Evaluation of Fonts for Digital Publishing and Display

C. Y. Suen[A], N. Dumont[B], M. Dyson[C], Y.-C. Tai[D], X. Lu[E]

A. CENPARMI, Concordia University, Canada

B. Design & Computer Arts, Concordia University, Canada

C. Typography and Graphic Communication, The University of Reading, U.K.

D. Vision Performance Institute, Pacific University, U.S.A.

E. ICST, Peking University, China.

ABSTRACT

Advances in digital technology have greatly facilitated the design of new type fonts. Today, hundreds of thousands of fonts can be found in various visual appearances or styles, which are used in digital publishing and information display. As a result, it has become important to find ways of evaluating their impact on our daily lives: (1) ease in reading, (2) comprehension of the texts, and (3) eye-strain. This paper summarizes an in-depth inquiry into the following topics: (a) impact of fonts on digital publishing and display, (b) the influence of typographic features on reading, (c) the role of fonts in reading, (d) effect of spacing on reading speed and comprehension, and (e) machine reading of early styles of ancient Chinese characters. Several insightful questions on this subject are asked, and answers have been provided through this paper and the oral presentations. A comprehensive list of references is included at the end of each section for further studies and research.

Keywords: fonts, evaluation, reading, digital publishing, display, typographical features, spacing, character recognition

A. INTRODUCTION, OBJECTIVE & RATIONALE

Ching Y. Suen <suen@cs.concordia.ca>

Thousands of years ago, humans created symbols to represent the things they saw, heard, touched, found, remembered, imagined, and discussed. They were carved onto rocks, walls, shells, bones, and other materials. From these symbols, pictograms, letters, words and alphabets were invented, then modified and expanded into different languages that have evolved over the years. The invention of paper and writing instruments followed, allowing different ways of representing the same symbol, and forming the basis of different stylistic variations and eventually different font types. Just like the evolution of different models of calligraphy, different fonts have been introduced which can mark the distinctive styles of different publishers, printers, word processors, and font producers.

In the last century, computers and digital technology have emerged, allowing the alphabets of all languages in the world to be printed and displayed digitally. Once a symbol is represented in a digital format, there are virtually infinite ways of representing it in the form of unlimited fonts. Such a variety of typefaces can be chosen and combined for publishing casual and legal documents, manuals and notices, newspapers and magazines, books and notes, notices and advertisements, arts, etc. The same variety of fonts can be applied to digital displays and electronic devices, such as computer screens, cell phones, cameras, e-books, etc.

With the latest advances in science and technology, society has become more complex, and we have to use more modern equipment and devices, and constantly adapt to more sophisticated tasks, e.g. we use the computers now more than ever, read a lot more than our ancestors, and text has become an indispensable means of communication in our daily lives. As a result, today's children have to study and read a lot of materials each day, and many of them have presumably become more knowledgeable and smarter than previous generations. However, such technology also comes with a greater demand on the constant use of our eyes at close proximity, and an increase in the incidence rate of myopia among children as well as adults. Actually, according to recent studies, the eyesight of today's generation is worse than that of their ancestors. Indeed, the font literature is full of papers on legibility studies, myopia, reading habits, and the influence of font designs [1, 2]. New studies on human perception of typeface personality traits and the elicitation of personal preferences for font types have also appeared [3-5], and it has also been shown that "if it's hard to read, it's hard to do" when the instructions to do the task are presented in easy- or difficult-to read print fonts [7].

At CENPARMI, we have conducted several studies on methods of assessing the readers' preferences for fonts in English, Chinese, and Arabic [4, 5], and their relation to machine recognition of characters and words (OCR)[6]. We

IEEE computer society

have also resumed our research on effects of printed fonts on reading comprehension [8].

Hence it seems that this is a good time to extend the above studies and ask the following intriguing questions:

"Do font styles play a role in legibility, readability, and comprehension?"

"What are the major differences between human reading and machine reading?"

"Which fonts are best for human reading and machine reading?"

"Can we develop a systematic way of evaluating the qualities of different fonts?"

"Can a font be designed that makes reading easier, thereby reducing eye strain?"

"How can we stop or reverse the incidence rate of myopia in children?"

"How do font designs and their digital displays affect human perception and reading comprehension?"

"What are the traits of fonts that may elicit different feelings, perceptions, preferences and meanings?"

To answer these questions and prepare ourselves for further investigations, we have assembled this panel of experts to provide their answers and opinions on this subject. We have also asked them to include a comprehensive list of references on this subject to facilitate future research.

[1] R. J. Woods, K. Davis, and L. F. V. Scharff, "Effects of typeface and font size on legibility for children," Am J of Psychological Research, vol. 1, 86-102, 2005

[2] D.-L. Huang, P.-L. P. Rau, and Y. Liu, "Effects of font size, display resolution and task type on reading Chinese fonts from mobile devices," Int. J. Industrial Ergonomics, vol. 39, no. 1, 81-89, 2009.

[3] A. D. Shaikh, B. S. Chaparro, and D. Fox, "Perception of fonts: perceived personality traits and uses," Usability News, vol. 8, 1-7, Feb. 2006.

[4] Y. Li and C. Y. Suen, "Personalities of English fonts,"... Proc. DAS (Int. Workshop on Document Analysis Systems), pp. 231-238, Boston, May 2010.

[5] B. Zhang, Y. Li, C. Y. Suen and X. M. Zhang, "Chinese fonts & comprehension," Proc. ICDAR 2011

[6] C. Y. Suen, S. Nikfal, Y. Li and N. Nobile, "Evaluation of typeface legibility based on human perception and machine recognition," Proc. ATypI International Conf., pp. , Dublin, Ireland, Sept. 2010.

[7] H. Song and N. Schwarz, "It it's hard to read, it's hard to do," Psychological Science, vol. 19, no. 10, 986-988, 2008.

[8] C. Y. Suen and M. Komoda, "Legibility of digital type-fonts and comprehension in reading," in J. C. van Vliet (ed.), Text Processing and Document Manipulation, Cambridge University Press, 1986.

B. The influence of typographic features on legibility

What type designers wish they could learn from research?

Nathalie Dumont < nathalie.dumont@concordia.ca>

I. INTRODUCTION

Some typographic features are generally regarded within the typography domain as supporting a better legibility. And yet, little research has been made to verify these precepts. Larger x-heights, open counters, serifs and a diagonal axis of the strokes are features commonly considered preferable for continuous reading [1]. Collaborative research teams that include type specialists could lead to the creation of typefaces better adapted for reading longer texts.

II. DISTINCTION BETWEEN LEGIBILITY AND READABILITY

Legibility refers to the ease with which the individual characters are deciphered. Design attributes such as character shapes and proportions, stroke weight and axis, affect legibility. Legibility is about perception. Readability refers to comprehension and visual comfort in reading long text passages [2]. People who design types, i.e. type designers, have a direct influence on legibility and people who set type, i.e. typographers, are determinant in text readability.

III. TYPOGRAPHIC FEATURES CONSIDERED TO PERFORM BETTER

A. Large x-height

The x-height corresponds to the middle part of the lowercase letters, ascenders and descenders excluded (fig. 1). Because of its flat top and bottom parts, the letter x is used to measure the x-height. For the same type size, a typeface with a larger x-height seems bigger and is believed to be more legible [3].

The first Latin typefaces with larger x-heights were created by Ameet Tavernier [4] in the Netherlands around 1550 and paved the way to 'the Dutch taste' [5], characterized by sturdy types, dark in color, and with high x-height.

There are multiple examples of contemporary work by renowned type designers portraying large x-heights for legibility matters and this notion is frequently referred to in the literature. Adrian Frutiger was very concerned with questions of legibility during his fruitful career, "[…] the generally higher x-height gives an open appearance to the counters. This means that his typefaces are readable, even at small point sizes." [6]

The typeface Photina by the type designer José Mendoza y Almeida was designed in 1972 for photocomposition and is praised for its legibility: "Thanks to its large x-height and short ascenders, which it has in common with Times New

Roman, it is an eminently legible typeface even at very small point sizes, despite its strong contrast." [7]

The typeface Helvetica wouldn't obtain unanimity from the typographic community for its legibility performance. Its small apertures are believed to hinder character differentiation. Despite that, "[o]ne of Helvetica's most remarkable features is its large x-height […]. This gives the letterforms an increased volume, allowing for better legibility than many san serifs." [8] Many other examples could be brought as an important number of the recent typefaces are designed with a fairly large x-height. The increased legibility provided by this feature seems broadly accepted by the typography circle.
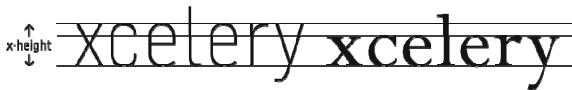

Figure 1. Flama & Perpetua have different x-heights at the same type size

B. Open counters

Counters are the spaces partly or fully enclosed by the letterforms (fig. 2). It is believed that open counters support legibility [9] [10] by helping to distinguish better each character's particularities; for instance, an open lowercase e is less likely to be confused with the letter o if its bottom stroke doesn't extend as high.

Early typefaces of the 15th and 16th century were inspired by humanist handwriting and had large apertures. Over the centuries, printed letterforms were progressively rationalized and slowly departed from calligraphic forms. Baskerville, 1757, had smaller apertures than Garamond, c. 1540, and Didot's apertures, 1784, were even smaller. Renaissance forms were rediscovered in the 20th century and larger apertures reappeared.

A good example of this change in taste is the typefaces Univers, 1957, and Frutiger, 1976. Adrian Frutiger designed the latter typeface with better legibility in mind and opened the counters of the letterforms [11]. Spiekermann and Ginger also agree with the open counters theory. According to them, the legibility of the typeface Frutiger is improved "by keeping letter shapes open and more distinct from one another" [12]. Similarly, Matthew Carter's Galliard has generous and open counters which supports legibility [13].
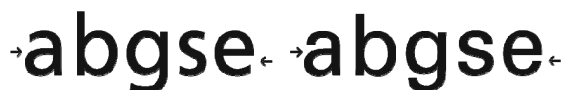

Figure 2. Counters of Frutiger are more open than those of Univers

C. Seriffed typefaces

Serif typefaces are preferred for continuous reading by most typographers [14] and some think that they perform better [15]. Serifs are believed to help create more distinctive letterforms [16] and to support the horizontal flow of the eye along the line of text whereas sans serif typefaces are considered too monotonous to sustain visual interest [17]. Studies on this topic have been considered inconclusive and unreliable [18] [19]. More specific answers would beneficiate to the work of type designers and typographers [20], therefore there's a need for more research on this question (fig. 3).

Figure 3. The sans serif typeface Myriad and the seriffed Minion

D. Stroke axis

The axis of the stroke is the angle of distribution of the thick and thin strokes (fig. 4). Typefaces with an oblique axis maintain calligraphic influences. It was suggested that such shapes support better the horizontal movement of the eye along the lines of text [21]. These humanistic or calligraphic characteristics are present in both serif and sans serif typefaces. Research on their influence on legibility could also clarify the serif vs. sans serif debate.
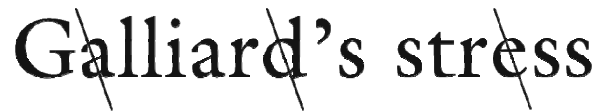

Figure 4. Galliard is a typeface with an oblique stroke axis (or stress)

IV. CONCLUSION

This review suggests that the typography domain could benefit research on the effect of design features on legibility. Collaborative research teams that include type specialists could tackle such specific questions and lead to new type designs informed by scientific data.

REFERENCES

[1] I. Strizver, Type rules: The designer's guide to professional typography, Third edition. Hoboken, NJ: Wiley, 2010, pp. 73–76.

[2] W. Tracy, Letters of credit. Boston: Godine, 1986, pp. 30–32.

[3] W. Hill, The complete typographer, third edition. London: Thames and Hudson, 2010, p. 119.

[4] J. Middendorp, Dutch type. Rotterdam: 010 Publishers, 2004, pp. 17–18.

[5] D. B. Updike, Printing types: Their history, forms, and use., Fourth edition, expanded. New Castle, Delaware: Oak Knoll and London: The British Library, 2001.

[6] H. Osterer and P. Stamm, Eds, Adrian Frutiger – typefaces: The complete works. Basel: Birkhäuser, 2009, p. 415.

[7] M. Majoor and S. Morlighem, José Mendoza y Almeida. Paris: Bibliothèque Typographique, 2010, p. 77.

[8] P. B. Meggs and R. McKelvey, Eds, Revival of the fittest. New York: RC Publications, 2000, p. 139.

[9] W. Hill, The complete typographer, third edition. London: Thames and Hudson, 2010, p. 119.

[10] C. Perfect and J. Austen, The complete typographer: A manual for designing with type. Englewood Cliffs, NJ: Prentice Hall, 1992, p. 203.

[11] A. Frutiger, À bâtons rompus. La Tuilière, France: Atelier Perrousseaux, 2001, pp. 64–65.

[12] E. Spiekermann and E. M. Ginger, Stop stealing sheep & find out how type works, second edition. Berkeley, CA: Adobe, 2003, p. 81.

[13] M. Re, Typographically speaking: The art of Matthew Carter. University of Maryland, Baltimore County, 2002, p. 14.

[14] J. Felici, The complete manual of typography. Berkeley, CA: Adobe, 2003, pp. 68–69.

[15] R. McLean, The Thams & Hudson manual of typography. London: Thames & Hudson, 1980, p. 44.

[16] A. Frutiger, About legibility. Last consulted July 1, 2011: http://www.linotype.com/2258-16905/aboutlegibility.html

[17] C. Perfect and J. Austen, The complete typographer: A manual for designing with type. Englewood Cliffs, NJ: Prentice Hall, 1992, p. 203.

[18] O. Lund, "Knowledge construction in typography: the case of legibility research and the legibility of sans serif typefaces," PhD: University of Reading, 1999.

[19] O. Lund, "Why serifs are (still) important," Typography Papers, 2, 1997, pp. 91–104.

[20] G. Unger, While you're reading. New York: Mark Batty, 2007, pp. 160–168.

[21] O. Lund, "Description and differentiation of sans serif typefaces." Postgraduate Diploma: University of Reading, 1993.

C.   The role of fonts in reading

Clutter or cues?

Mary C. Dyson <M.C.Dyson@reading.ac.uk>

I.   INTRODUCTION

Font recognition is an important element in automatic document processing as it helps in character recognition and in identifying the font to use in typesetting [1]. But does the font play any part in reading? Evaluating which fonts are better for reading is one area of legibility research which is carried out by a relatively small number of psychologists, with an even smaller number comparing fonts. Various authors have reviewed legibility in general [2-8]; legibility of fonts [9-11]; and screen fonts [12].

Although there are some differences in the relative legibility of fonts, a skilled reader recognizes most words within a fraction of a second despite the letters being in different fonts [13]. With relative ease, we translate variant visual forms (such as different fonts and sizes) into invariant representations, described as abstract letter identities [14]. A similar skill is demonstrated when we perceive and understand speech from many different talkers with considerable variation in the acoustic properties of speech [15].

Yet most models of reading omit explanations of how variations in fonts that are typical of our normal reading material are handled. Psychologists aim to understand the reading process, and look for generalities; hence they may have little interest in differences among fonts. In contrast, typographers and type designers are interested in what we read and pay critical attention to how fonts are used, i.e., choice of font, font size, number of characters per line, spacing between lines. Through adopting an interdisciplinary approach, greater insight may be acquired into how our perceptual system deals with font variability.

II.   HOW WE IDENTIFY LETTERS

A. The letter as the unit in reading

Within psychology there is broad agreement that letter identification is critical to recognizing words [16]. A letter-based (as opposed to word-based) strategy for reading makes sense when considering the problem of invariance. It is more economical to deal with 26 letters than tens of thousands of words [17]. But this does not rule out the involvement of larger units as evidence has been found for the use of letters, words and sentences in reading, with letters contributing most to reading rate [18]. Despite the importance of letters, we do not yet have a robust account of the early stages of reading as visual word recognition research still glosses over letter perception [19].

B. Perceptual experiments

Research into letter identification has mainly focused on how letters are distinguished from each other, i.e. distinctive features. However, along with creating individual letters that

are clearly different from each other, a crucial aspect of type design is creating a uniformity of design. The variability within a font is constrained so that individual letters have commonalities in style with other letters so as to be identifiable as belonging to the font. These details, such as weight, contrast and stress or axis of the letters, may facilitate letter identification (Fig. 1). This relationship among letters within a font was modeled and investigated through perceptual experiments more than twenty years ago [20, 21] and has been followed up by some more recent work [22, 23].

References [20, 21] suggest that the perceptual system can become tuned to a particular font over time and a set of font parameters is developed (described as 'font tuning'). According to this account, distinct font changes (from letter to letter), will disrupt the translation into font-invariant forms. This was tested in a series of experiments which reliably showed that mixing fonts leads to less efficient letter identification than using the same fonts.

Figure 1. Font characteristics that distinguish among fonts but relate letters within a font

The fonts used in [20,21] were crude in comparison with current technology; subsequent research has used much higher resolution fonts and compared very dissimilar styles, e.g. Cooper Black and Palatino Italic [23]. Work in progress by Dyson suggests that text fonts may need to be very different from each other to show the effects of font tuning. According to [23], very similar fonts will not require a different set of font-specific translation rules. Our perceptual system is probably rather tolerant of variations from the prototypical structural features' [23] or 'essential or structural forms' [24] of letters. Reference [24] describes the essential forms as 'the simplest forms that preserve the characteristic structure, distinctiveness, and proportions of each individual letter'.

III. IDENTIFICATION OF FONTS

A. Time course of font information

In reading, we may therefore make use of commonalities within a font to facilitate the translation into an invariant form. However, this does not require explicit identification or classification of the font.

Some argue that there is a need to preserve font-specific information beyond letter identification, using the example of recognizing an individual's handwriting [25]. We are also sensitive to the font of a word when recognizing brand names or corporate identities [26]. But a counter argument is that fonts have little communicative value compared with voices which convey the talker's gender, age, etc. [27]. Research has produced mixed results as to whether any font information is retained following letter identification [27].

Font tuning data suggests that font parameters or translation rules are available following letter identification as the effect of mixing fonts has been shown to occur across trials, not just within a single trial [21]. The time between trials might be critical and there is some indication of unconscious strategic control of this font information [23].

B. Perceptual experiment

Dyson has drawn on speech research which has shown that the identification of a test word immediately following an introductory sentence is influenced by the properties of the sentence [28]. If font tuning is considered within this paradigm, exposure or tuning to a particular font might affect subsequent perceptions (in this case, identifying the font). This could also be couched in terms of adaptation and visual after-effects. For example, exposure to a face can produce a bias in subsequent face identity, that is in the 'opposite' direction [29].

A continuum of 12 fonts was created by interpolating between Garamond and Bodoni (Fig. 2). Eight participants were asked to identify examples of the 'word' Hamdurefonsiv as most like Garamond or most like Bodoni. Examples came from all 12 points along the continuum (1 being Garamond and 12 Bodoni). A baseline measure established the identification function without prior exposure. Two further conditions introduced a statement, before each test word, that required a true or false response. This was presented in either Garamond or Bodoni. Fig 3 illustrates the change in the identification functions following exposure to the two fonts. Having read a statement in Garamond, participants are less likely to judge a font towards the middle of the continuum (5-9) as Garamond, than if they had not read the statement. There is a much smaller (non-significant) effect when reading a statement in Bodoni.

These results can be interpreted as evidence of adaptation to a font or tuning to the characteristics of that font which leads to a change in the perception or categorization of other fonts.

1   hamdurefonsivHAMDUREFONSIV.,
2   hamdurefonsivHAMDUREFONSIV.,
3   hamdurefonsivHAMDUREFONSIV.,
4   hamdurefonsivHAMDUREFONSIV.,
5   hamdurefonsivHAMDUREFONSIV.,
6   hamdurefonsivHAMDUREFONSIV.,
7   hamdurefonsivHAMDUREFONSIV.,
8   hamdurefonsivHAMDUREFONSIV.,
9   hamdurefonsivHAMDUREFONSIV.,
10   hamdurefonsivHAMDUREFONSIV.,
11   hamdurefonsivHAMDUREFONSIV.,
12   hamdurefonsivHAMDUREFONSIV.,

Figure 2. Continuum from Garamond to Bodoni

Alternatively, the changes may reflect a criterion shift if the font of the test word is judged relative to the preceding statement. The asymmetry, such that Bodoni has less of an adapting influence, may reflect the extent or manner of departure from the essential or prototypical form.

IV. CONCLUSION

This research suggests that fonts may have some role in the identification of letters that underlies human word recognition. Rather than treating font characteristics as detail that must be discarded, these may facilitate letter recognition. Our perceptual system appears to tolerate variation in fonts without disrupting letter identification unless this is quite extreme, or possibly of a particular kind. The multidimensional nature of differences among fonts, i.e. weight, contrast, proportions, basic shapes, terminals and serifs, makes comparisons a challenge for empirical research. An interdisciplinary approach, drawing on design expertise and knowledge of psychological theories and methods, is one way of meeting this challenge.
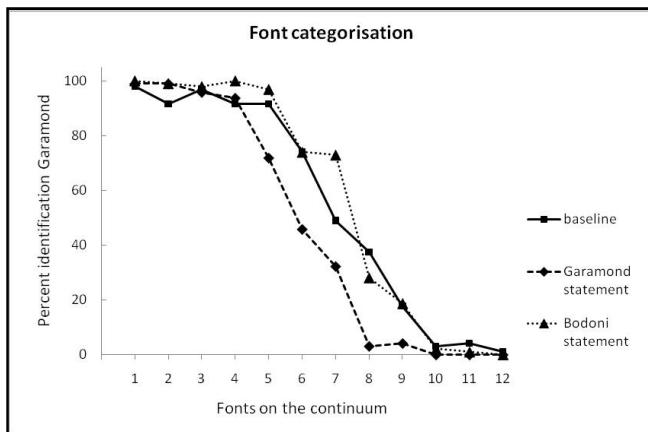

Figure 3.   Effects of reading Garamond or Bodoni on subsequent identification of fonts on the continuum

REFERENCES

[1] Y. Zhu, T. N. Tan, and Y. H. Wang, "Font recognition based on global texture analysis," IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 23, 2001, pp. 1192-1200.

[2] G. W. Ovink, Legibility, atmosphere-value and forms of printing type. Leiden: Sijthoff, 1938.

[3] M. A. Tinker, "Influence of simultaneous variation in size of type, width of line and leading for newspaper type," Journal of Applied Psychology, vol. 47, 1963, pp. 380-382.

[4] M. A. Tinker, Bases for effective reading. Minneapolis: Lund Press, 1965.

[5] B. Zachrisson, Studies in the legibility of printed text. Stockholm: Almqvist and Wiksell, 1965.

[6] H. Spencer, The visible word. London: Royal College of Art, 1968.

[7] J. J. Foster, Legibility research 1972-1978: a summary. London: Graphic Information Research Unit, Royal College of Art, 1980.

[8] L. Reynolds, "The legibility of printed scientific and technical information," in Information design: the design and evaluation of signs and printed material, R. Easterby and H. Zwaga, Eds. Chichester: John Wiley, 1984, pp. 187-208.

[9] E. C. Poulton, "Letter differentiation and rate of comprehension in reading," Journal of Applied Psychology, vol. 49, 1965, pp. 358-362.

[10] E. C. Poulton, "Size, style and vertical spacing in the legibility of small typefaces," Journal of Applied Psychology, vol. 56, 1972, pp. 156-161.

[11] O. Lund, "Knowledge construction in typography: the case of legibility research and the legibility of sans serif typefaces," PhD: University of Reading, 1999.

[12] M. C. Dyson, "How do we read text on screen?," in Creation, use, and deployment of digital information, H. v. Oostendorp, L. Breure, and A. Dillon, Eds. Mahwah,NJ: Lawrence Erlbaum Associates, 2005, pp. 279-306.

[13] K. Rayner and A. Pollatsek, The psychology of reading. Hillsdale, New Jersey: Lawrence Erlbaum, 1989.

[14] D. Besner, M. Coltheart, and E. Davelaar, "Basic processes in reading: computation of abstract letter identities," Canadian Journal of Psychology, vol. 38, 1984, pp. 126-134.

[15] C. S. Martin, J. W. Mullennix, D. B. Pisoni, and W. V. Summers, "Effects of Talker Variability on Recall of Spoken Word Lists," Journal of Experimental Psychology-Learning Memory and Cognition, vol. 15, 1989, pp. 676-684.

[16] K. Larson, "The science of word recognition or how I learned to stop worrying and love the bouma," Typo, vol. 13, 2005, pp. 2-11.

[17] J. Grainger, A. Rey, and S. Dufau, "Letter perception: from pixels to pandemonium," Trends in Cognitive Sciences, vol. 12, 2008, pp. 381-387.

[18] D. G. Pelli and K. A. Tillman, "Parts, Wholes, and Context in Reading: A Triple Dissociation," PLoS ONE, vol. 2, 2007, pp. e680.

[19] M. Finkbeiner and M. Coltheart, "Letter recognition: From perception to representation," Cognitive Neuropsychology, vol. 26, 2009, pp. 1-6

[20] T. Sanocki, "Visual knowledge underlying letter perception: font-specific schematic tuning," Journal of Experimental Psychology: Human Perception and Performance, vol. 13, 1987, pp. 267-278.

[21] T. Sanocki, "Font regularity constraints on the process of letter recognition," Journal of Experimental Psychology: Human Perception and Performance, vol. 14, 1988, pp. 472-480.

[22] I. Gauthier, A. C.-N. Wong, W. G. Hayward, and O. S. Cheung, "Font tuning associated with expertise in letter perception," Perception, vol. 35, 2006, pp. 541-559.

[23] P. Walker, "Font tuning: A review and new experimental evidence," Visual Cognition, vol. 16, 2008, pp. 1022-1058

[24] E. Johnston, Writing & illuminating, & lettering, 21st reprint ed. London: Pitman, 1945, p239..

[25] V. Bruce, P. R. Green, and M. A. Georgeson, Visual perception: physiology, psychology and ecology, 4th ed. Hove: Psychology Press, 2003.

[26] P. Walker and L. Hinkley, "Visual memory for shape-colour conjunctions utilizes structural descriptions of letter shape," Visual Cognition, vol. 10, 2003, pp. 987-1000.

[27] S. D. Goldinger, T. Azuma, H. M. Kleider, and V. M. Holmes, "Font-specific memory: more than meets the eye?," in Rethinking implicit memory, J. S. Bowers and C. J. Marsolek, Eds. Oxford: Oxford University Press, 2003, pp. 157-196.

[28] P. Ladefoged and D. E. Broadbent, "Information conveyed by vowels," Journal of the Acoustical Society of America, vol. 29, 1957, pp. 98-104.

[29] D. A. Leopold, A. J. O'Toole, T. Vetter, and V. Blanz, "Prototype-referenced shape encoding revealed by high-level after effects," Nature Neuroscience, vol. 4, 2001, pp. 89-94.

D. The Magic of Spacing in Text Display

Yu-Chi Tai <YTai@pacificu.edu>

I. Introduction

In painting, white space is part of the art; for reading, it is part of the information.

In typography, spacing (also called *tracking*) refers to the space between characters. Different from *kerning*, which is the special space adjustment between designated pairs of letters for esthetic and readability considerations, spacing affects the general inter-letter and -word arrangement.

Spacing is a critical and ubiquitous feature in typography. It is an equal and integral partner in both typeface design and text layout. Although not carrying specific information code itself, spacing affects the overall text appearance, information density, and the efficiency of text processing. How information is parsed affects how it is perceived. Improper spacing can compromise text readability, even with large font size. In a series of studies, we investigated the role of spacing in recognition of letters and words, regular text reading, and its application in parsing a word to facilitate word processing.

II. Inter-letter Spacing and Word Recognition

Visual processing of individual letters within a word can interfere with one another thereby decreasing word legibility, which is likely due to lateral interference (also called *crowding*) from neighboring letters. Presenting a same word with different spacing changes the dynamics of lateral interference and could result in dramatic changes in visual appearance and performance. Figure 1 shows an example of 10-point Verdana font with condensed and expanded spacing from the default spacing.

Using the step-back distance visual acuity paradigm, adapted from the standard clinical test of visual acuity [1], we found word legibility (i.e., the smallest angular size to recognize a word) as a function of inter-letter spacing [2]. As shown in Figure 2, compared to the legibility of single letters, legibility of words with default spacing is poorer, and even worse with condensed spacing, which has been attributed to the lateral interference in retinal detectors [3-5] and cortical competition in the primary visual cortex during feature integration [6-10]. When spacing is close to the default size, word legibility remains the same. As spacing increases, word legibility likewise increases and gradually reaches asymptote at approximately the same legibility as individual characters.

Spacing	Example
0.6 condensed	The quick brown fox
0.4 condensed	The quick brown fox
0.2 condensed	The quick brown fox
0.0 default	The quick brown fox
0.2 expanded	The quick brown fox
0.4 expanded	The quick brown fox
0.6 expanded	The quick brown fox
0.8 expanded	The quick brown fox
1.0 expanded	The quick brown fox
2.0 expanded	The quick brown fox
2.5 expanded	The quick brown fox
3.0 expanded	The quick brown fox
4.0 expanded	The quick brown fox
5.0 expanded	The quick brown fox
6.0 expanded	The quick brown fox
7.0 expanded	The quick brown fox
8.0 expanded	The quick brown fox
9.0 expanded	The quick brown fox
10.0 expanded	The quick brown fox

Figure 1. Examples of condensed, default, and expanded letter-spacing on word appearance. (Numbers represent the points by which the text is condensed or expanded from default spacing. Using a special program provided by Microsoft Corp., spatial accuracy is up to $1/64^{th}$ pixel.)
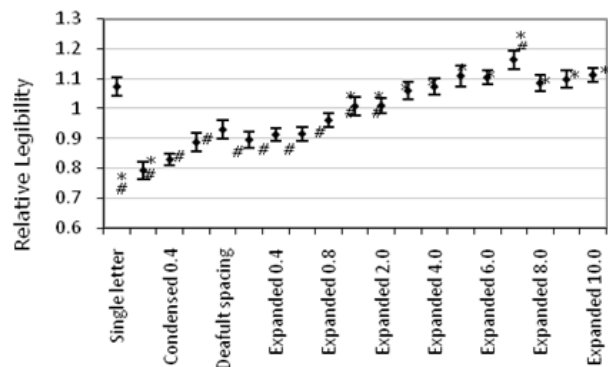

Figure 2. Relative legibility of individual letters and words at different spacing levels. (Error bars show the standard error of the measures. "#" indicates a significant difference ($p < 0.05$) from the single letter legibility. "*" indicates a significant difference ($p < 0.05$) from the legibility with default spacing.)

The result shows that, with unlimited visual exposure, wider spacing enhances the readability of a word and permits a word to be recognized at a smaller visual angle. Similarly results have also been obtained in single letter recognition with flanks [11-15] and visual search [6, 16], and demonstrated both in the fovea [17-19] and the retinal periphery [3, 17, 19], suggesting that it is a general constraint in visual processing.

III. Optimal Letter Spacing and Font Size

With commonly used font sizes, letter spacing scales directly with character size. Such proportional scaling maintains the shape integrity of the word across all sizes. However, since lateral interference operates over a relatively fixed retinal distance [20], proportional scaling may not be the best strategy for optimizing letter spacing. Figure 3 shows the testing results of this assumption [21].

The most commonly used font sizes for reading are between 10 and 12 point, largely been empirically determined. At a typical computer screen viewing distance of 50 cm, these lowercase letters have acuity sizes of 20/54 and 20/66, respectively. These commonly used font sizes are legible as evidenced by their response time close to the asymptotic value, which is the same as the response time to letters. However, 6- and 8-point fonts (acuity size of 20/41 and 20/48) are more within the sloped portion of the curves with longer response time than larger fonts and greater separation between letter and word responses, indicating strong effect of lateral interference.
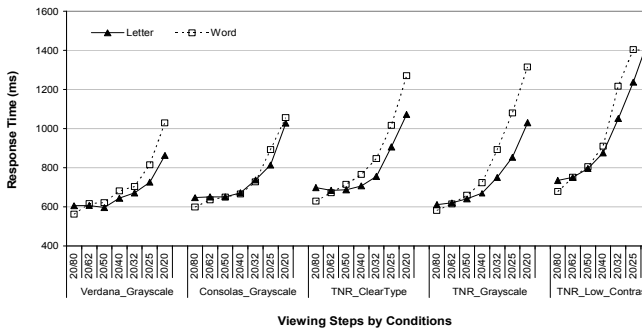

Figure 3. Average response time (RT) for orally reporting the identity of individual letters and words with five font types. RTs are shown for several supra-threshold sizes (20/80 as largest). At a viewing distance of 50 cm, 6-, 8-, 10-, and 12-point lowercase Verdana font have acuity sizes of 20/41, 20/48, 20/54, and 20/66, respectively.

These results suggest that empirical design of the default spacing for common used fonts skirts the limit of lateral interference, which is to be avoided for good readability. The default spacing appears to be just large enough for commonly used letters unburdened from lateral interference of neighboring letters but not big enough to render smaller fonts as legible as individual letters. This suggests that proportional spacing across all font sizes may not be the best strategy; word legibility for smaller fonts could be enhanced with greater spacing, and word legibility for larger fonts may not be compromised with less spacing. These hypotheses were tested in the following study [22].

Words of high- and low-frequency words and letter strings were created in 72-point font with serif (Georgia) and sans-serif (Helvetica) fonts, equally distributed among 7 spacing levels: -15, -10, -5, 0, +5, +10, or +15 pixels from the default spacing of 72-pt font. To create the effect of font size without changing text resolution, viewing distance was set to be 50, 150, 300, 360, 450, and 600 cm so the resulted

angular size was equal to 72-, 24-, 12-, 10-, 8-, and 6-point font viewed from 50 cm. The result showed that response accuracy and speed remained at ceiling for larger font for all spacings but significantly improved with wider spacing for smaller font. Unfamiliar words (low-frequency words or pseudowrds) were affected more by condensed spacing, suggesting the higher reliance of features extraction than with high-frequency words. Serif fonts also suffered more from condensed spacing at smaller sizes than sans serif fonts.

Together, these results suggest that, while default proportional spacing works well for commonly used 10-point fonts, it can be further reduced with larger font sizes for more efficient use of display space and visual processing and increased for smaller font sizes to achieve optimal performance. In addition, spacing can be adapted according to the text content and typeface. As smaller font, serif typeface and unfamiliar words are particulay vulnerable to lateral inhibition, hence wider spacing is preferred. With top-down fortification, familiar words will be tolerable to condensed spacing.
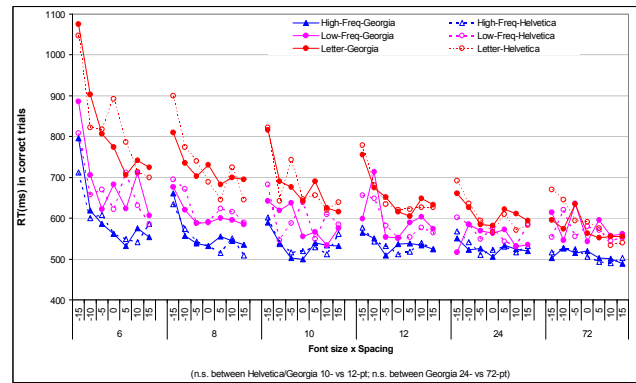

Figure 4. Average response time (RT) for read aloud letters and words at different font sizes (6, 8, 10, 12, 24, & 72 point) and spacing (-15, -10, -5, 0, +5, +10, +15 point from the default proportional spacing).

IV. Inter-letter Spacing and Reading

While the above legibility studies indicate that generous letter spacing is preferred for better recognition of isolated words, it could be difficult for reading continuous text because the excessive space may disturb the internal linking of the letters within a word and obscure the boundary between words, and thus endanger comprehension of the text.

In a study [2], reading performance and eye movements were measured with default spacing, 4 levels of condensed spacing (0.5, 1.0, 1.5, and 1.75 points), and 4 levels of expanded spacing (0.5, 1.0, 1.5, and 2.0 points). The findings indicated that the oculomotor system responds to the change of spacing by adjusting eye movement pattern to maintain the similar size of information as with default spacing. In other words, as spacing increases, saccade amplitude increased and fixation duration decreased (Figure 5), more regressions occurred, but the number of words processed per fixation (figure not shown) and the overall

reading speed (Figure 6) remained unaffected. The opposite pattern was observed with condensed spacing.
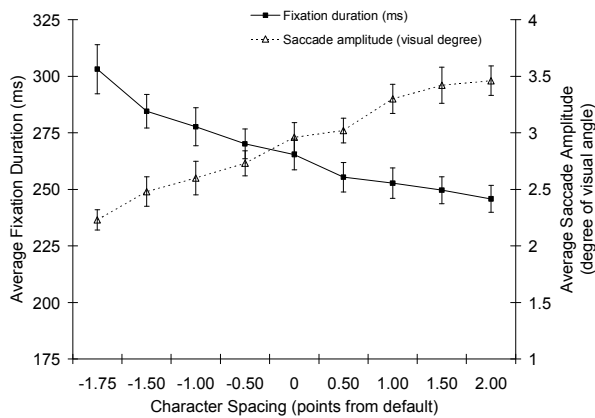

Figure 5. The opposite patterns of saccade amplitude and fixation duration in response to changes of letter spacing.
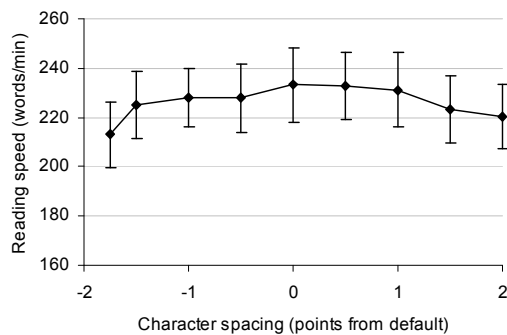

Figure 6. The overall reading speed remained unchanged within the range of the tested letter spacing.

The results demonstrate that spacing changes were compensated by changes in eye movements with no net change in reading speed, at least within the tested range of spacing where all texts were readable without overlap, though subjective choice indicates that the default spacing was more preferred by most testing participants. This suggests that the underlying cognitive demand govern the eye movements and ultimately limit one's reading speed. The finding helps to illuminate the underlying reading process and the ideal text outlay. The cognitive mechanism underneath the reading process seems to prefer operating at a constant rhythm that is automatic and unconscious to the reader. The ideal typography should aim to construct text layout to hook reader's attention and facilitate a regular, rhythmical eye movements and reading rate. Letter spacing must be great enough to minimize lateral confusions but not be so large that cross-letter binding or constructive conjunction is inhibited. Over-expanded or compressed spacing will spoil almost any typeface and make reading attentive and interrupted [23].

V. Dividing Words: Within-word Segmentation and Lexical Access

While most researchers agree that the primary task in reading is word recognition, there are disputes about the length of patterns being recognized – individual letters, sub-units within a word (e.g., syllables or morphemes), whole word, or groups of words and phrases. The best way to present text should be consistent with the way a word is processed. In a recent study [224] we examined whether visually segmenting a word into sub-units based on some hypothesized processes would differentially affect the accuracy and latency of lexical access and reading performance. If one of these processes is more critically utilized in lexical access than others, the corresponding segmentation method should result in greater benefit in those tasks.

Individual words with similar frequency were parsed into syllables and morphemes. Segmentation was achieved by inserting 2 extra pixels of space between segments. Post-test inquiry showed that participants were unconscious to such subtle differences between segmentation conditions. The results showed that, for skilled native English readers, within-word segmentation enhances word processing. Syllable segmentation improves the accuracy of word recognition (Figure 7 top) and morpheme segmentation facilitates the accuracy in lexical decision (Figure 7 bottom). However, the subtle change of letter arrangement within a word produced mixed effect on reading and appeared to be modulated by individual's reading strategy and word decoding skills. Compared to performance without segmentation, comprehension of readers with good word-decoding skills was enhanced by within-word segmentation (both types) but at the cost of slower reading speed (6-8 words less per minute). Readers with poorer decoding skills were benefited from syllable segmentation when they read at a slower speed (Figure 8).
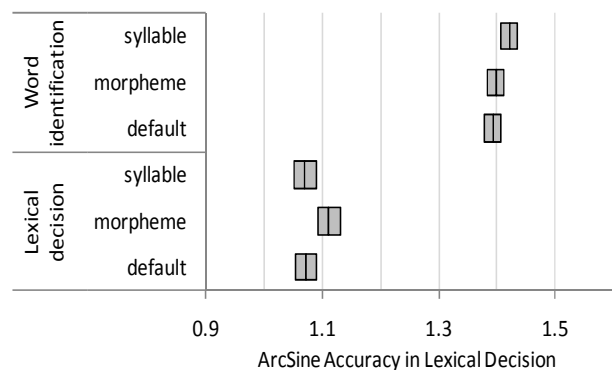

Figure 7. Within-word syllable segmentation enhanced the accuracy of word read aloud while morpheme segmentation improved accuracy on lexical decision (to judge whether a word can be used as a noun).

The above findings point out a new use of spacing to improve text processing or reading. Readers obviously take in all visual features, consciously or unconsciously, and adapt to it with different strategies. Good word decoders

seemed to be ready to take in any visually-provided information, sound or meaning, although the visual ir-regulation may disrupt the automatic rhythm and slow down the reading slightly. For poor decoders, however, auditory cues seemed easier to be picked up from syllable segmentation to activate the phonological route. This is congruent with the current literature that normal reading seems to go through 3 typical stages: an initial phonological stage (mapping phonemes onto written graphemes) during the primary grades, followed by an orthographic stage (automatic retrieval of the orthographical word from) during the upper elementary grades, and then the morphological stage (using morphemes to assist understanding of new words) during the upper elementary to middle school years [25-32]. While the above finding does not exclude the use of other routes for word processing, it suggests the strong facilitation effect of within-word parsing on reading, furthers our understanding of underlying reading processes, and points out an innovative approach to display text that can potentially facilitate reading comprehension.
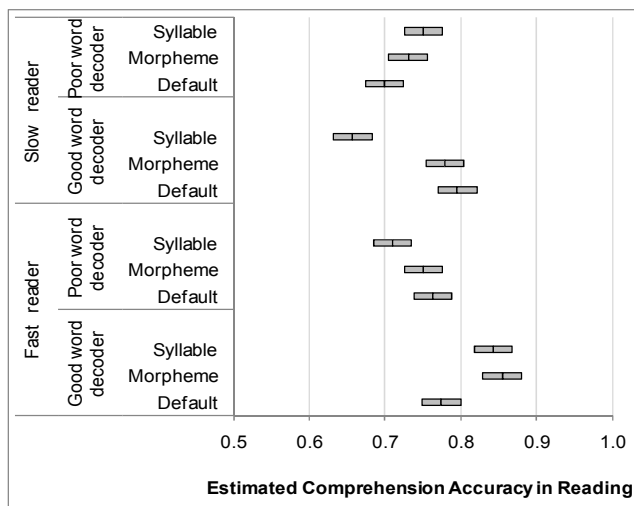

Figure 8. Within-word (syllable and morpheme) segmentation facilitated reading comprehension for readers with good word decoding skills while syllable segmentation improved comprehension for poorer decoders when they read more slowly.

VI. Conclusion

This paper describes the role of spacing on word recognition and text reading, and how it can be used to gauge the underlying reading process along various stages of reading development. While using as a pause for signals, spacing actually carry the functions of signal grouping and has the potential to illuminate the black box of reading process.

While isolated letter/word processing pleases for wider spacing, reading text with continuous flow seems to demand automatic rhythmic movement along the space. Although readers seem to tolerate a certain amount of spacing variations, the default proportional scaled spacing seems to

work best for the commonly used fonts and needs to be enlarged for smaller fonts.

The insights regarding reading development derived from the innovative within-word segmentation should be further investigated. Who knows, the white space that looks like carries no information may bring us closer to secrete of reading and better text layout.

References

[1] ISO (1994). Ophthalmic optics - visual acuity testing - standard optotype and its presentation. International Standards Organization (NY: American National Standards Institute.

[2] Tai YC, Sheedy J, Hayes J. Effect of letter spacing on legibility, eye movements, and reading speed. Vision Sciences Society abstract 2006;248.

[3] Flom, M.C., Weymouth, F.W., & Kahneman, D. (1963b). Visual Resolution and Contour Interaction. J Opt Soc Am, 53, 1026-1032.

[4] Gilbert, C.D., & Wiesel, T.N. (1989). Columnar specificity of intrinsic horizontal and corticocortical connections in cat visual cortex. Journal of Neuroscience, 9 (7), 2432-2442.

[5] Tripathy, S.P., & Levi, D.M. (1994). Long-range dichoptic interactions in the human visual cortex in the region corresponding to the blind spot. Vision Research, 34 (9), 1127-1138.

[6] He, S., Cavanagh, P., & Intriligator, J. (1996). Attentional resolution and the locus of visual awareness. Nature, 383 (6598), 334-337.

[7] Bex, P.J., Dakin, S.C., & Simmers, A.J. (2003). The shape and size of crowding for moving targets. Vision research, 43 (27), 2895-2904.

[8] Pelli, D.G., Palomares, M., & Majaj, N.J. (2004). Crowding is unlike ordinary masking: distinguishing feature integration from detection. Journal of Vision, 4 (12), 1136-1169.

[9] Bex, P.J., & Dakin, S.C. (2005). Spatial interference among moving targets. Vision Rresearch, 45 (11), 1385-1398.

[10] Strasburger, H. (2005). Unfocused spatial attention underlies the crowding effect in indirect form vision. Journal of vision, 5 (11), 1024-1037

[11] Whittaker, S., Rohrkaste, F., & Higgins, K. (1989). Optimum letter spacing for word recognition in central and peripheral vision. Digest of Topical Meeting on Noninvasive Assessment of the Visual System ,56-59, Optical Society of America Washington, DC.,

[12] Arditi, A., Knoblauch, K., & Grunwald, I. (1990). Reading with fixed and variable character pitch. Journal of the Optical Society of America. A, Optics, image science, and vision., 7 (10), 2011-2015.

[13] Flom, M.C. (1991). Contour interaction and the crowding effect. Problems in Optometry, 3, 237-257.

[14] Latham, K., & Whitaker, D. (1996). A comparison of word recognition and reading performance in foveal and peripheral vision. Vision Research, 36, 2665-2674

[15] Sheedy, J.E., Subbaram, M., Zimmerman, A., & Hayes, J. (2005b). Text legibility and the letter superiority effect. Human Factors,

[16] Westheimer, G., Shimamura, K., & McKee, S.P. (1976). Interference with line-orientation sensitivity. Journal of the Optical Society of America., 66 (4), 332-338.

[17] Flom, M.C., Heath, G.G., & Takahashi, E. (1963a). Contour Interaction and Visual Resolution: Contralateral Effects. Science, 142, 979-980.

[18] Liu, L., & Arditi, A. (2000). Apparent string shortening concomitant with letter crowding. Vision Res, 40 (9), 1059-1067.

[19] Levi, D.M., Hariharan, S., & Klein, S.A. (2002). Suppressive and facilitatory spatial interactions in peripheral vision: peripheral crowding is neither size invariant nor simple contrast masking. Journal of Vision, 2 (2), 167-177.

[20] Pelli, D.G., Palomares, M., & Majaj, N.J. (2004). Crowding is unlike ordinary masking: distinguishing feature integration from detection. *Journal of Vision, 4* (12), 1136-1169.

[21] Tai, Y.-C., Sheedy, J. E., & Hayes, J. (2007, October). Can threshold legibility predict suprathreshold performance? Paper presented at the American Academy of Optometry Annual Conference in Tampa, Florida

[22] Tai, Y.-C., Yang, S.-N., Hayes, J., & Sheedy, J. (2010). Effect of character spacing on text legibility. Technical report on Pacific University Vision Performance Institute website (http://www.pacificu.edu/optometry/research/publications/documents/EffectofCharacterSpacingonTextLegibility.pdf). The study was presented in American Academy of Optometry Annual Meeting on November 17th, 2010 in San Francisco, Ca.

[23] Tinker, M.A. (1963). Legibility of Print. (p. 329). Ames: The Iowa State University Press.

[24] Tai, Y.-C., Yang, S.-N., Larson, K., Reder, R., & Sheedy, J. (in preparation). Th epotential effect of within-word segmentation on lexical processing and reading.

[25] Moats, L. (2000). *Speech to print. Language essentials for teachers.* Baltimore: Paul H. Brookes Publishing Co.

[26] Templeton, S., Bear, D. (1992). (Eds.). *Development of orthographic knowledge and the foundations of literacy* (pp. 307-332). Hillsdale, NJ: Lawrence Erlbaum Associates.

[27] Berninger, V., & Richards, T. (2002). *Brain Literacy for Educators and Psychologists*. San Diego: Academic Press (Elsevier Imprint).

[28] Nagy, W. E., Berninger, V.W., & Abbott, R.B. (2006). Contributions of morphology beyond phonology to literacy outcomes of upper elementary and middle-school students. *Journal of Educational Psychology*, *98*(1), 134-147.

[29] Aylward, E.H., Richards, T.L., Berninger, V.W., Nagy, W.E., Field, K.M., Grimme, A.C., et al. (2003). Instructional treatment associated with changes in brain activation in children with dyslexia. Neurology, 61, 212-219.

[30] Nagy, W., Berninger, V., Abbott, R., Vaughan, K., & Vermeulin, K. (2003). Relationship of morphology and other language skills to literacy skills in at-risk second graders and at-risk fourth grade writers. *Journal of Educational Psychology, 95*, 730-742.

[31] Shaywitz, B. A., Shaywitz, S. E., Blachman, B. A., Pugh, K. R., Fulbright, R. K., Skudlarski, P., et al. (2004). Development of left occipitotemporal systems for skilled reading in children after a phonologically-based intervention. *Biological Psychiatry, 55*(9), 926-933.

[32] Simos, P.G., Fletcher, J.M., Bergman, E., Breier, J.I., Foorman, B.R., Castillo, E.M., Davis, R.N., Fitzgerald, M. and Papanicolaou, A.C. (2002). Dyslexia-specific brain activation profile becomes normal following successful remedial training. *Neurology, 58*, 1203-13.

E. Shape Analysis of the Characters in Oracle Bone Inscriptions

Lu Xiaoqing, Cai Kaiwei, Song Jianguo, Wang Xiao

The Institute of Computer Science and Technology, Peking University, Beijing, China

Beijing Founder Electronics Co., Ltd., Beijing, China

Center for Chinese Font Design and Research, Beijing, China

<{lvxiaoqing, caikaiwei, songjianguo,wangxiao}@icst.pku.edu.cn>

Abstract- **Oracle bone inscription (OBI), from which Chinese writing originated, is the root of Chinese calligraphy and an important source of modern font design. The primitive picture-character styles of OBI are distinctive and clearly evident, without such standard glyphs as in its descendants. Therefore, computers find it difficult to recognize them automatically. Based on an analysis of the graphic features of inscriptions, the present paper proposes a shape descriptor combining point distribution feature and pair-wise point relationship feature. Preliminary experimental results show that the proposed method is effective in OBI classification.**

Keywords-component; OBI; character recognition; shape descriptor; shape classification

I. INTRODUCTION

Oracle bone inscription (OBI), developed more than 3,000 years ago during the Shang Dynasty, is the earliest systematized Chinese character set. The divinations and supplications of the emperors to the gods and the replies they received comprise the main content of OBI. Among the presently recovered 4,700 round characters appearing on about 100,000 pieces of extant animal bones and tortoise shells, 1,800 of them have been identified.

OBI has already evolved into a mature character system both in terms of the number of characters it has and its graphemic structure. All six categories of Chinese characters, namely, self-explanatory characters, pictographs, pictophonetic characters, associative compounds, mutually explanatory characters, and phonetic loan characters, can be seen in the system.

However, compared with the seal script, clerical script, semi-cursive script, and regular script, OBI remains to be at early stage of grapheme evolution. It possesses many distinctive or individual features of drawing and there are no such standard glyphs as in its descendants. Therefore, the broad variety of characters' shape serves as the key obstacle for computers to recognize these characters automatically.

Figure 1 shows different images of the same character in OBI, and challenges are analyzed as follows.

As a pictograph, most characters in the OBI describe the shape of objects in the real world, without limitations in the length, position, and even the number of strokes used.

Therefore, images of the same character look more or less different from each other.

The stroke width of OBI characters also varies dramatically because all characters are carved individually on animal bones or tortoise shells with knives. The deformation of strokes is very common as the nicks have withstood abrasion for many years.

The characters of OBI also vary in size. To describe complicated objects, some of them are several times larger than the average character, whereas some are small. Simultaneously, the layout of OBI is quite irregular with uneven margins.

Fig 1 The different images of character Nu (Woman, 女) in OBI

Given the above issues, the recognition and classification of OBI have yielded little progress, although the technology of optical character recognition (OCR) is used widely in the recognition of modern printed characters.

Researchers continue to explore methods to address current challenges in the field, especially in relation to the recent progress in graphic recognition.

Research on describing general character shapes is developing rapidly. Many techniques, including moment methods and Shape Context, are employed to describe and match character shapes [1, 2]. However, few of these techniques are directly used in OBI recognition.

Methods for OBI recognition were reported in [3, 4], with emphasis on conversion from the spatial configuration of character strokes to undirected graphing and analysis of their topological features. OBI patterns were also studied in [5-8]. Related research fields include optical and handwritten character recognition [9-12]. As discussed above, these methods necessitate further exploitation so that they may be applied to OBI recognition.

To this end, we propose a new method for describing OBI characters as shapes. The requirements for a typical shape descriptor, i.e., rotation, translation, and scale invariance, are satisfied by employing the techniques frequently used in developing general shape description. L_2 normalization is used to measure the differences among various characters. The effectiveness of the proposed method is then verified in a classification experiment.

II. CLASSIFICATION METHOD

This work aims to classify OBI characters on the basis of their shapes. Figure 1 depicts the difficulty of obtaining a closed OBI curve. Previous methods that require the closed curves of 2D objects are unable to effectively handle OBI classification. Here, we interpret shape as a 2D point set. Given that point distribution is uniquely mapped to a 2D object, the point distribution of shape is regarded as a discriminant feature.

To capture the point distribution of a shape, we preprocess an OBI image to obtain its contour points, which do not need to constitute a closed curve. These points are considered an unordered point set. The proposed shape feature is detailed as follows, with some notations introduced. Let $P = \{(x_i, y_i) \mid i \in [1, n]\}$, $p_i = (x_i, y_i)$ be a shape representation, where p_i denotes a point in a shape contour. OBI images hold difference scales and the positions of an OBI object in an image may differ. Thus, processing is necessary to achieve scale and translation invariance. For translation invariance, the geometric center of P is computed and the geometric center as a zero point in the coordinate system is plotted. With respect to scale invariance, L_2 normalization is employed to normalize the point set. In this step, each point is treated as a vector. The area of P is partitioned into several bins, which are constructed in polar coordinates. Figure 2 shows an example of a partition.
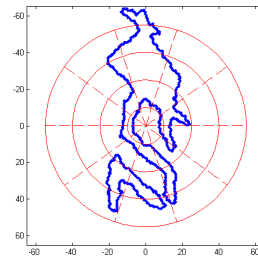

Fig 2 Partition of Nu in OBI

With partition bins, the number of points located in every bin is calculated. This procedure completes the computation of point distribution, which is then represented as a 2D histogram. However, this 2D histogram is not rotation invariant. According to the Fourier transform theorem, a signal may be transformed into a frequency domain to derive its magnitude as rotation invariance. This feature is called the point distribution feature (PDF).

Aside from the PDF, pair-wise point relationship is determined as the second feature. Given a point set P, the geometric center of P is fixed as a reference point denoted as p_0. Then, any point pair (for example p_i, p_j) exhibit relative angle and length ratio relationships. The relative angle is $\angle p_i p_0 p_j$, and the length ratio is $|p_i p_0| / |p_j p_0|$. After the relative angle and length ratio for every point pair is computed, the angle and length ratio is partitioned into several bins. Subsequently, a 2D histogram is obtained by counting the distributions of both relationships. This pair-wise point relationship feature (PPRF) is also rotation, scale, and translation invariant. By concatenating the PDF and PPRF, the final feature representation is determined. In implementing an algorithm, the PDF and PPRF with

different weights are combined. The results are shown in Figure 3. The similarity between shapes S_1 and S_2 is denoted as $\|F_1 - F_2\|_2$, which is the Euclidean distance of their features.

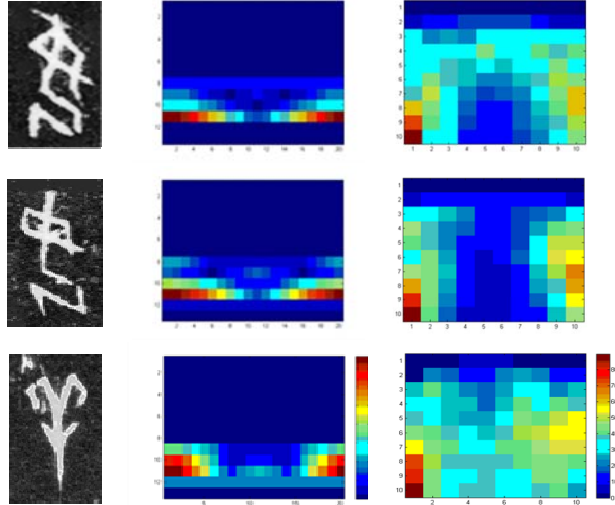Fig 3 Different characters in OBI with different distance histograms

III. EXPERIMENT AND RESULT

The new descriptor is adopted in the classification experiment on an image set composed of isolated OBI characters. The image set contains the images of 10 characters, each having 30 variants.

A support vector machine classifier is used in the experiment, with RBF kernel and parameters c and g set to 2. Twenty samples of each character class are randomly chosen for training, and the remaining 10 are used for testing.

Table 1 shows the classification rate of each character class. The average classification rate is 85%. The results show that the proposed method efficiently classifies characters. However, the descriptor captures the geometrical information of character shape; although some character

TABLE 1 CLASSIFICATION RESULTS FOR THE 10-CHARACTER DATASE

Chara.	Pron.	Meaning	Mis. Chara.	#Mis.	Acc.
人	Ren	human		0	100%
保	Bao	protect	天 2 马	3	70%
天	Tian	sky	禾人	2	80%
女	Nu	woman		0	100%
牛	Niu	cow	保	1	90%
祝	Zhu	pray	女	1	90%
禾	He	grain	女	1	90%
羊	yang	goat	马	1	90%
首	shou	head		0	100%
目	Mu	eye	人	1	90%
马	Ma	horse	羊保	2	80%
安	An	safe		0	100%

variants share similar point layouts, they vary in terms of topology. These features are the main cause of misclassification.

IV. CONCLUSION

On the basis of the analysis of the graphic features of inscriptions, we propose a new shape descriptor that facilitates the recognition of ancient characters. The descriptor is translation, rotation, and scaling invariant. Preliminary experimental results confirm its effectiveness in character classification.

Future research may focus on the exploitation of the topological information of characters (e.g., the number of holes, connected domains, etc.).

REFERENCES:

[1]. Haibin, L. and D.W. Jacobs, Shape Classification Using the Inner-Distance. Pattern Analysis and Machine Intelligence, IEEE Transactions on, 2007. 29(2): p. 286-299.

[2]. Belongie, S., J. Malik and J. Puzicha, Shape matching and object recognition using shape contexts. Pattern Analysis and Machine Intelligence, IEEE Transactions on, 2002. 24(4): p. 509-522.

[3]. Xinlun, Z., et al., Research on recognition of Jia Gu Wen. Journal of Fudan University(Natural Science), 1996. 35(5): p. 461 - 486.

[4]. Feng, L. and Z. Xinlun, RECOHNITION OF JIA GU WEN BASED ON GRAPH THEORY. Journal of Electronics, 1996(S1).

[5]. Jinfeng, L. and K. Honghai. The Pattern Recognition of Inscriptions on Oracle Bones by Esthetics Analysis in Computer Image. in Computer Engineering and Applications (ICCEA), 2010 Second International Conference on. 2010.

[6]. 刘一曼, 甲骨文字的特点及主要内容. 档案管理 （ARCHIVES MANAGEMENT, 2000(01): 第40 -41页.

[7]. Aimin, W., G. Yanqiang and L. Guoying. Research on key technologies of the computer aided rejoining of Oracle Bone Inscriptions. in Information and Financial Engineering (ICIFE), 2010 2nd IEEE International Conference on. 2010.

[8]. Liu, Y. and Y. Han. Application of Apriori Algorithm in Oracle Bone Inscription Explication. in Computer Science and Information Engineering, 2009 WRI World Congress on. 2009.

[9]. Santosh, K.C., C. Nattee and B. Lamiroy. Spatial Similarity Based Stroke Number and Order Free Clustering. in Frontiers in Handwriting Recognition (ICFHR), 2010 International Conference on. 2010.

[10]. Impedovo, S., et al. Zoning Methods for Hand-Written Character Recognition: An Overview. in Frontiers in Handwriting Recognition (ICFHR), 2010 International Conference on. 2010.

[11]. Liu, C. and K. Marukawa, Pseudo two-dimensional shape normalization methods for handwritten Chinese character recognition. Pattern Recognition, 2005. 38(12): p. 2242-2255.

[12]. Hailong, L. and D. Xiaoqing. Handwritten character recognition using gradient feature and quadratic classifier with multiple discrimination schemes. in Document Analysis and Recognition, 2005. Proceedings. Eighth International Conference on. 2005.