glyphs of an existing typeface, the base font, with manual manipulation after reviewing 35 systems of font creation by parameters (Amado, 2011).

We selected Source Han Sans JP as the base font for the reason that it is a high quality open source project of the CID-keyed OpenType font and its character collection is large enough for Japanese typefaces.

Tools adopted during the process include RoboFont, Glyphs, and command line tools of AFDKO (Adobe Font Development Kit for OpenType).

We named the typeface created in this research the *LiS Font*. It will contain 2778 characters when completed. In this paper, however, we present the first prototypes of the *LiS Font*, which contains 274

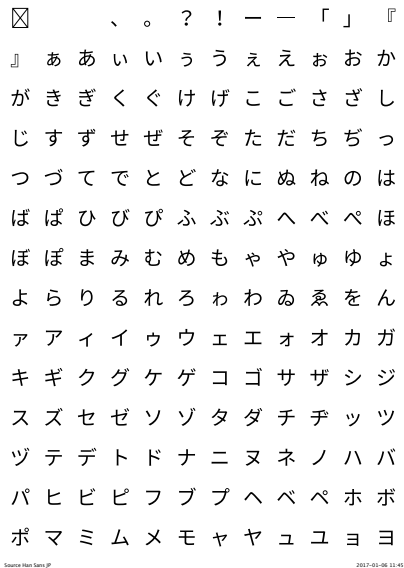characters. *Figure 11* and *Figure 12* show the character collection of the prototypes of the *LiS Font*.

⊠　　　、　。　？　！　ー　―　「　」　『
』ぁあぃいぅうぇえぉおか
がきぎくぐけげこごさざし
じすずせぜそぞただちぢっ
つづてでとどなにぬねのは
ばぱひびぴふぶぷへべぺほ
ぼぽまみむめもゃやゅゆょ
よらりるれろゎわゐゑをん
ァアィイゥウェエォオカガ
キギクグケゲコゴサザシジ
スズセゼソゾタダチヂッツ
ヅテデトドナニヌネノハバ
パヒビピフブプヘベペホボ
ポマミムメモャヤュユョヨ

Source Han Sans JP　　　　　　　　　　　　　　2017-01-06 11:45

Figure 8 Character collection (1)

ラ　リ　ル　レ　ロ　ヮ　ワ　ヰ　ヱ　ヲ　ン　ヴ
ヵ　ヶ　一　右　雨　円　王　音　下　火　花　貝
学　気　九　休　玉　金　空　月　犬　見　五　口
校　左　三　山　子　四　糸　字　耳　七　車　手
十　出　女　小　上　森　人　水　正　生　青　夕
石　赤　千　川　先　早　草　足　村　大　男　竹
中　虫　町　天　田　土　二　日　入　年　白　八
百　文　木　本　名　目　立　力　林　六　⊠　⊠
⊠　⊠　⊠　⊠　⊠　⊠　⊠　⊠　⊠　⊠　⊠　⊠

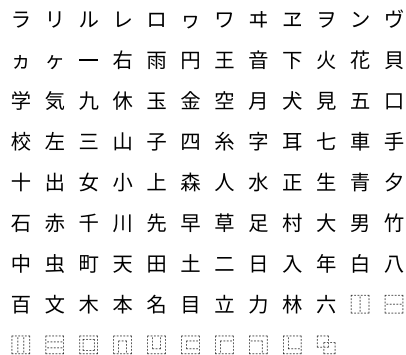Source Han Sans JP　　　　　　　　　　　　　　2017-01-06 11:45

Figure 9 Character collection (2)

Two variations of the *LiS Font* are presented in this paper: the *LiS Font walnut* fulfills the desideratum a, b, c, d, and f; the *LiS Font cashew* fulfills the desideratum a, b, c, d, e, and f. Both contain two versions—version *A* and *B*: version *A* stands for the kanji characters without additional framing lines implicating their structures while version *B* stands for the kanji characters with those additional framing lines, which means the desideratum h is applied.

4.1.2 Results

In the *LiS Font walnut A*, the desiderata for Japanese typefaces for dyslexic readers are adopted as follows:

Selecting Source Han Sans JP Medium as the base font for the *LiS Font Regular* (desideratum c),

Scaling the glyphs to 1.05 units both in width and height by Python scripts (desideratum a),

Further scaling the glyphs to 1.05 units in height (desideratum d),

Rounding the corners of the glyphs by 50 units in radius within the font editor Glyphs (desideratum b),

Applying the following manipulation to Kana characters with similar shapes:

Enlarging the *futokoro* of "は", "ぬ", and "ね" (desideratum f-1),

Transforming the shapes of "へ", "る", "め", "あ", "ら", "ソ", "ン", "フ", "ツ", "シ", "エ", "サ", "リ", "マ", "ム", and "チ" (desideratum f-2),

Rotating "い" and "れ" 10° clockwise, and "こ" and "わ" 10° anticlockwise (desideratum f-3),

Desideratum f-4 and g not applied.

Figure 13 demonstrates the *LiS Font walnut A* in use with the text. *Figure 14* shows Source Han Sans JP Regular in use with the same text.

In the *LiS Font cashew A*, the desideratum e was applied on the basis of the *LiS Font walnut A*. *Figure 15* shows the *LiS Font cashew A* in use.

　　イーヨーは、地面においてある三本の棒をながめていました。二本は、かたほうのはしでぶつかっていて、もう一方のはしでは、はなれていました。そして、その二本の上に、もう一本の棒がのっていました。コブタは、きっとこれは、なにかのわなだろうと思いました。
「あのイーヨー。」と、コブタはもういちどいいました。「ぼく、ちょっと──」
「コブちゃんかな？」イーヨーは、まだ棒をながめながら、いいました。
「ええ。イーヨー。ぼくね──」
「おまえ、これ、なんだか知っとるか？」
「いいえ。」
「これは、Ａの字じゃ」
「ああ。」と、コブタがいいました。
「アーじゃないぞ。エーじゃ。」イーヨーは、こわい声でいいました。

Figure 10 *LiS Font walnut A* in use

　　イーヨーは、地面においてある三本の棒をながめていました。二本は、かたほうのはしでぶつかっていて、もう一方のはしでは、はなれていました。そして、その二本の上に、もう一本の棒がのっていました。コブタは、きっとこれは、なにかのわなだろうと思いました。
「あのイーヨー。」と、コブタはもういちどいいました。「ぼく、ちょっと──」
「コブちゃんかな？」イーヨーは、まだ棒をながめながら、いいました。
「ええ。イーヨー。ぼくね──」
「おまえ、これ、なんだか知っとるか？」
「いいえ。」
「これは、Ａの字じゃ」
「ああ。」と、コブタがいいました。
「アーじゃないぞ。エーじゃ。」イーヨーは、こわい声でいいました。

Figure 11 Source Han Sans JP Regular in use

　イーヨーは、地面においてある三本の棒をながめていました。二本は、かたほうの
はしでぶつかっていて、もう一方のはしでは、はなれていました。そして、その二本
の上に、もう一本の棒がのっていました。コブタは、きっとこれは、なにかのわなだ
ろうと思いました。
「あのイーヨー。」と、コブタはもういちどいいました。「ぼく、ちょっと──」
「コブちゃんかな？」イーヨーは、まだ棒をながめながら、いいました。
「ええ。イーヨー。ぼくね──」
「おまえ、これ、なんだか知っとるか？」
「いいえ。」
「これは、Ａ の字じゃ」
「ああ。」と、コブタがいいました。
「アーじゃないぞ。エーじゃ。」イーヨーは、こわい声でいいました。

Figure 12 LiS Font cashew A in use

In the *LiS Font walnut B* and *LiS Font cashew B*, the desideratum h was applied on the basis of either the *LiS Font walnut A* or *LiS Font cashew A. Figure 16* shows 14 kanji characters to which the desideratum h has been applied. Since the desideratum e was only applied to Kana characters, *LiS Font walnut B* and *LiS Font cashew B* share the kanji characters.
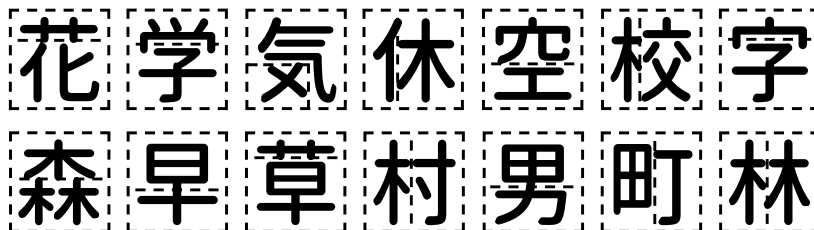
花 学 気 休 空 校 字
森 早 草 村 男 町 林

Figure 13 Kanji characters with additional framing lines

4.2 Evaluation

4.2.1. Methods

Now that the first prototypes of Japanese typefaces for dyslexic readers have been created through this research, an evaluation has to be conducted to assess the effectiveness of these typefaces.

Based on a review of the literature review of empirical studies of readability and legibility of typographic elements (Lonsdale, 2014; Beier, 2012) and the empirical research concerning the readability and legibility of typefaces on dyslexic readers (Hillier, 2006; De Leeuw, 2010; Rello & Baeza-Yates, 2013; Pijpker, 2013; Ramsey, 2014; Tani,

2016), we propose our evaluation methods as shown below. Since this is the framework for a preliminary evaluation of the prototypes, it will be modified after the first evaluation.

Participants: Children from elementary schools who have been assessed to be dyslexic or have symptoms of dyslexia will be involved to the evaluation. The control group which consists of children without dyslexia will not be set in the preliminary evaluation, but it will be considered in future studies. There will be 4 or 6 children participating in the preliminary evaluation.

Materials: Eight kinds of stimuli will be used in the evaluation: two scripts (a Japanese article of 320 characters and 50 random kana characters) in four typefaces (*LiS Font walnut*, *LiS Font cashew*, Hiragino Maru Gothic, and Hiragino Mincho). All the stimulus will be set in vertical direction and will be printed with black ink on white A4 paper.

Procedure: We will conduct rapid reading tasks on the participants. The participants will be asked to read out the materials as fast and accurately as possible. The reading will be recorded with an IC recorder and the reading time and number of errors and self-corrections will be recorded afterwards. After the tasks, the participants will be asked to name the typeface they prefer most. Since we do not have a control group in the preliminary evaluation, an IQ test and other examinations will not be conducted before the tasks. In future studies, however, WISC-IV Intelligence Scale, Raven's Colored Progressive Matrices, and Screening Test of Reading and Writing for Japanese Primary School Children are planned to be conducted beforehand.

Measures: The reading time and numbers of errors and self-corrections are the objective measures, and the preference of participants is the subjective measure of the readability and legibility of the typefaces.

4.2.2. On the Protection of Personal Information and Human Rights

The evaluation will be conducted under the approval of the Research Ethics Committee of the University of Tokyo.

During the research process, the IDs will be associated with each participant so that the information obtained will remain confidential. Published data will contain no information related to the participants. The electric information will be managed on the secure computers and printed information will be kept in a secure place.

We will inform the participants of details of the research and obtain their consent in writing. Since the assumed participants are children in the preliminary evaluation, we will ask the participants' parents or legal guardians for their permission.

5. Conclusion and Discussion

In this paper, we revealed the possible effectiveness of Japanese typefaces for dyslexic readers in light of the evidence of the previous research and implementation. After proposing the framework of this research, we conducted three studies which make up a part of the research, with the remaining studies to be conducted in the future.

In Study 1, we extracted the characteristics of Latin typefaces for dyslexic readers by both

objectively and subjectively comparing the elements of dyslexia typefaces to those of standard typefaces.

In Study 2, we defined the desiderata for Japanese typefaces for dyslexic readers by mapping the characteristics extracted in Study 1 to Japanese typefaces. The previous research reporting the similarity of the character recognition process across the languages and the similar visual symptoms of dyslexia in English and Japanese provides the basis for the mapping.

In Study 3, we created two prototypes of Japanese typefaces for dyslexic readers—LiS Font walnut and LiS Font cashew—by applying the desiderata defined in Study 2 both programmatically and manually to an open source font Source Han Sans. We also proposed the methods for the preliminary evaluation of the prototypes based on the previous studies.

The critical limitation of this study is the lack of the evaluation, and so the effectiveness of the typefaces created in this study is yet to be revealed. In future studies we will conduct the evaluation and use the resulting data to adjust the design of the typefaces. The quality of the typefaces created and the efficiency of the creation process is also to be improved.

Moreover, since the symptoms of dyslexia vary from person to person, which is implied by previous research, the impact of the universal Japanese typefaces for dyslexic readers is possible to be subtle to some subtypes of dyslexia. Therefore on the basis of the typefaces we created in this research, a typeface customization system for dyslexic readers and a wide variation of typefaces specialized for

certain symptoms of dyslexia is expected to be developed in future research.

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