Quantitative Insights for the Development of Universal Design Hangeul Typefaces

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Abstract

Background In the current historical context, the typeface design industry is demanding for multilingual solutions. Old and new type foundries are focusing on the production of multi-script fonts. Integrating Hangeul typefaces within this context represents a challenge due to the intrinsic workload required for the development when compared to other scripts. Background research can facilitate the design and can promote the advancement towards an improved reading experience. Legibility issues affecting Hangeul typefaces have been already studied from a qualitative point of view and the principles to maintain a high legibility have been determined. Following these principles, this study aims to deliver quantitative data for guiding the development of future Hangeul typefaces with high legibility in mind, thus heading towards Universal Design.

Methods Three tests were conducted. Each test focused on a feature of Hangeul syllabic blocks, known as the causes of legibility issues: stroke thickness, secondary stroke length, and the separation of the letters. A selection of syllables has been modified, creating scales of variations of the three mentioned features. The created stimuli were administered to the participants following a method derived from the classic clinical measurement of visual acuity and the reading errors for each participant were recorded.

Results The tests confirmed that stroke thickness, secondary stroke length, and the separation of the letters have an impact on the legibility of Hangeul typefaces. Test A determined the range of stroke thicknesses within which the syllables maintain excellent legibility. Test B provided the ideal range of lengths for the secondary strokes. Test C defined the optimal separation of the letters. Further details emerged from the collected data, such as the impact of character size on legibility. Comments on the interaction among the three different parameters are also provided.

Conclusions The development of a Universal Design Hangeul typeface can be facilitated when taking into account its intrinsic legibility influencing factors and maintaining the values of the syllabic block features within the ranges defined in this study. Furthermore, the three syllabic block features are correlated. Therefore, the designers should consider the three syllabic blocks as a system, rather than individually.

Keywords Universal Design, Typeface Design, Hangeul, Legibility, Design for All

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1. Introduction

1. 1. Hangeul typeface design context overview

Developing a new typeface that comprehend Korean characters is a design goal that should be carefully planned compared to the design of a Latin script: Hangeul is composed by only 19 consonants and 21 vowels in the modern alphabet, but designing a full Hangeul type set means providing the 11,172 possible combinations of the placements that the letters can assume when building a syllabic block (considering the Unicode standard). If these numbers are compared to the total of 52 uppercase and lowercase letters in a Latin alphabet type set, it is possible to understand the reason why even in this era of open-source tools, there is not a proliferation of new Hangeul typefaces. A pertinent example of the workload to design a full Hangeul type set (also commonly called a "pro" Hangeul font) is the current development of 마루 부리 typeface by Naver, for which the timeline has been planned to be three years (Naver, 2020), a release of a limited subset of 3027 자모 after several months of pure glyph design and a complete release few months later (Naver, 2020 /2).
Furthermore, the current historical contest is demanding for multilingual, multi-script and cross-platform solutions, with the case of Noto being the most emblematic, supporting more than 800 languages and 100 writing scripts (Monotype, 2016), followed by other notable examples, like the award-winning type foundry Rosetta, established under the vision of "addressing the needs of global typography. [...] create original fonts for a polyphonic world. Our work [...] enabled people to read better in their native language" (Rosetta, 2020), or the indie type design business 29Letters, whose vision points also in the same direction of "designing [...] multi script fonts that cater to the global community" (29Letters, 2020).
Considering the above, it is understandable the importance and the urge of background researches to support and facilitate the development of future Hangeul typefaces.
The emotional, stylistic, historical aspects have been the subject of multiple studies (e.g.: HY Kim, 2018; JS Yoo, 2010; JH Yim, 2002) and researches focusing on the legibility have also been conducted, but considering legibility in specific contexts (e.g.: SW Jeong, 2016; KS Lee, 2007; RH Myung, 2003), while there is a lack of precise indications that can help the development of new high legibility typefaces on more common printed media; within this seldomly explored area of research, lies the scope of the study here presented.

1. 2. Legibility issues of Hangeul typefaces

A previous study analyzed in detail the possible legibility issues affecting Hangeul typefaces (Capestrani, 2019): the tests conducted confirmed that letters deformation (compression and stretching) and reduction of the interspace between the letters in a single block, intrinsic in the alphabetic syllabic nature of Hangeul, influence the legibility of the letters themselves and to solve these legibility issues, three design principles have been formulated:

A. limit the compression of the secondary strokes
B. maintain the separation of the letters inside a syllable/block
C. maximize the stroke thickness, respecting the two previous principles

1. 3. Notes on Hangeul script terminology

The terms adopted in this study to refer to the composition principles of Hangeul and its typographic features are shared throughout the literature of linguistics studies and typography. For clarity and for reference, here below are reported recurrent terms present in this study:

· the “initial”, the “medial”, and the “final” indicate the three positions the syllable is divided into, as represented in the following figure (e.g.: National Institute of Korean Language, 2020)

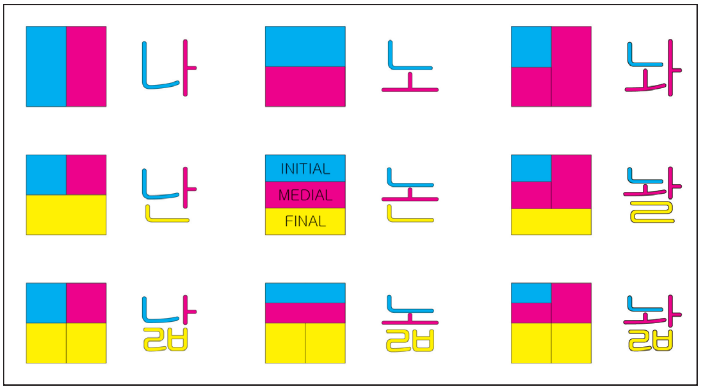

Figure 1 Composition of the syllabic block

· “syllabic system” and “syllabic block” refer to the correspondence of a letter and a syllable in Hangeul writing system, as opposed to phonemic systems, where a letter is comparable to a consonant or a vowel (e.g. HK Pae, 2011)

· “dark”, “bright”, “neutral” vowels is a reference to the phonetics of the language but also to the composition and form of the vowels themselves and in particular the direction which the short strokes are pointing at. 아 / 야 / 오 / 요 / 애 / 와 / 외 / 왜 / 얘 are bright vowels, 어 / 우 / 여 / 유 / 에 / 예 / 워 / 위 / 웨 are dark vowels, 으 / 이 / 의 are neutral vowels (e.g.: KO Kim, 1977)

· while for Latin-script typefaces the term kerning describes the adjustment of the spacing between characters, kerning for Hangul fonts considers the inner space and contour region of Hangul syllables (e.g.: World Wide Web Consortium, 2020). Since this study is focused on the syllable itself, the more term “separation”, used also in studies about visual acuity (e.g.: Stuart & Burian, 1962), has been preferred and indicates the distance between the letters composing a syllabic block

Figure 2 Separation of the letters

· Hangeul vowels are formed by horizontal and vertical strokes and combinations of these; originally a third letter was marked as a dot and evolved then in a “short” stroke (e.g.: Fouser, 2016). The term short, implying a predetermined proportion in between the strokes, could create ambiguity within the purpose of this study. In the literature, short strokes are also called “additional”, but there is also an ambiguous use of this term, since this is often referring exclusively to the strokes used to form y-diphthongs ㅑ, ㅖ, ㅒ, ㅕ, ㅠ or to the strokes used to form aspirated consonants ㅋ, ㅌ, ㅊ, ㅎ (e.g.: SD Cho, 2019).
To indicate these short strokes, within this study, the term “secondary” has been preferred. “Secondary” is extensively used in typography for Latin scripts (e.g.: Rabinowitz, 2015) to simply indicate the strokes that are drawn after the “main”, thus in the case of Hangeul also matching the order in which strokes are actually drawn.

Figure 3 Secondary Strokes

1. 4. Scope of the study

While the three principles mentioned in section 1.2.1 can offer indications for the overall design of a new typeface, providing quantitative data can further support a design that goes in the direction of a Universal Design typeface, with a high legibility in mind.
The aim of this study is to define the ranges within which the three parameters (secondary strokes dimension, separation of the letters, stroke thickness) allow to maintain a good legibility.
A Universal Design approach to Hangeul typefaces aiming at a better legibility can help in creating a more pleasurable reading experience for the average population, and improve it for the visually impaired and the elderly.

2. Method

In order to obtain quantitative data correlated to the principles expressed in the “Outlining Guidelines for the Development of Universal Design Hangeul Typefaces” study (Capestrani, 2019), three tests have been designed and conducted to define ranges of values within which the legibility of Hangeul typefaces remains high: Tests A, B and C.
The three tests are directly related to the three principles expressed in the previous study: Test A focuses on stroke thickness, Test B focuses on the length of secondary strokes, Test C focuses on the separation of the letters.
Test A has also been utilized as a preliminary test to determine the most proper font size to subsequently conduct Tests B and C

2. 1. Legibility method and procedure

The design and the legibility method for the three tests are derived from the classic clinical measurement of visual acuity and have already been used before, to study typefaces legibility (e.g.: Sheedy and Bailey, 1994). Other researchers relied on the distance between the stimulus and the eyes of the participant, thus the dimension of the text, in their studies about legibility (e.g.: Phillips et al., 1983; Bouma, 1971; Sanford, 1888).

The stimulus for all the three tests is meant to be used like a Rosenbaum eye chart to test near vision acuity: placed at a standard reading distance, the participant is then asked to read out clearly the syllables presented by the researcher/tester. Each misread syllable or not read syllable was noted as one error. No multiple attempts to interpret a syllable were allowed.

In order to reduce external factors influencing the visibility of the stimulus (detailed in section 2.2.1), the stimulus itself has been placed on a bookstand and the distance between the stimulus and the eyes have been calibrated for each participant at 355 mm. An office chair allowed height and tilt adjustments to align the eyes of all participants with the horizontal midline of the printed stimulus. Illuminance of 1250 lux has been provided to evenly illuminate the stimulus, being this value the amount in between the needs of precision/detailed work (1500 ÷ 2000) and normal activity needs (500 ÷ 1000 lux), according to “Light and lighting - Lighting of workplaces - Indoor work places” indications (EN 12464, 2002).

Each test involved 41 participants, recruited among the local population, with ages ranging from 19 to 65 years; all of them have been preliminarily tested using a Rosenbaum chart to verify their current visual acuity. The use of prescription lenses has been allowed throughout this preliminary test and the following ones. All the participants should have been able to read the 3 points height letters and symbols (distance test equivalent to 20/20).

2. 2. Syllables selection

The stimulus for all the three tests consisted of a selection of Hangeul syllables considered more prone to reading errors (Capestrani, 2019). Letters deformation (compression and stretching) and reduction of the interspace between the letters in a single block, intrinsic in the alphabetic syllabic nature of Hangeul, influence the legibility of the letters themselves, but also, specific arrangement of the strokes can influence legibility:

· blocks of three or four letters composed by a medial horizontal vowel with a double consonant or a ㄹ or a ㅎ or a ㅍ as an initial

· blocks of two and three letters of which the initial is a ㅃ followed by a vertical vowel or diphthong

· blocks of three letters of which the initial is a double consonant and the medial is a dark vowel

· blocks of three letters of which the initial is a ㅎ, ㅍ, ㅌ or a double consonant and the medial is a horizontal vowel

· blocks of three letters constructed with a horizontal medial vowel

· blocks of three letters composed by a double consonant (ㄸ, ㄲ, ㅆ, ...) as initial and followed by a diphthong or a vowel composed by four of five strokes (ㅘ, ㅝ, ㅙ, ㅞ, ...)

· blocks of three letters with a double consonant as final

The complete list of the selected syllable is as follows:

뽑 꽐 빽 뗑 훑 움 숙 쫠 붉 낄 태 품 군 훌 롱 릍 빼 홈 뷸 쨱 꽥 뺀 홉 틈 곪 줅 뻬 좁 훑 뺑 뚤 붉 쌤 쏠 굶 폴 큉 삔 빽 폴 뚫 꼭 꽝 꿇 짬 폐 꽁 콕.

2. 3. Test stimulus overview

The syllables more prone to legibility issues, selected according to the criteria detailed in the previous section, have been arranged on standard A4 formats as shown in Figure 3, laser printed in black at 1200dpi on matte coated paper, in order to avoid visibility issues due to the printing itself and bias in the result. The same support has been used to produce the stimuli of all the three tests.

Stroke thickness, secondary stroke length and the separation of the letters have been modified using Fontlab software, to accurately adjust the selected parameters in a measurable manner and without altering the overall design of the fonts. Furthermore, Fontlab software uses UPM, Units-Per-eM, as the font unit of measure, so relative coordinates rather than specific physical distances, allowing the results to be scalable and interpreted independently of any specific character size.

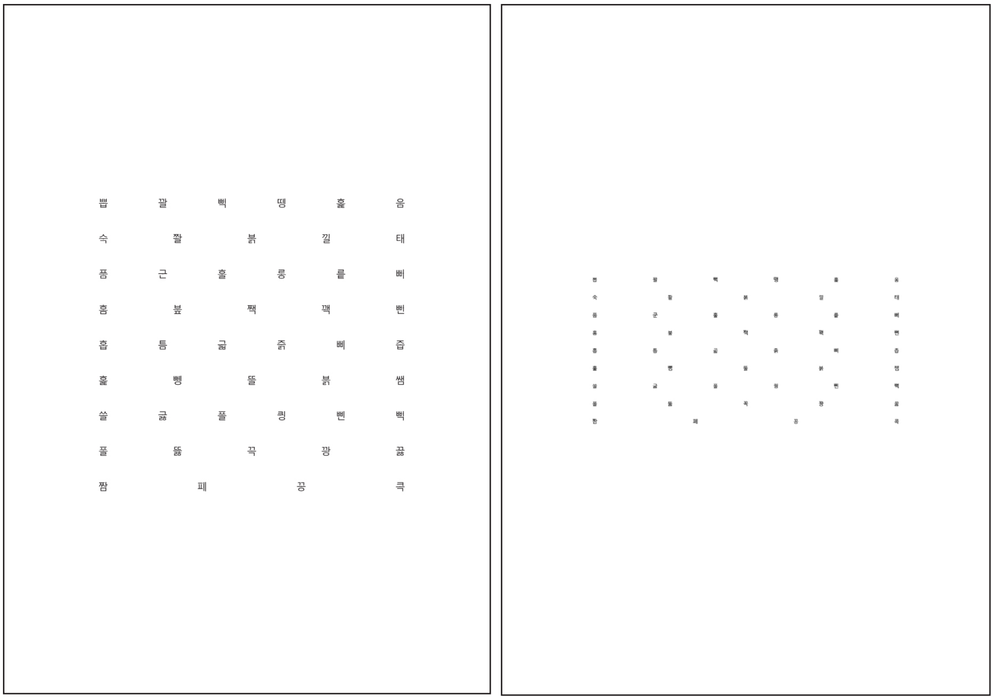

Figure 4 Examples of the stimuli for Test A:12 points syllables, 6 points syllables (original page size: ISO 216 standard A4

2. 3. 1. Notes about Typefaces metrics

Here following is provided the essential information to understand the terminology and logic behind the units used in this method section and in the results section. Each glyph is designed in a space called an Em. The Em in metal type was originally a square of metal the same height and width as the point size. In digital type, the Em is an imaginary space, subdivided into a grid for design purposes. The division is usually 1000 or 2048 units, referred to as Units Per eM (UPM) size.

When type is imaged on screen or in print, the Em is scaled to the desired size. Defining a font within this coordinate system allows a single outline to be scaled to any size requested. It is also independent of any single writing system, allowing a common scale for things as diverse as symbol fonts, or alphabets (Fontlab, 2019).

2. 3. 2. About visual acuity

The design of the stimulus, detailed in the following sub-section (2.2.5) relies on some basic properties of the human eye and clinical measurement of visual acuity worth to review: angular resolution of a naked eye is about 1 arcminute, approximately 0.02°or 0.0003 rad (Yanoff and Duker, 2009), which corresponds to 0.3 mm at a 1 m, or 0.11 mm at 355 mm, the reading distance to which the stimuli have been positioned at. This represents the limit which the average naked eye cannot discern the typefaces details, thus representing also the lower limit for all the alterations applied to the syllables contained in the stimuli.

2. 3. 3. Typeface selection and typeface alteration

Among the seven most common typefaces available to the general local public (StatCounter, 2019; R. Koehler, 2010; Korea Audit Bureau of Certification, 2018), Malgun Gothic resulted the perceived most readable typeface (Capestrani, 2019), thus it has been selected to conduct all the three tests.
Only the parameters involved in the different tests has been modified (stroke thickness, secondary stroke length and separation of the letters), maintaining all the other font features intact.
Worth to note that in Test C, to increase the separation of letters, the syllables have not been exploded, homogeneously increasing the distance among the letters, but only the separation between vowels and consonants has been increased instead, following the results of the previous study (Capestrani, 2019, section 3.2). The example illustrated in Figure 5 is also illustrating this approach: ㅇ distance has not been increased, since it does not represent a legibility issue, while the distance between ㅃ and ㅔ emerged among the main issue, so it has been modified.

2. 3. 4. Test stimulus design details

For Test A, as shown in Figure 5, the thickness of the typeface has been lowered up to the standard visual acuity limit (for a height of 6 points) in three steps, and increased using the same proportion. In the relative coordinates system: the original thickness range is 113÷156 UPM; all the steps are as follows: 67÷110 UPM, "83÷126 UPM", "97÷140 UPM", "113÷156 UPM (original)", "127÷170 UPM", "133÷186 UPM", "157÷200 UPM".

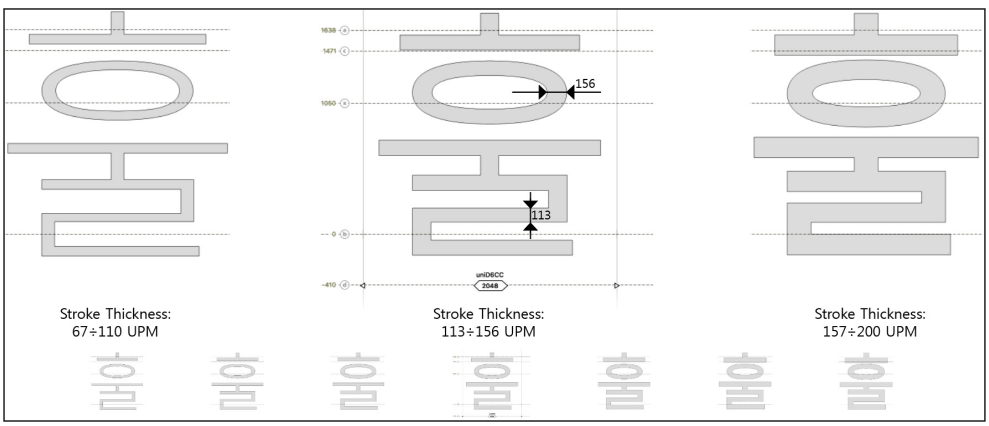

Figure 5 Test A, Detailed view of one syllable.

For test B, as shown in Figure 6, the length of secondary strokes has been lowered up to the standard visual acuity limit in three steps starting from the original one and also raised of the same amount of other three steps. In the relative coordinates system: for an original secondary stroke of 110 UPM all the steps are as follows: 30 UPM, 57 UPM, 83 UPM, 110 UPM, 137 UPM, 163 UPM, 190 UPM.

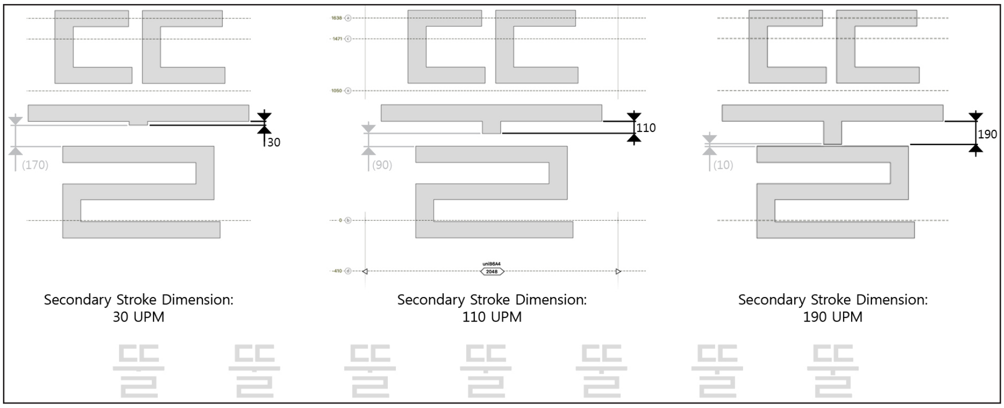

Figure 6 Test B, Detailed view of one syllable.

For Test C, as shown in Figure 7, the separation of the letters has been lowered up to the standard visual acuity limit in three steps starting from the original one and also raised of the same amount of other three steps. In the relative coordinates system: for an original distance 110 UPM all the steps are as follows: 30 UPM, 57 UPM, 83 UPM, 110 UPM, 137 UPM, 163 UPM, 190 UPM.

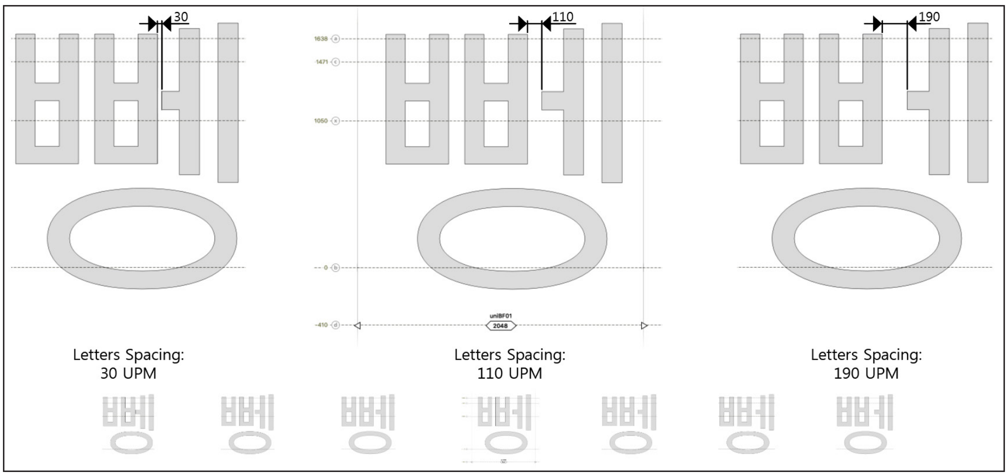

Figure 7 Test C, Detailed view of one syllable.

3. Results

3. 1. Test A, Preliminary test results

As already emerged in previous studies, print size has a crucial role in reading performance (Legge and Bigelow, 2011), but the data available are related to readability more than legibility and, furthermore, the study here presented is focused specifically on Hangeul, so Test A has been adopted also to identify the typeface size threshold under which the selected syllables start to be prone to reading errors, therefore this size has been chosen to conduct Test B and C.

As shown in Chart A, there is a clear gap in between the legibility of sizes 12, 10, 8 and size 7 and 6: considering all the stroke thicknesses, chances of reading error are doubling when lowering the size of two points, from 12 to 10 (from 0.85% to 2.00%) and from 10 to 8 (from 2.00% to 3.85%); but chances of reading errors are more than doubling when lowering the size of only one point, from 8 to 7 (from 3.85% to 10.42%) and chances of reading errors increase even further when the size of the syllables is lowered of another point, to 6 (14,85% of reading errors).

Considering only the original font or a minor increase or decrease in thickness, again from 12 points down to 8 points, it is not possible to detect significant lowering in legibility (0 to 0.66% of reading errors), while there is a clear diminishing in legibility starting from size 7 (4.33% reading errors at 7 points, 6,00% at 6 points).

According to these results, to be able to record relevant variances in the legibility, it has been decided to conduct Test B and C on the most critical size: 6 points.

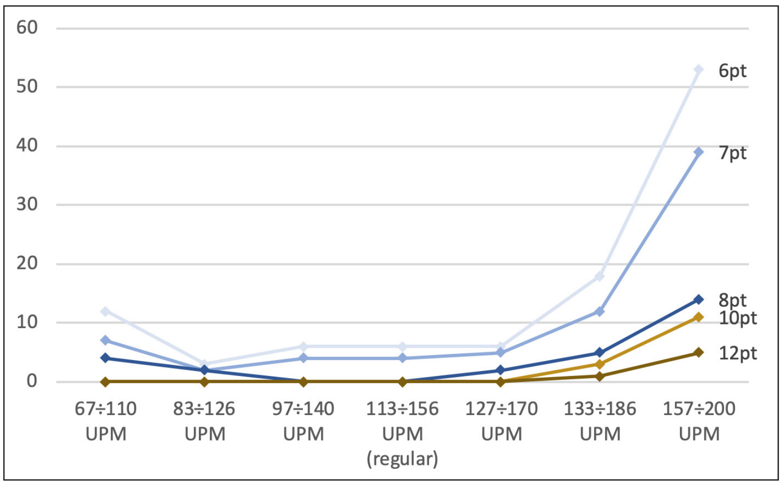

Chart A Test A.
Recorded reading errors (%) per different stroke thicknesses.

3. 2. Test A, Stroke thickness test results

The test confirms that lowering and increasing the original thickness of the typeface has an impact on legibility and more specifically it is possible to note that:

· within the range of 83 UPM (the thinnest strokes in the syllable) and 170 UPM (the thickest strokes in the syllable) the syllables reading errors are negligible, since not diverging from the number of errors committed on the original thickness

· sizes of 12 and 10 points allow a high legibility, with no error registered, even when the thickness is lowered at 63 UPM (the thinnest strokes in the syllable)
· excluding sizes 12 and 10, lowering the stroke thickness below 83 UPM has an impact on legibility and at 63 UPM the chances of reading errors on the selected syllables are clearly higher compared to the average on the central range of thicknesses (4% vs. 1.5% at 8 points, 7% vs 4.5% at 7 points, 12% vs 6.5% at 7 points)
· increasing the stroke thickness over 170 UPM have a strong impact on legibility and at 186 UPM the chances of reading errors are sensibly higher compared to the central range of thicknesses (14% vs. 1.5% at 8 points, 39% vs 4.5% at 7 points, 53% vs 6.5% at 7 points). This very low legibility could be related to the simultaneous violation of another legibility principles, since the excessive thickness lowers also the separation of the letters
· Chart A exhibit an asymmetric distribution of the values on the sides of the “original thickness” mean value, so it is possible to infer that increasing the thickness of the strokes over 30 UPM has a more significant impact on legibility than a lowering of 30 UPS. This asymmetry can be explained considering that over this limit, the separation of the letters starts to diminish and another legibility principle is being not respected.

3. 3. Test B, Secondary stroke length

The reading errors of all the participants have been recorded and summarized in Chart B (the lower position on Y axis, the better the legibility).

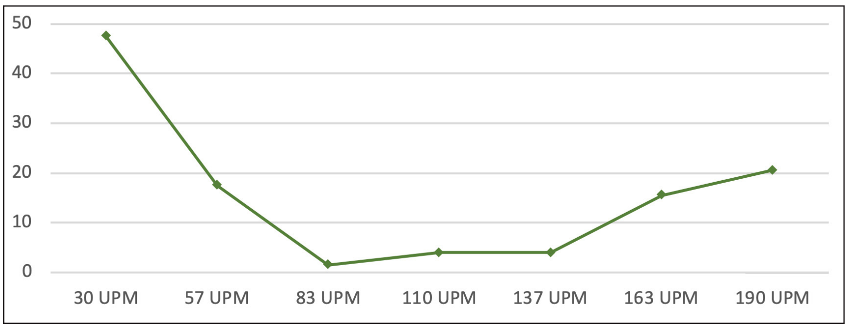

Chart B Test B.
Recorded reading errors (%) of the selected syllables per different

In section 2.2.5, the term “secondary stroke” has been contextualized within the detailed purpose of this study, so it does not refer to every secondary stroke in every letter, but to more specific cases; in this section for brevity it is only mentioned as “secondary stroke”.
It has been verified that the length of secondary strokes has an impact on the legibility of the selected syllables and more specifically:
· the most readable syllables presented a stroke length in the range of 83-137 UPM (and consequently a separation from the adjacent letter of within a range of 117-63 UPM)
· a slight increase in legibility (reading errors drop from 4% to 1.5%) is obtained when lowering to 83 UPM the secondary stroke length (thus increasing the distance from the adjacent letter to 117 UPM)
· lowering the secondary strokes’ length below 83 UPM noticeably increases the chances of reading errors (17.5% at 57 UPM vs. 1.5% at 83 UPM). The extreme decrease in legibility at 30

UPM (47.5% of reading errors) can be explained by the length of the secondary strokes to be at the proximity to the natural human visual acuity limit.
· increasing the length of secondary strokes above 137 UPM noticeably increases the chances of reading errors (15.5% at 163 UPM, 20.5% at 190 UPM)
· an excessive lowering of the secondary stroke length has a stronger negative impact on legibility compared to an excessive increasing (Chart B exhibit an asymmetric distribution of the values on the sides of the "original thickness" mean value); this can be explained with the fact that, even though the separation among the letters is compromised, all the strokes are nevertheless visible.

3. 4. Test C, Separation of the letters

Reading errors of all the participants have been recorded and summarized in Chart C (the lower position on Y axis, the better the legibility).

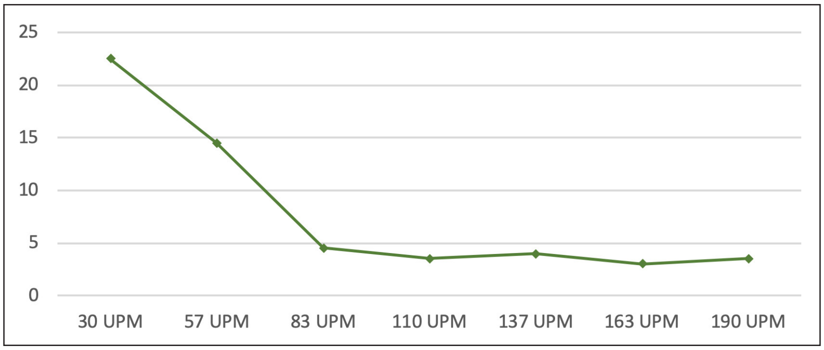

Chart C Test C:
Recorded reading errors (%) of the selected syllables per different separation of the letters.

In section 2.2.4, the term "separation" has been contextualized within the detailed purpose of this study; in this section for brevity it is only mentioned as "separation".
It has been verified that the separation of the letters has an impact on the legibility of the selected syllables and more specifically:
· syllables that presented a separation in the range of 83 UPM to 190 UPM are all equally legible (reading errors 3%÷4.5%)
· legibility starts to drop for a separation of letters below 83 UPM: chances of reading errors are roughly three and four times higher when reducing the separation to 57UPM and 30 UPM (14.5% at 57 UPM, 22.4% at 30 UPM vs. 4.5% at 83 UPM).

4. Conclusion

In order to provide indications for the development of a UD Hangul typeface, three tests were conducted to quantify the effects of stroke thickness, secondary stroke length and separation of letters on legibility. It is possible to summarize the findings as follows:

· independently of the size of the text, a very low chance of reading errors (or high legibility) is maintained within specific ranges:
- stroke thickness is maintained within the range of 83÷170 UPM
- secondary stroke length is maintained within the range of 83÷137 UPM
- separation of letters is maintained above 83 UPM
· considering that these three legibility influencing factors are correlated (i.e.: at the increase of stroke thickness also the dimension of the secondary strokes and the separation of the letters can vary), while designing a UD typeface they should be considered as a whole, balancing them, to remain within the provided high legibility ranges.
It is also worth to note that:
· the variations applied to stroke thickness, secondary stroke length and separation of letters do not have a relevant impact on legibility for sizes of 10 points and above at a conventional reading distance
· for smaller sizes, from 8 points and below, legibility decreases rapidly outside the high legibility ranges.

4. 1. Further deepening and possible correlated studies

Due to its widespread use and demonstrated good legibility, Malgun Gothic typeface has been selected as a base to conduct the tests in this study; nevertheless Malgun Gothic is one single typeface with specific anatomic characters (sans-serif, well-regulated strokes, moderate open counters, visual center-line); typefaces with very different anatomic structures could be eventually tested to detect discrepancies and refine the results here presented
. this study focuses purely on the legibility of the typeface (single isolated syllables, decontextualized from a text), and can eventually become the foundation of further studies that focus on readability, as how easily a text (multiple letters, lines, paragraphs) can be read.

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