Legibility of Bengali Typeface:

The role of letterform anatomy in Type Design

A thesis submitted in partial fulfilment of the
requirements for the Degree of

Doctor of Philosophy

in Design by

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Supervisor

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Indian Institute of Technology Guwahati
Guwahati, Assam, India

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Declaration

I hereby declare that the work contained in this thesis entitled "Legibility of Bengali Typeface: The role of letterform anatomy in Type Design" is my own work and done under the guidance of Dr. D. Udaya Kumar, Associate Professor at the Department of Design, Indian Institute of Technology Guwahati, North Guwahati, Assam, India. To the best of my knowledge, it contains no materials previously published or written by another person or substantial properties of material which has been accepted for the award of any other degree or diploma at Indian Institute of Technology Guwahati or any other educational institution, except where due acknowledgement is made in the thesis. Any contribution made to this research by others, with whom I have worked at Indian Institute of Technology Guwahati or elsewhere, explicitly acknowledge in the thesis.
I declare that the intellectual content of this thesis represents my own work and words. I have adequately cited and referred to the original work where others' ideas, work and words have been included. I also declare that I have adhered to all principals of academic honesty and integrity and not misrepresented or fabricated or falsified any idea/ data/ fact/ source in my submission.

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Certificate

This is to certify that the work contained in this thesis titled "Legibility of Bengali Typeface: The role of letterform anatomy in Type Design" submitted by Mr. Subhajit Chandra to the Indian Institute of Technology Guwahati for the award of the degree of Doctor of Philosophy has been carried out under my supervision. This work has not been submitted elsewhere for the award of any other degree or diploma.

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Abstract

India is a multilingual country with various scripts. Bengali is one of them. The anatomy of Indic scripts including Bengali has rarely been discussed and are not adequately defined. There is a lacuna of substantial work in typeface anatomy of Bengali script. Similarly, there is hardly any literature on legibility of Bengali typeface. One of the major issues with reading is legibility. Legibility is the perception of letter (of a typeface) with adequate distinctiveness in letterform. Letters are crucial for reading since it constructs the meaning of any given word. To achieve the research objective, we set to determine the anatomy of Bengali typeface and important anatomical features that are essential for letter recognition. The aim of the study is to find the role of anatomical features in typeface legibility. The methodology adopted for the study is 'Design Research Method or DRM' proposed by Blessing and Chakrabarti in 2009.

The typeface anatomy of Bengali was prepared based on Semiotics that comprised two stages of analysis: Syntactic and Semantic. The structural formation of a typeface was investigated in the Syntactic analysis. To create logical parts out of that structure, a normalised approach has been introduced that broke down all the complex features to a single unit. The data from syntactic analysis were considered in the semantic study for meaning-making. The semantic study was carried out in two phases, Syntagmatic and Paradigmatic analysis. The syntagmatic analysis was used to determine the letter-parts with nomenclature. By repeated measures, similar letter units were grouped accordingly and were coded with identity. The study proposes seventeen distinct anatomy of Bengali letters after analysing vowels and consonants. The paradigmatic analysis is a comparative study that carried out here to validate the anatomy with four typefaces. The proposed anatomy can be further used in OCR systems for identification of letters. A categorization of letters was also prepared based on common character and common structure of letters.

Legibility is the measure of reading performance in correlation with visual variables. For successful reading, a letter should have the quality of being perceived, recognised and be identified correctly by any means. An eye-tracking study was conducted to establish the role of anatomical features in letter identification. Ten blocks of three to four different letters (letter height 4cm) were presented in low contrast condition. They appeared one by one at mid position from left to right at equal distance with a time gap of five seconds. Participants were asked to read aloud quickly and accurately as they appeared on the screen. The data from participants revealed that a specific feature or combination of features is repeatedly detected in most of the cases. A letter was identified by explicit anatomical feature or in combination of more than one feature.

The second experiment was conducted to determine the anatomical features that are essential for the letter identification. To reveal the anatomical features, a 'short exposure' test was carried out using 'Bubble' as mask on letters to reveal the features. A total number of one thousand four hundred and ten masked letters were exposed in front of participants for a short span of time. The analysis of data revealed fifty-nine important features that were essential for Bengali letter recognition. Among them, thirty-four features were significant in recognition process.

A critical analysis of individual letters was conducted considering eye-tracking and short exposure data. The analysis extrapolates the role of anatomical features in letter identification. The combination of anatomical features was explicit and made letter unique by design. The combination of features triggered the recognition process that led to successful identification of letters. Based on the data, a list of essential letter features was prepared for design. The study proposes a design guideline for type designers considering the role of anatomical features in letter identification process.

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Chapter One

Introduction to Typeface

Introduction

Early humans made sounds for the purpose of communication. It is an evolutionary footstep and demonstration of intelligence that humankind had achieved the ability to communicate through sound. Writing is a visual manifestation of spoken sound. Images, signs, symbol and letters are the graphic representation of spoken counterpart. The limitation of the spoken sound is the frailty of human memory that can exceed the expression over time (Goswamy, 2007). From the beginning of the human race till present, spoken words have disappeared without any clue of event, whereas written form has remained for a long period of time providing information about history, science, culture, technology and many more.

A script is a collection of readable characters that are implicitly connected to its visual form. It consists of letters, numbers and punctuation marks. A group of unique quality of sound introduces a script and this is similar for many scripts throughout the world. A letter is a written form of a single character. A group of letters makes a script with certain similarity that is shared by a group of people or community. Such communities around the world use various scripts for written communication. Every script is developed in a personalised way for representing the visual of the letterforms considering writing tools, availability of writing materials, ideology or philosophy of state, mind and communication (Sinha R. M., 2009; Pflughaupt, 2007; Meggs & Purvis, 2006). Altogether, it helps in the progress of the community by advancing the written communication in education, science and technology. It is the writing system which enables us to communicate in a visual language that uses simple pictogram

with close relation to its original object. Later, abstract geometric signs were used as communicative visual forms based on sound.

The uniqueness of a script lies in the distinctive characteristics of the visual form of the letters. The comprehensive visual form has established certain visual grammar or style like Arabic or Chinese that becomes stylistic character of the script (Mohanty, 1998; Coles, 2012). However, similarity has been found in terms of neighbouring scripts like Chinese and Japanese. The functionality of a script is entirely reliant on script grammar which has developed over the period of evolution (Sinha R. M., 2009). There are multiple scripts in India, used by various communities. These scripts are sometimes complex and multi-structural like the living-land itself (Goswamy, 2007).

There are several scripts in the world. Latin script is one of them. The Latin script is the set of letterforms that have been derived from the Cumaean Greek version of Greek letters. Most of the letters are combination of linear and curvilinear strokes (Cheng, 2005). According to Unicode[1] (version 9.0), there are 1350 characters set including letters, numbers, punctuation marks and signs, diacritics, spacing modifier letters, phonetic extensions, superscripts and subscripts, half-width and full-width forms. There are fifty-six basic characters with an even distribution of uppercase and lowercase letterforms. The emergence of printing and the prosperous typographic culture and activity make the Latin script accessible to all (Ross & Shaw, 2012). On the other hand, non-Latin scripts remain under the shadow in typographic study. The history of typography is mostly available in Latin than the non-Latin scripts.

[1] "The Unicode Consortium is a non-profit organization founded to develop, extend and promote use of the Unicode Standard and related globalization standards which specify the representation of text in modern software products. The Unicode Standard provides a unique number for every character, no matter what platform, device, application or language. It has been adopted by all modern software providers and now allows data to be transported through many different platforms, devices and applications without corruption" (Unicode, Inc., 2017).

1.1. Introduction to Bengali

There are many scripts in India that are used by Indian populace. Among them, eleven scripts are used to write twenty-two official languages of India. Bengali is one of them and it is the official language of two Indian states West Bengal and Tripura. The Bengali language is written using Bengali script. The script is one of the most prominent Indic scripts used by 80 million Bengali speaker in West Bengal, India and 160 million in Bangladesh (bbs.portal.gov.bd, 2017) (Fig. 1.1). The minor typographical variant of the script is used by Assamese language, the official language of Assam. The script is also used to write other languages like Meithei, Bishnupriya Manipuri, Rangpuri or Rajbangshi, and Sylheti.

The Bengali script has evolved from 'Siddham' script. 'Siddham' is an offspring of 'Brahmi', which is the origin of all Indic scripts. Brahmi evolved and took its shape between the third century Before Common Era (BCE) to fifth century Common Era (CE) (Chatterji, 2011). The first Bengali script was encountered in Deopara inscription by Kumar Saratkumar Ray (Majumdar N. G., 1933-34). The inscription is one of the evidence of primitive Bengali that was written in the middle of the tenth to eleven century during Sena dynasty (Fig. 1.2). The modern Bengali script was found in 'Charyapada' or 'Charya manuscript', written between eight to twelfth century, discovered by Haraprasad Shastri at the Nepal Royal Court Library in 1907. It consists of an anthology of 47 padas or verses written by 23 different poets in 'Sandhya' language, a natural and regional spoken form of Sanskrit language (Majumdar R. C., 1971). Many scholars have claimed the similarities of the language of Charyapada with Assamese, Bengali, Maithili and Oriya (Banerji, 1919). There are several debates on the language of 'Charyapada', but the written letters on it is in modern Bengali.

Fig. 1.1: The region where Bengali script is used

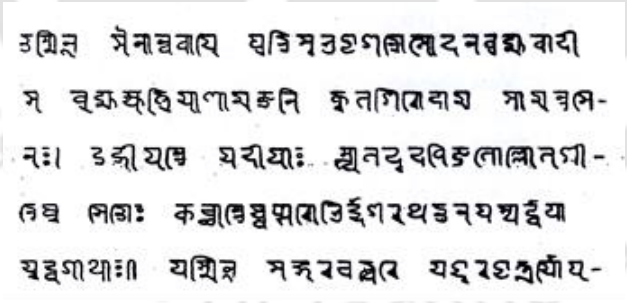


Fig. 1.2: Deopara Inscription (Naik, 1971, p. 150)

The Modern Bengali is standardized by Pundit Ishwarchandra Vidyasagar (also known as Ishwarchandra Bandyopadhyay) who was one of the pioneers of Bengali literature. Bengali script has twelve vowels and thirty-seven consonant letters. The Assamese language shares same scripts with additional letter 'Khya' (ক্ষ) and

difference ‘Ra’ (ৰ) and ‘Ba’ (ৱ). The letterforms of the script are structurally complex with sinuous shape. Moreover, there are certain groups of letters that are very different from other groups of letters considering their shape, proportion, height, width, stroke and path of the stroke. There is an extensive diversity within the letterforms. The writing system of the script falls under ‘Abugida’. The features of this system are as follows-

- It is written from left to right.
- A distinctive horizontal line runs along the top of the letters that link them together, which is known as Matra (মাত্রা).
- **Diacritics:** A sign mark that comes at the four different positions of letter. The positions can be top, below, before or after the consonant to pronounce the consonants in the different inherited sound of the same letter. The diacritics forms are only alternative forms of vowels that are inherited by the consonant sound. In Bengali, the ‘Paa/পা’ is the ‘aakaar’ or ‘আ-kar’ of প.
- **Conjuncts:** Conjuncts are single letterform of two or more consonants and/or vowels combined vertically or horizontally (Fig. 1.3). It is a fused form of two or more letters that are placed on top of one another, can share their vertical line or side-by-side or one-half of the letter comes with another letter. The general shape of the conjuncts is multi-tier. There are a large number of conjuncts in Bengali that are in use. Sometimes, a completely different form can appear in place of such fused form.

Fig. 1.3: Conjuncts of Bengali

There are two sets of Bengali vowels that are used in writing. The regular forms are used as words and the diacritics or vowel sign marks. The diacritics combine with the consonants to finish the consonant sound to the inherited vowel sign. Their position of attachment is also varied based on sound and consonants. Table 1.1 shows the vowel letterforms with diacritics.

Table 1.1: Bengali vowels

Vowels	Full name	Diacritic form	Diacritic name	Roman name
অ	a			a
আ	aa	া	a kar	aa
ই	Hrosbo i	ি	Hrosbo I kar	i
ঈ	Dirgho i	ী	Dirgho I kar	i or ee
উ	Hrosbo u	ু	Hrosbo u kar	u
ঊ	Dirgho u	ূ	Dirgho u kar	u or oo
ঋ	(Hrosbo) ri	ৃ	(Hrosbo) ri kar	ri
ঌ	(Hrosbo) li		(Hrosbo) li kar	li
এ	aya	ে	e kar	e
ঐ	oi	ৈ	oi kar	oi
ও	o	ো	o kar	u or o
ঔ	ou	ৌ	ou kar	ou

The consonant letters are typically pronounced as just a consonant sound with the inherent vowel ‘a’/ ‘অ’. ‘অ’ sound is the default inherited vowel sound for most of the consonant letters in Bengali. The inherent vowel is naturally assumed to be there, but not in the written form. As a result, most letters sound similar to the other letter with minor variation. Table 1.2 is a list of given consonants of Bengali.

Table 1.2: Bengali consonants

Consonants	Full name	Roman name
ক	ka	ka
খ	kha	kha
গ	ga	ga
ঘ	gha	gha

ঙ	ungo	ngo
চ	cha	cha
ছ	chha	chha
জ	Borgiyo ja	ja
ঝ	jha	jha
ঞ	e no	no
ট	tta	tta
ঠ	ttha	ttha
ড	doe	dda
ঢ	dhoe	ddha
ণ	Murdhonyo na	nna
ত	ta	ta
থ	tha	tha
দ	da	da
ধ	dha	dha
ন	na	na
প	pa	pa
ফ	fa	fa
ব	ba	ba
ভ	bha	bha
ম	ma	ma
য	Antastha ja	jja
র	ra	ra
ল	la	la
শ	Talobyo sho	sha
ষ	Murdhonyo sa	ssa
স	Dontya sa	sa
হ	ha	ha
ড়	doe shunyo rho	rho
ঢ়	dhoe shunyo rho	dha ra
য়	Ontostho o	jja ra
ৎ	Khandyat ta	ta
ংঃ	Biswargha	biswa
ঁ	Chanda bindu	Dot or nukta

Additional, Assamese letterforms are below-

ৱ	ra	as ra
ৰ	wo	wo
ক্ষ	Khya	khya

1.2. Typeface and letterform

A typeface is a collection of characters or glyphs[2] that share common design features (Bringhurst, 2004; Beier, 2012). It is a medium through which every letter of a typeface confines its physical embodiment. It is a common design characteristics of a group of letterforms that sometimes extend across to multiple scripts. The term 'typeface' is often confused with the word 'font' which is different from each other. In type design, the definition of 'font' has changed over the period of time. A font is a set of glyphs in a particular size, weight and style of a typeface. In the digital era, a font can be defined as reproducible characters that are printable or displayable in a specific style and weight. However, the font size has become very common that can be well-controlled at any point of design process. A font is basically the physical or digital representation of a single typeface. In details, 'Thesis' is a typeface family, 'TheSans italic' is a typeface, and 'ThaSans italic 12-point' is a font. In practice, font and typeface are often used interchangeably but they are different in theory.

A 'typeface family' sometimes consists of a set of fonts that are designed with common design features. 'TheSans', 'TheSerif' and 'TheMix' are three typefaces that belong to the 'Thesis' family (as in Fig. 1.4). Each member of a type family can be represented by a single typeface that is designed with common weight, style, width, slant and ornamentation; at least varying one design feature. The style or the design of the typeface completely depends on the designers who design the family. There is no standard rule to design such a family but certain guidelines and working principals have emerged in the field of type design practice. The weight of typeface determines the thickness of the stroke or the heaviness of the strokes. The general created weights are Thin, Regular, Bold, Black and occasionally a Semibold in between. The wide range of weights allows typographers and graphic designers to apply the typeface in a wide range of context. Their design characteristics have to be

[2] A 'glyph' is a readable symbol or character.

maintained to consider them as a single family without varying the stroke-weight (Karow, 1994; Karow, 2013; Bringhurst, 2004; Cheng, 2005).

The digital design of letterforms is stored in the form of digital files. There are many popular file formats. Among them, True Type (TTF) and Open Type (OTF) are widely used. True Type Font or TTF format is relatively old and was designed to support all Windows and Macintosh systems including any kind of printer. On the other hand, OTF format has been newly developed by a joint venture of Adobe with Microsoft. It is a cross-platform format that opens many possibilities by extending the capabilities of TTF format. The major advantage of OTF over TTF format is the number of character set that extends from 256 to 65,000 glyphs per font (Adobe Inc., 2015; Karow, 1994).

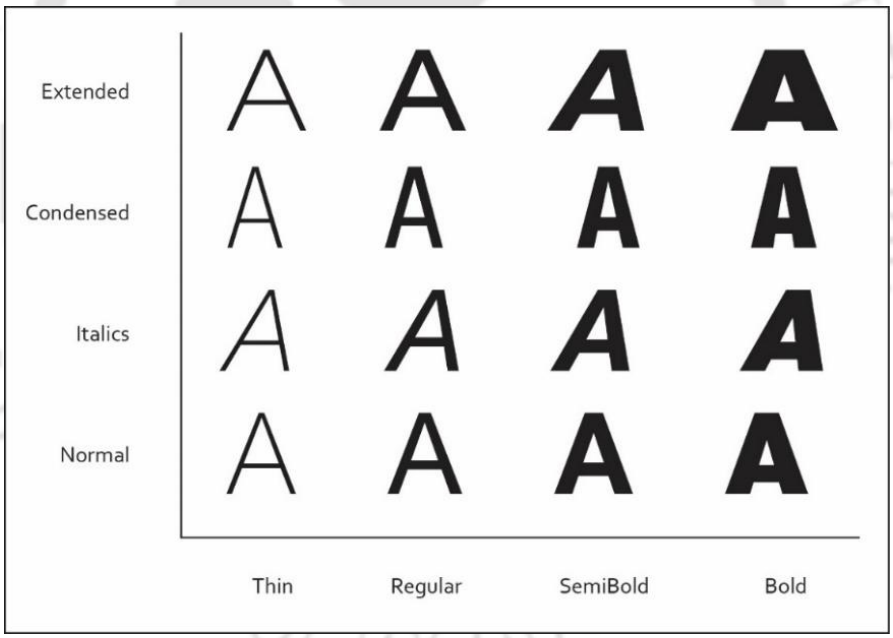


Fig. 1.4: Design space of typeface

Visual character of letterforms is important in identification of letters. The letterforms follow a grammar, a harmonious design, to be a member of a typeface (Fig. 1.5). Letters are the combination of different strokes and the strokes are embedded with design characteristics of letters.

According to the Laurent Pflughaupt (2007) –

"Letters, regardless of their style, are composed of a certain number of curved, straight, simple, and complex strokes, connected in specific ways. Each letter's ductus, or framework, demonstrates the order and direction of each stroke. Character strokes fall into two categories: straight lines (horizontals, verticals, and diagonal) and curved lines. The arrangement of the straight lines creates a different type of angles that structure the letters. The openness of its angles gives the letter its specific characteristics. The shape and location of the empty spaces in and around a character also play a determining role in constructing this letter 'identity'. (Pflughaupt, 2007)"

Fig. 1.5: Typefaces vs letterform

With the change of typeface, the stroke path and other design variables of each letterform change, such as Times New Roman (TNR) Regular and Arial Regular. The TNR and Arial have different stroke weight and width. TNR is a serif typeface whereas Arial is a sans serif typeface (Fig. 1.6). The stroke width, weight, stroke path and other design factors vary for every typeface. Their design characteristics and style are significantly different in most of the cases (Spiekermann, Truong, & Siebert, 2006). However, letters of almost all typefaces are recognisable despite such variations in design. There is a certain configuration of letter stroke that is the key to letter identity. Human brain always recognizes a human face, which is varied for every person, but the anatomical structure of a face is similar for all. Similarly, anatomy of the letterforms initiates the understanding process of a letter and eventually the typeface.

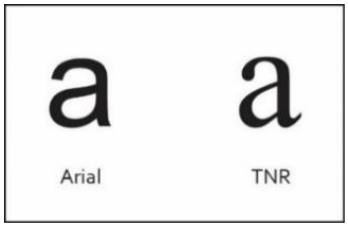


Fig. 1.6: Arial Regular & Times New Roman Regular

1.3. Typeface Design

Typeface design is a branch of design where design philosophy, process, management and technical discourse of a typeface is discussed. It is practised by type designers and font developers to create 'fount' (old British form) or 'font' for mass production of the printing or digital text materials (Ross & Shaw, 2012). The advances in the field are typically achieved by the practitioners with the help of engineers and researchers. Nonetheless, many problems still exist in the domain of typeface design and designers, for which researchers are collaborating to solve it. Many tools, methods and designs have been introduced with many alterations to seek solutions for the existing problems. The typical difficulties are –

- Every time a new typeface is created; the specifications of the style become one of the primary issues with the designer. The necessity of a new font has to justify in the context of purpose.

- In the digital era, the display or web fonts create a diverse set of challenges for designers. The issues of font 'adaptability', 'usability' and 'legibility at low-resolution display' are the present research domains that require the attention of the designers and researchers.

- Apart from the global design context i.e. Latin typeface design, the vernacular scripts are also becoming a concern for designers. The designers have already started the subject domain of 'multi-script design'. The vernacular context of

type design is becoming popular in the twenty-first century with a new set of challenges.

1.3.1. The design process

Type design is the art and technique of designing the typefaces. It is a process by which glyphs are defined by its shape. It is often interchangeably used with 'font design' which is, practically, different from type design. Technically, font design refers to the process of designing letter into the presentable form that is compiling them into a digital file. The drawn glyphs go through several stages of processing that interchange the raw information of glyphs into compatibles or direct executable format for screen display. But in general, type design refers to the complete process of designing typeface for font production.

In the beginning, typefaces were prepared in the form of movable type made of wooden or metal type. The early printing with movable type emerged in China. In the middle of fifteen century, Gutenberg's intervention changed the complete history of printing with an adaptable mould that can accommodate a number of types in a variety of widths. There is a very narrow letter like 'I' and also wide letter like 'M' in Latin. The widest size is known as 'Em', referring to the maximum width of letter 'M', which the unit of the type size.

The printing industry experienced an amount of printing tool that evolved throughout 1890 to 1960. In the beginning, the American type founders started to design large size letters using Benton pantograph. It was a punch cut technique to fit the matrices in mounting process. It retained until the end of century, photo composition came. It was extensively used in the western world for printing, but in India movable type remained dominant. Besides, many typefaces were developed using photocomposition. Later, Linotype and Monotype typesetting machine became dominant and were used by most of the press and large enterprises.

At the end of 1980s, digital software like Freehand and Illustrator finally showed up and they became the successor of the type design tool. Later, dedicated type design editors like Fontographer and FontLab emerged to fulfil the designers need. Once mechanical industry, it has now completely transformed into software industry. The current design process is described through the following points.

- Before going into the design of letterforms, a thorough research is needed to understand the prerequisite, requirement and necessity of the new design. Letters can be drawn by a stylus on the digital surface or hand-drawn and scanned to digital media. The design of the typeface completely depends on designers' objective, skill and requirement. The scan or digitized letter is stored as bitmap (scaler image) or vector (scalable outline) format that is processed further.

- The digital file is then ready for the processing to prepare a font file in PostScript, TTF or OTF format. From this point, the job can be carried out by the designers or can be transferred to a specialist, often known as 'font engineer'. The font production involves Bezier curve correction, kerning, hinting, anchoring (for diacritics), preparation of GPOS and GSUB table, feature defining and corresponding substitution code writing. Testing is mandatory after every stage of design process. The general structure of font file is given in Fig. 1.7.

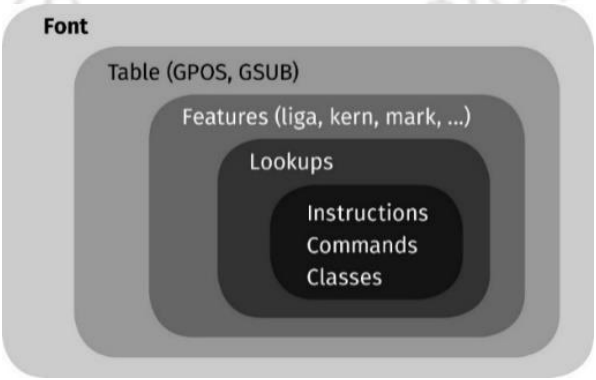


Fig. 1.7: Structure of an OTF font (Karow, 1994)

- **Bezier curve correction:** The correction is essential for adjusting the incorrect position of the anchors, removing the undesirable anchors from curves and to adjust the Overshoot and Undershoot[3] of the letters. The Alignment zone is the representative of Overshoot and Undershoot to control the appearance of the extended part. Apart from Alignment zones; consistent terminals, specific vertical and horizontal stroke width are the few essential corrections that need to be done at this stage of the design process.

- **Kerning:** Kerning is a process of adjusting the space between two characters. The equal spacing among letters appears as uneven adjustment due to the different letter width, hanging edges and round letterforms. The equal arrangement makes letter-spacing scatter and optically imbalanced. The spacing has to be adjusted between the letters to look visually balanced.

- Apart from these two corrections, the position of the diacritics (in case of non-Latin typeface) has to be set accordingly. Later, the position information needs to be stored in GPOS table.

- The glyph substitution information is stored in GSUB table. The Glyph Substitution or GSUB table consists of all information about glyph substitution that is necessary against the conjuncts. The substituted letter has to be designed separately and it substitutes the half form of consonants with inherited conjunct.

- **Hinting:** According to the type designer Peter Biľak –

  "Hinting, or screen optimising, is the process by which TrueType or PostScript fonts are adjusted for maximum readability on computer monitors. This text compares

[3] Overshoot and Undershoot are small unit of extension in height of round and pointed letters. They reduce the illusion of small appearance and make equal in height to rectangular letters.

different ways of hinting (Black & White, Grey-scale, ClearType, DirectWrite), and explains the behaviour of fonts under different rasterisers." (Biľak, 2010)

The hinting refers to the optimizing method of fitting the outline of a letterform to the pixel presented on a digital surface. The display screens are available from minimum 72 dpi to above. In most of the cases, the fonts are designed in higher resolution of 1200 dpi and above for the purpose of printing. The digital drawing is stored as Bezier curves of outline for the letters. The enclosed space is represented by pixels that are perfectly arranged for high-resolution display screens. But, it is not the same for low-resolution screens. The pixels are outfitted at curvatures due to high inclination. As a result, the display of letters gets distorted and they become illegible to read. The curve crosses the pixel from the inside, leaving it in toggling state either on or off. Many times, the vertical or horizontal stroke does not match the pixel edge or stroke width does not match the perfect number of pixels. The offsetting of the curve causes the grey formation around the letters and sometimes uneven stroke width (too thin or too thick). To control the shift, there are few readymade hinting technologies such as grey-scale, true-type, clear-type and anti-aliasing that come with software to prevent it from distortion. Even though, it is not enough for low-resolution display screens.

The legibility is a key challenge that remains in the design of a text-based typeface. The visual quality of a continuous text or reading materials must achieve the precision in glyph order, rhythm and balance. This concern leads the designers to the legibility that is one of the most fundamental issues. The adaptability of design is another key concern for designers since screen display involves from small low-resolution to large high-resolution screens. It is a fact that the large letterforms are recognized by the edge or outline exposing their shape, whereas small letterforms are recognized by gross stroke (Majaj, Pelli, Kurshan, & Palomares, 2002). A continuous text only reveals the textures of text body. Thus, the structure of the letterforms needs to be taken care during design of letterforms. The success of a typeface depends on

the requirements that are met during the design process considering the possibilities discussed above. An exquisite typeface may not have an eye-catching texture or adequate legibility when reading a body of text.

1.3.2. The type design in Bengali

The design process of non-Latin typeface is complicated and complex. The Bengali letterforms are not out of that intricacy. According to Changizi and Shimojo (2005), the average character length of Bengali script is 3.95. It is almost half of Latin script i.e. 2.08 for lowercase and 2.50 for uppercase letters (Changizi & Shimojo, 2005). The density of the letterforms is much higher than Latin, which makes letterforms complex. The basic letter set of Bengali is also more than Latin in terms of numbers. There are letters with vowel signs and a large number of conjuncts. The technical procedure of the font production might have similarity with Latin, but the job of font production is more tedious and time-consuming activity due to a large number of glyph set and complexity of the letterform structure.

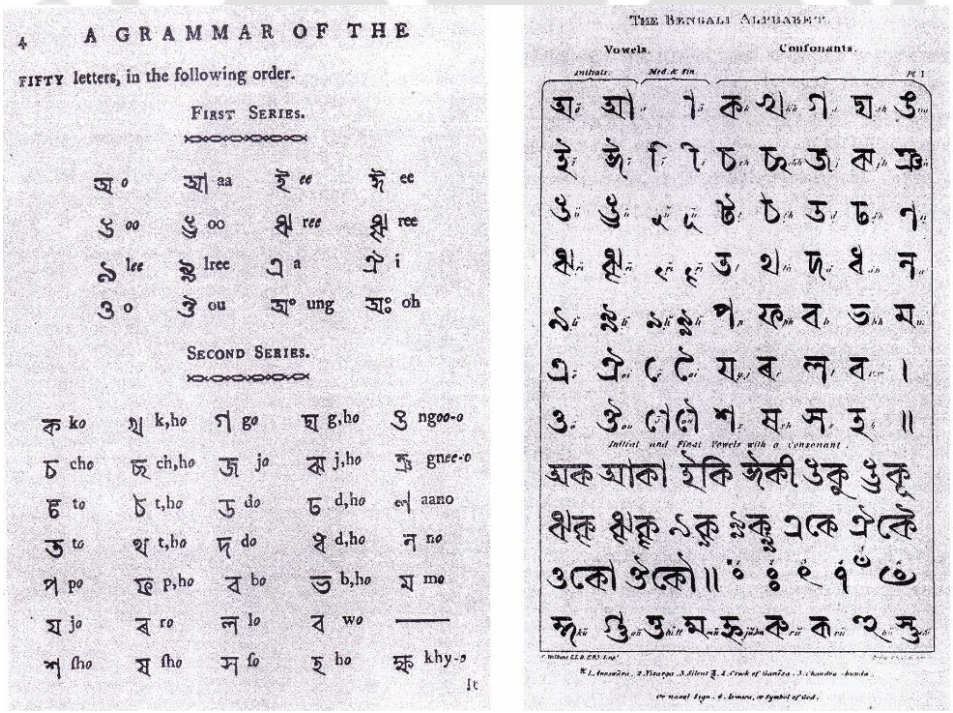
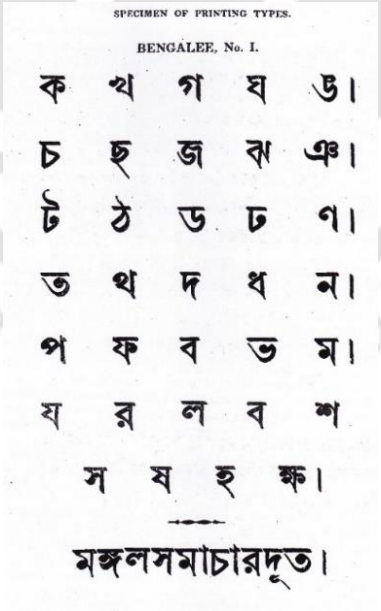


Fig. 1.8: Charles Wilkin's first font - CW1 (Left), fourth font - CW4 (Right)

The early printing in Bengali started at the end of eighteen century. Charles Wilkins, a British writer, was employed to develop a Bengali imprint by the East India Company in eighteenth-century (Ross, 2009). With the endeavour of Charles Wilkins, many new presses came to light with the scope of mass production of printed materials. The 'Chronical Press' (1786-1797) was one of them with the publication named 'Calcutta Chronicle'. They preferred to use the Wilkin's font especially the first one the 'CW1' (Ross, 2009). At the beginning of the nineteen century, missionaries started to extend their roots. Under them, two prominent presses the 'Serampore Mission Press' and the 'Baptist Mission Press' published many documents that are significant in terms of historical evidence under the supervision of William Carey (Fig. 1.9). The typeface used by these two presses reveals new genre of typeface design in Bengali incorporating Wilkin's letterform with printer friendly features. The appearance of the 'blob' feature in the script was a distinct step in design which continues till date. Previously, the printed typefaces were too much curvilinear and dominated by hand-written style. But, the printed letters in mission presses were more structured in terms of design.


SPECIMEN OF PRINTING TYPES.

BENGALEE, No. I.

ক খ গ ঘ ঙ।

চ ছ জ ঝ ঞ।

ট ঠ ড ঢ ণ।

ত থ দ ধ ন।

প ফ ব ভ ম।

য র ল ব শ

স ষ হ ক্ষ।

মঙ্গলসমাচারদূত।

Fig. 1.9: 'Bengalee No. I' of Baptist Mission Press, Calcutta, 1826

Throughout the nineteen century, the typefaces developed by mission presses were predominantly used. Few new presses came to light such as the 'Girisa Vidyaratna Press' and 'Sanskrit Press'; all of them followed the same typefaces developed by missionaries for printing. During the same period, a standard set of Bengali characters were revised and published by Sanskrit Press in the mid-nineteenth century. The publication was authored by Pundit Ishwarchandra Vidyasagar and Madanamohana Tarkalankara, a benchmark that gave rise to a new genre of Bengali letterforms. The work 'Varnaparicaya' by Pundit Ishwarchandra Vidyasagar (Vidyasagar, 1971; Ross, 2009, p. 127) was one of the most significant works.

In late nineteenth century, many type foundries and printing press came from Europe to expand their circle. The fonts from the Linotype foundries were exemplary in this regard. They prepared the first set of hot metal block of Bengali in 1934 (Fig. 1.10) maintaining a standard grammar of letterform developed by missionaries. The first punch-cutting was done by Suresh Chandra Majumdar, commissioned by Sri Gouranga Press under the proprietorship of 'Ananda Bazar Patrika', the daily newspaper, which still holds the reputation and functions as a prosperous label in Bengal. Their designed typeface has been dominant in printing industries and still maintains the standards of those times.

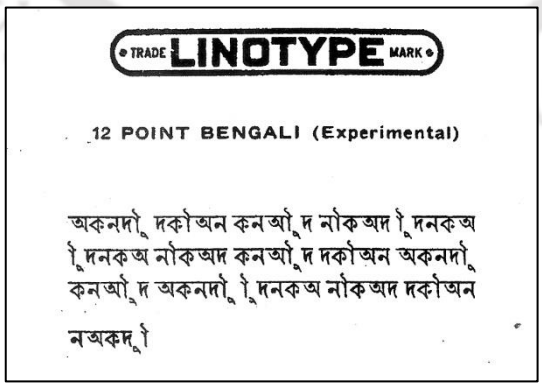


Fig. 1.10: Linotype 12-point Bengali, 1934

The intervention of Linotype and Monotype corporations completely changed the use of typeface culture in Bengali printing. The structural forms, arrangement, systematic 'Matra' line and the most notable letter proportion are the foremost influenced factors by which the script got its richness in print art (Ross, 2009; Ross, 2013). But with advancement, there was a problem too in the Monotype machines; particulary in printing complex characters of Bengali. The adaptation of western equipment in vernacular fonts was constantly compromised due to mechanical components whih were actually meant for Latin script (Ross, 2009, p. 174). At the same time, the calligraphic style of the script had remained suppressed in printing. The calligraphic quality of the script was nurtured in other fields of communication designs such as magazines, posters and film titles. The art of writing and lettering never met the conspicuous attention of the printing (Ross & Shaw, 2012). The calligraphic style never faded due to few leading graphic artists and designers such as Satyajit Ray (Fig. 1.11). The influence of calligraphic style on Bengali script is eminent. It requires an extensive study to understand the degree of calligraphic influence on Bengali type design which is beyond the scope of present study.

Fig. 1.11: Works by Satyajit Ray

The current type design and font manufacturing processes allow too many scopes and possibilities. It solves many difficulties from the mechanical type-setting but also introduces new complications. The legibility issues in mechanical process were in the nature of printing ink and surface of metal block. The legibility issues were taken for granted in Bengali text production since punch-cutting, typesetting and printing were too complicated with the Bengali script. The time required to design a typeface and reproducing of printing materials needed a large number of human resources. Moreover, the job included many people who were not native to the Bengali script. The problems associated with legibility were too expensive for them to work on it or think about it. In recent years, with the advancement of computer software and hardware, things have been made easier for designers. The OpenType technology opens the scope to solve the number of glyph issues with Bengali script.

1.3.3. Typeface Design and Legibility

The term 'legibility' defines the quality of being clear enough to identify a character without any hesitation (Gaultney, 2000). It is one of major concern of many type designers and researchers in designing letterforms. Type design is often considered as a part of typography. But in practice, type design and typography are completely different. The arrangement of words or letters in a continuous text is the concern of typography whereas, type design deals with the design of typefaces and its processes. The parameters related to typography are the medium of reading, word-spacing, line-spacing, word count in a line, reading speed, reading pattern (number of columns, margin etc.), reading distance, luminosity, viewing angle and many more. The type design parameters include Gridlines, Stroke path and Treatment, Stroke contrast, Stroke density, Stroke width and weight, Terminals, Optical size, and Stroke contrast. These variables sometimes share common ground which is correlated and is often hard to separate from one another.

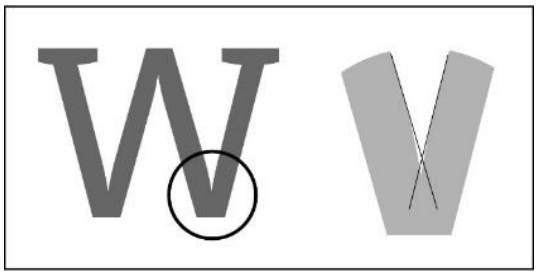


Fig. 1.12: Tapping at joinery

Sofie Beier (2009) discusses in her doctoral thesis that much anticipations have been made by different researchers in different field without justifying the terminology type design. Such attempt questions the internal validity of research methods. She explains in her thesis that the reason for neglecting such crucial information in studies is as follows –

> *"This lack of understanding of other trades also appears to be present in relation to knowledge on legibility – an area dominated by the two cultures of the empirical scientific approach and of the more design-orientated approach. The empirical approach is based on the testing of hypotheses. It is a problem-solving approach where assumptions are tested with an outcome of some form of conclusion. The experiments are often carried out by people with a psychological and scientific background, but without any real knowledge of the design aspect of typography." (Beier, 2009, p. 16)*

She explains that there are two types of culture or knowledge domain doing legibility research, one is academic legibility research and the other is type design and research. Their common ground of understanding the trade 'legibility' is very less than revealed in the different meanings of study. The academic intention is to objectify the basic knowledge of legibility by establishing previous trade of knowledge domains, whereas designers' intention basically aims towards subjectivity of typeface that accomplishes the objective of design. In empirical research, factual evidence is

necessary for scientific research to establish any claim. But, practice-based research is more flexible to process and focuses on the quality of output (Beier, 2009).

Also, the term legibility is often confused with the term 'readability'. These two terms were previously used by researchers interchangeably. They have also overlapped the concept and confusion between them. They both deal with the reading performance but their objective for successive reading is different. The two fundamental confusions with the definition of design, legibility and readability have led to unacceptable results in many studies (Beier, 2009).

Miles A. Tinker (1944, 1963), one of the pioneers of legibility researcher, preferred the term legibility by rejecting the term 'readability' to simplify both the constructs. In current years, researchers have started differentiating the meaning between readability and legibility. Readability is the ease of reading a continuous text (Tracy, 1986). The ease of reading depends on the content of the text and the typographical arrangement of the text. Thus, it is a variable that deals with the typographical aspect of the text but not design aspects of letterforms. In contrast, legibility is the term that deals with the perceptibility of letters or a distinguishing factor of letterforms from other letterforms (Tracy, 1986). The construct legibility is even more confusing when it is used in larger context. Researcher, Miles A. Tinker called the construct 'legibility; by differentiating it as 'letters', 'words' and 'continuous-text'. However, many researchers are in a dilemma about these constructs and are reluctant to use it interchangablily. It is a known case when researchers measure the legibility in the other domain, such as ergonomics, vision science and psychology. An effort was made by legibility researchers like Water Tracy (1986), Ole Lund (1999). To avoid confusion, they proposed to use the term 'legibility of the letter in isolation' and the 'legibility of the letters in continuous text or word formation'. They have rigorously examined many definitions of the 'legibility & readability' and differentiated them by employing constraints in the context of their nature of use.

1.3.4. Typeface Anatomy and Legibility

Anatomy is the study of the structure of the body and physical relationship involved between body parts (Waugh & Grant, 2001). It is the science of structure and the relationships among structures (Tortora & Derrickson, 2012). The definition suggests that it deals with a physical entity that has a structure like formation such as the human face. The characteristics of faces are consistent irrespective of geographical distribution, space, race, gender and resources. Only shapes of every feature like the nose, eye or mouth are or can be changed. The human eye can identify every feature distinctly. All features together stimulate the perception of human face. The common character of a human face can be observed in skeleton level where the anatomical structure is almost similar for all human face.

In other words, anatomy is the fundamental knowledge of structure and its formation that possesses an identity of a particular body or body like structure. The argument can be illustrated by considering the structural formation of Sunflower and Rose. They both have common features like petals and receptacle. However, the shape of petals or receptacle is dissimilar in each case which makes a Sunflower different from a Rose. The shape is the distinguishing feature for both of them, but their anatomical structures suggest that they belong to the flower family (Athavankar, 1989). Similarly, the typeface can be explained as the shape of letterforms that shares design characteristics among all letterforms. It is the means of communication through which letterforms are formed. The basic anatomical structure of any typeface is supposed to be alike among a vast range of typefaces that exists in different shape, style, or genre. Despite such design variations, every letter is recognised in human brain without losing its identity. There is a certain affordance of the shape that makes the letters understandable. The understanding of such knowledge is the perceptibility of letterforms.

Letter perception refers to the type form or type anatomy. Legibility is about clear perception of characters or letterforms where letterforms are operationalised by anatomy. By controlling the anatomy, the letter perception can be controlled since typeface is the skin or mesh on the letter-anatomy that regulates the overall shape of the letter. The intention here is to understand the anatomy of the letterforms that can contribute to the legibility of typefaces directly or indirectly.

1.4. Motivation for the research

The study is undertaken to identify the causes of legibility issues in display screens. The reading materials such as posters and books are well and precisely printed in Bengali typefaces. But it is not the case with digital typefaces. Eventually, there is hardly any study that evaluates reading comfortability with the Bengali display typefaces (Ross & Shaw, 2012). The existing literature on digital text typeface is not satisfactory to evaluate legibility of Bengali letterforms.

1.5. Research Problem

The thesis highlights the lacuna in the field of legibility studies in Bengali script. Over the last century, typographers and type researchers have extensively studied the anatomy and legibility of Latin script. For the last two decades, non-Latin scripts[4] are getting more attention from the research community. Sixty percent of the global population is dependent on non-Latin scripts including Indic scripts. It is widely used in education, politics, economics and cultural purposes. There are many print-media such as newspaper, magazines, hoardings, and posters that gets regularly printed using non-Latin scripts including Bengali. Even non-Latin netizens are increasing day-by-day (Ross & Shaw, 2012).

[4] The term non-Latin script is referred to vast collection of scripts around world other than Latin. The term interchangeably is used to refer Bengali script in this thesis.

It is through the means of typefaces that any script can be printed or displayed for communication. Bengali has a rich history in print and publication over the last 70 years, though it started 200 years back. Typeface design in Bengali or any Indic scripts involves calligraphic knowledge of the script. Understanding the 'script composition grammar' of letterforms can certainly assist the type designer to design any typeface to achieve legibility.

The research is designed to create a support for the type designers. We are assuming that the knowledge domain of anatomy can provide support to typeface legibility. After all, the design of the typeface is also the initiation of the legibility issue. The method by which a typeface is designed can also be taken as a vantage point to solve legibility issues.

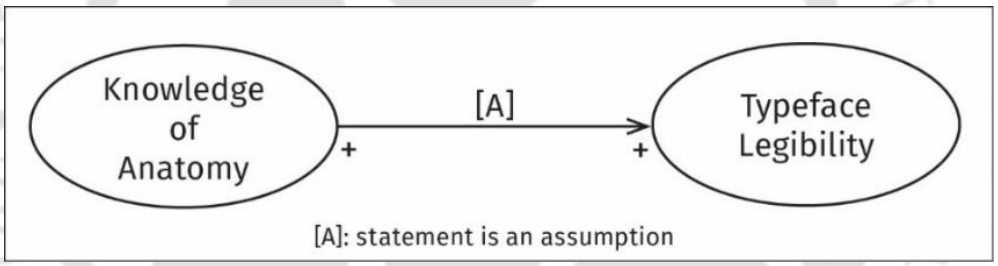


Fig. 1.13: Research assumption

There is hardly any study or research on legibility in Bengali typeface. Extensive study has been done on printing and developing typefaces. There is a scope to look into the legibility issues of Bengali considering letterform anatomy. Also there is a need for investigation into the design aspects of Bengali letterforms.

1.5.1. Research Assumption

The anatomy is a predetermined structure that is the backbone of letterforms. The 'role of the anatomy in design process' is the primary concerns of this thesis. Thus, one of the scopes of this thesis is to study the anatomy of Bengali letters. The other scope includes legibility study of letterforms accessing anatomical information. The

results of the legibility study can provide the critical information about letterforms that can be useful for type designers. The anatomical information of letters will not only ease the design process of letterforms but also the entire process of reading experience that can be achieved without any difficulty. It aims for the type designers to provide adequate information of anatomy that would help them to achieve legibility in design process. The assumptions of the thesis are listed below –

- Anatomy helps designer for a better understanding of letters.
- Anatomical information can contribute to achieving legibility of letterforms in the process of letterform design.

1.6. Research Objective

Based on the research problem and assumption mentioned above, the objectives of this thesis are –

- Identification of anatomy of Bengali typeface.
- Identifying important anatomical features for letter identification.

This thesis demonstrates through various cases, and comparative studies that the parameters identified previously in Latin are not reliable to define legibility of Indic typefaces[5]. The analysis is based on anatomical features, stroke, letter binding and support, the direction of the stroke, stroke density, and variance. Further, the study identifies important features responsible for letter identification in Bengali script for better legibility.

In this study, the construct legibility is defined as perception of letters in isolation or visibility and perception of letters in group or legibility (Lund, 1999). Visibility study has been done to identify important letter features for letter

[5] The term Indic typeface is interchangeably referred to Bengali script in this thesis. Here, the scope is narrowed to the Bengali script due to vastness and diversity of Indic scripts.

identification. Later their significance in design will be examined. Finally, the thesis proposes a guideline for the type designers to achieve legibility during the process of designing Bengali typeface.

The approach towards legibility may not be entirely similar for all non-Latin scripts. Each non-Latin script has a specific set of characteristics and script composition grammar that needs to be addressed individually. Individual, systematic study is required for each of the scripts considering these features.

1.7. Research Methodology

The role of letterform anatomy in typeface legibility is examined and based on evidence, a design guideline has been proposed. Some facts are observed in practice, but there is no such proof to confirm the role of anatomy in design. A semiotic analysis has been used as method to establish the letterform anatomy and a experimental method 'short exposure test' has been used to identify the role of anatomy to validate it. The cognitive process of letter legibility and reading has also been employed to understand the complexity of letterform and involvement of external factors to clarify the complex nature of design.

The research has been done based on the Design Research Methodology (DRM) proposed by Blessing and Chakrabarti (2009). Design Research Methodology (DRM) provides the basic framework for design research. There are six different models of Design Research Methods. The DRM Type 2 has been adopted for carrying out this research. It consists of four stages – research clarification, the descriptive study and prescriptive study (Fig. 1.14) (Blessing & Chakrabarti, 2009). It is an appropriate model where previously said methods can be applied individually in descriptive study with successful and positive outcomes and further guidelines can be proposed and laid out for prescriptive study (ibid).

Research Clarification	Descriptive Study	Prescriptive Study
Review-based →	Comprehensive →	Initial
• Typeface Anatomy and Legibility • Letter recognition and design	• Detail analysis of typefcae anatomy • Analysis of Bengali typefcae legibility	• Anatomy of Bengali letterforms • Guideline for Type Designers

Fig. 1.14: Research framework (Blessing & Chakrabarti, 2009)

According to the Design Research Method: Type 2, the context of research is as follows –

> *"The study was undertaken to explore and identify the existing anatomy and legibility of Bengali typeface that was necessary to gain insights. The most relevant literature has been addressed to deal with the issues in order to analyze the Bengali typefaces. After that, a comprehensive descriptive study has been undertaken to fill the insufficiency that has found in literature. Once sufficient understanding has been gained, a prescriptive study has been undertaken to indicate how this understanding of anatomy can be used to improve typeface legibility" (Blessing & Chakrabarti, 2009).*

1.7.1. Methodological Framework

The method has been used here to analyse the present typeface anatomy and legibility. The most relevant literature has been studied to understand the anatomical features and legibility issues in Bengali. Based on the available literature, the research goal was set (Fig. 1.15) to reveal the insufficiency or gap in literature. In descriptive study, necessary analysis and experiments have been undertaken to fulfil the research gap in Bengali typeface anatomy and legibility. Based on the descriptive study, a design guideline has been proposed considering letter anatomy and legibility issues.

The Fig. 1.15 explains the complete research process that was undertaken for study of research. The goal of the research was set after reviewing literature

thoroughly on anatomy and legibility from letter recognition perspective. Next, the anatomical study and legibility measurement was done in descriptive study that determined a broad understanding of the relationships between anatomy and legibility. Further, eye-tracking and short exposure tests were undertaken to understand the relationship between anatomy and legibility. At last, this information in prescriptive study was synthesised by critical analysis to propose a guideline for Bengali letterforms.

1.8. Conclusion

This chapter gives a brief overview of research work of this thesis. The intention of the thesis started with the introductory chapter where the background of this research, research area and research problem have been introduced. The research plan with the methodological approach has been discussed briefly in this chapter. The study explores the anatomy of Bengali letterforms, investigating the role of anatomy in letter legibility. The structure of the thesis is to achieve the goal of the study i.e. to provide a guideline in context of legibility of Bengali script for type designers.

In the next chapter, detailed literature has been reviewed to investigate the current state of anatomy and legibility of Bengali script. The chapter contains relevant literature to understand the research gap and questions. With that research clarification, the further research has been done in three stages – analysis of anatomy of Bengali, determining the role of anatomy in letter identification and important anatomical features for letter identification. The anatomy of Bengali has been determined to begin the research. Then, the role of anatomy in letter identification was evaluated by considering the previous anatomy. Later, the important anatomical features were identified to propose a guideline for type designers. The guidelines are the outcome of the synthesis of all the results that came up during these three stages of investigations.

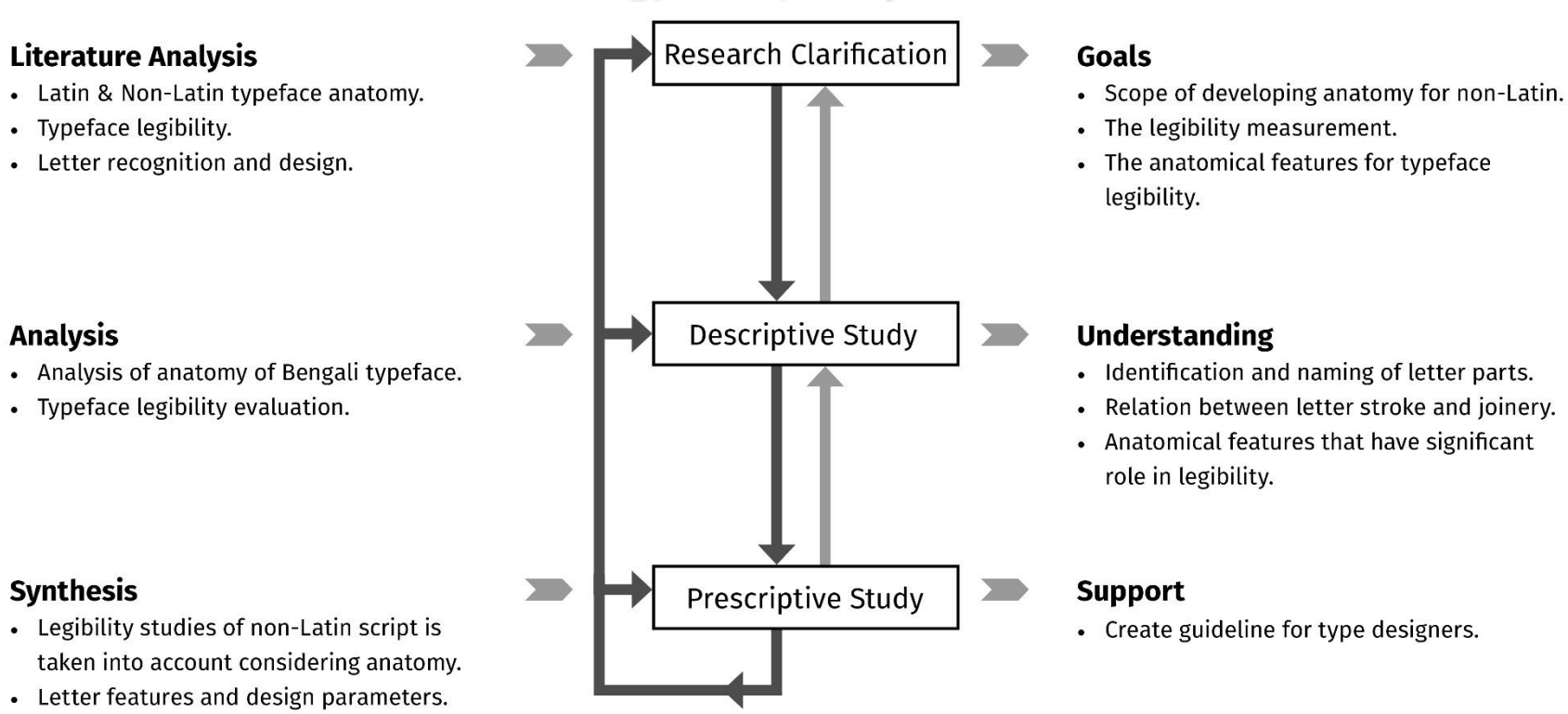


Fig. 1.15: Methodological framework

Chapter Two

Literature Review

Introduction

The literature of this research focuses on the anatomy and legibility issues of Bengali scripts. The anatomy and legibility of Latin script have been studied since the beginning of twentieth century. However, non-Latin scripts have long been a neglected subject of discourse. The relation between anatomy and legibility of a script was even far from any discussion. There has been a huge scope to do research with non-Latin scripts where legibility is a major concern. The purpose here is to identify the research problem in this chapter. This chapter explains the problem by tracing the trails in the domain of type design and considering works that have been done in other areas related to design such as psychology, ergonomics and vision research.

2.1. Typeface Anatomy

Anatomy is the study of bodily structure or structure like entity that involves physical relationship among body parts (Waugh & Grant, 2001). It is a detail scientific study of bodily structure and association of structure or structural parts. Anatomy is the fundamental knowledge of structure that is embedded within the body of a structure. Typefaces are generally two-dimensional structure or shape that possesses certain information about what it is. The understanding of shape is bounded by human knowledge to recognise it (Stiny, 2006). Letters of every typeface have to be within the limit of identifiable shape that possesses certain anatomy of letters (ibid). Such as the uppercase letter 'A' has two opposite inclined strokes '/' and '\' with a horizontal stroke '–'. Letterforms are available today in many different styles. Numerous groups

can be found such as handwritings, functional scripts and typographical text faces. According to Adrian Frutiger (1989) –

> *"Letterforms, shaped and refined through hundreds of years of use, are today available to us in many different styles as a means of communication. Numerous groups can be defined, including* ***handwritings, functional scripts*** *and* ***typographical text faces****. Readers are certainly capable of understanding a communication in any of these styles, but the extent of their effort to decipher the content depends in the first place on its degree of importance. … "Lettering" may well be a functional commodity, like food, clothing, and shelter, but its attraction will always lie in its variety of style. It can be assumed that readers remember the outlines of syllables and words in a kind of skeletal form and that the details determining the type style are taken in as the "resonance," which does not disturb the reading process so long as the typeface as a whole has been designed in accordance with the basic rules." (Frutiger, 1989, pp. 199-200)*

The text typeface is mostly used for publication to convey the meaning of presented text successfully. Here, the goal of the study is to improvise the legibility of the reading typeface and to investigate the anatomy of the letterforms that are used in text setting. There are different types of letterforms, categorised by researchers and designers, such as calligraphy, lettering and typeface based on the style and characteristics. Typefaces are comparable and are designed in structured and repetitive manner.

The structural formation of a script relies on the tools used during the initial development of the script. The arrangement of letter strokes reflects the mediums like stone engraving, calligraphic brushing or Palm leaf lettering used at the primary stage to develop the script (Naik, 1971; Pflughaupt, 2007; Udaya Kumar, 2010). Latin has a major history of stone inscription and that has led to the geometric structure of the letterforms (Meggs & Purvis, 2006). Thus, the vocabulary of anatomy would be

different for Latin and Indian scripts. The anatomy of Latin typeface is already well-established (Cheng, 2005). But, the anatomy of the non-Latin typeface including Bengali is sparsely found in literature. In many cases, it is directly borrowed from the Latin typeface such as Blob or Rounding, Dot, Stem etc.

2.1.1. Latin Typefaces

There is a long history of typographic culture with the Latin typefaces. The Latin has well-defined anatomy and the classification of typefaces. The two major aspects of Latin typeface will be discussed here, the anatomy of letters and classification of typeface.

The research and development with Latin typeface suggests a well-defined and functional anatomy of Latin letterforms (Pflughaupt, 2007; Cheng, 2005; Noordzij, 2006; Carter, Day, & Meggs, 2002). Most of the letters are geometric, a combination of linear and curvilinear strokes. By using repeated comparable strokes and unique structural arrangement, the letters are formed with less structural complexities (Cheng, 2005). The anatomy of Latin has been discussed in many studies. There is plenty of literature available on Latin, but primary literature is very limited. Karen Cheng (2009) explains that even though anatomy exists in Latin, yet conflicts occurred in many names within their letter-parts. Different authors have identified letter-parts in many names. These nomenclatures are developed through years of practice that lacks scientific rigour (Cheng, 2005). Anatomical features like Ascender, Bowl, Counter, Descender, Dot, Leg, Link, Loop, Shoulder, Spine, Spur, Stem, Terminal, Finial and Tail (Fig. 2.1) are few examples that are defined based on visual appearance of the letter parts (Cheng, 2005; Lupton, 2009; Carter, Day, & Meggs, 2002; Coles, 2012; Typedia, 2006–2015). The detailed anatomy of Latin letterforms is explained in Table 2.1.

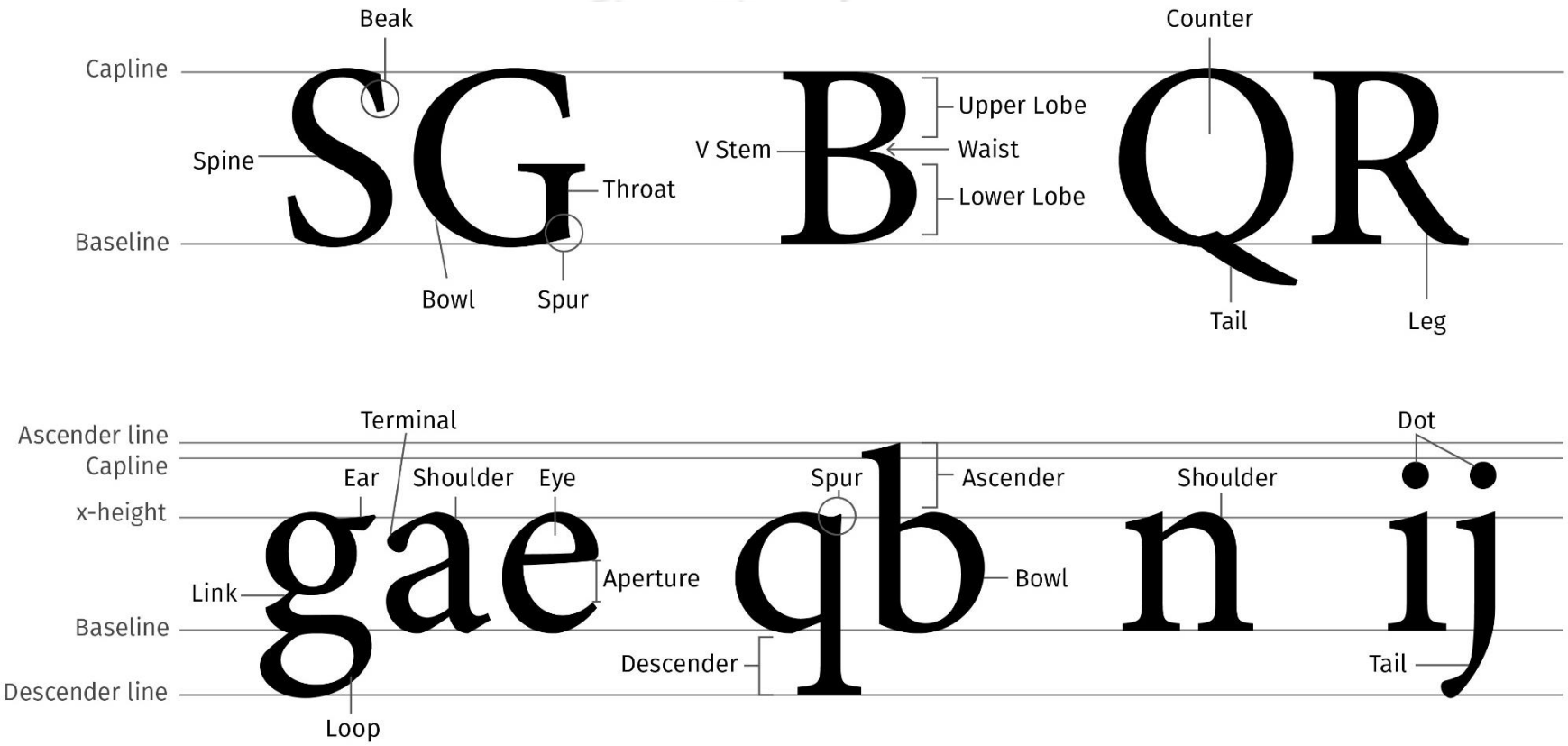


Fig. 2.1: Anatomy of Latin typeface

Table 2.1: Descriptions of Latin features

Feature	Description
Aperture	Opening at the end of an open counter.
Arm	A horizontal stroke not connected on one or both ends.
Ascender	An upward vertical stroke found on lowercase letters that extend above the typeface's x-height.
Baseline	The invisible line where letters sit.
Bowl	A curved stroke that encloses a letter's counter.
Counter	Entirely or partially enclosed space within a letter.
Crossbar	A horizontal stroke.
Descender	A downward vertical stroke found on lowercase letters that extend below the baseline.
Diagonal Stroke	An angled stroke.
Ear	A small stroke projecting from the upper right bowl of some lowercase g's.
Finial	A tapered or curved end.
Hairline	The thin strokes of a serif typeface.
Hook	Descender of letter 'j'.
Join	Meeting point of lines and curves.
Link	A stroke that connects the top and bottom bowls of lowercase double-storey g's.
Loop	The enclosed or partially enclosed counter below the baseline of a double-storey g.
Serif	"Feet" or non-structural details at the ends of strokes.
Shoulder	A curved stroke originating from a stem.
Spine	The main curved stroke for capital and lowercase 'S'.
Spur	A small projection from a curved stroke.
Stem	Primary vertical stroke.
Tail	A descending stroke, often decorative.
Terminal	The end of a stroke that lacks a serif.

2.1.2. Non-Latin Typefaces

The anatomy of non-Latin scripts such as Arabic, Chinese and Devanagari are few such scripts which have received considerable attention from researchers across the globe (Naik, 1971; Abulhab, 2008; Dalvi, 2009; Jiantang, 2012). Substantial work has been done in Arabic typeface. The script has the historical background of using calligraphic tools and is written from right to left in repeated forms. Horizontal

tooth-like appearance and variable or multiple x-heights are the specific characteristics of this script (Abulhab, 2008; Chahine, 2012). Arabic letterforms are prominent examples of calligraphic style of writing that has reproduces successfully from print to digital displays. Chinese letterforms are another example, which has a long history of printing. The Chinese letterforms are ideographic visual symbols that express emotion, narrative, and sentiment. Chinese letters are balanced through a central point of square that visually balances letterforms (Jiantang, 2012). Fig. 2.2 shows the grid system of Arabic and Chinese letterforms compared to Latin.

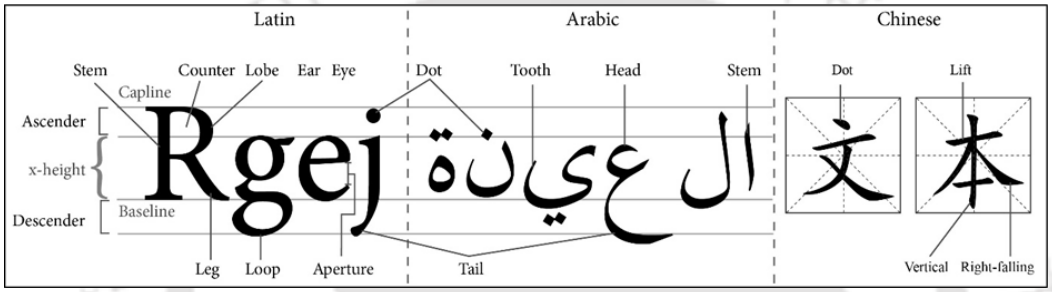


Fig. 2.2: Anatomy of Latin and Non-Latin scripts

2.1.3. Indic Typeface

There are twenty-two official languages in India. Eleven different scripts are used to write these languages in India (Ghosh P. K., 1983; Sinha R. M., 2009). The Indic scripts are diverse and also every letterform is different by shape, proportion, height, width, stroke ratio and path of the stroke (Mohanty, 1998). The overall grammar of each script is distinct. In spite of such variety, there is not so much of information available regarding the letterform anatomy and their legibility. Most of the literature available is on Devanagari script. Devanagari is a widely used script to write Hindi language which is one of the most largely spoken language in India.

The anatomy of Devanagari letterforms has been studied by many researchers. One of the pioneers is B. S. Naik (1971), who has extensively worked on Devanagari. Naik points out several features of Devanagari letterforms like Ikar, Single Matra,

Hrsva Valenti, Kana, and Hrsva Ukr (Fig. 2.3). The key finding of Naik's work is Horizontal grid lines. The seven different Horizontal grid lines are explained that define the vertical proportion of letters. The grid lines are Rafar line or Top most line, Matra Line, Headline or Sirorekha, Upper mean line, Lower mean line, Baseline and Rukar line (as in Fig. 2.3). The main letter-part comes within the upper mean line and lower mean line. Valenti comes in-between Matra line and Rafar line. Another researcher, M. W. Gokhale (2004) explains grid system based on stroke width and body proportion (Dalvi, 2009). Gokhale prepared several horizontal lines, and the distance between two lines is the stroke width of the letter (Fig. 2.4). According to Gokhale, the base character height or Headline to Footline can be divided into eight different parts. The consistency among letter proportion can be achieved by using these grid lines appropriately.

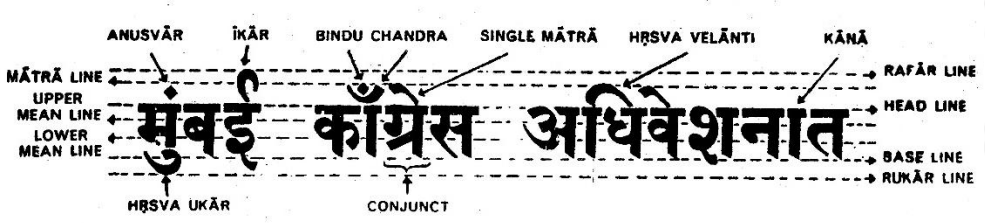


Fig. 2.3: Anatomy of Devanagari (Naik, 1971, p. 214).

First, Girish Dalvi (2009) unifies different approaches in defining the anatomy of Devanagari in a singular form. The author identifies several nomenclatures used by experts to describe specific letter parts (stroke elements). Often, the same elements are identified in different nomenclature. Some experts describe certain terms much more elaborately than others. However, there are certain similarities too, which ascertain the significant features and divisions of Devanagari letters.

The description of various letter-parts, which are identified by different names, sometimes appear as same part of a letter. The letter-part that Bhagwat refers to as a 'loop', the same is further identified by M. Patel into two types of features – blocked (filled) loops and open (with a counter) loops. The context of the placing of the loops

is 'at the end' and 'at the joints'. The same element is identified by type designer M. Patel as 'knot'. One of the most important elements of Devanagari script is the Shiro-rekha or headline which is defined in several ways. One group of authors proposes two reference lines an upper Shiro-rekha line and a lower Shiro-rekha line. Other experts propose Headline according to the width and the line that uses the upper limit of letter-body as a reference named only as Shiro-rekha.

In the division of gridlines, there is a similarity between Bhagwat's work and the Gokhale's gridlines. Both of their work is inspired by Naik's work of defining guidelines. These scholars have made an effort to come up with an ideal Gridline that divides the letter into logical parts. The difference between these models are compared below –

- Upper Matra line, Matra Line (topmost line)
- Shiro-rekha, Headline (headline)
- Initial line, Upper Mean line (shoulder line)
- Lower Kana line, Baseline, Lower Mean line (foot line)
- Lower Matra line, Rukar line (extreme bottom line).

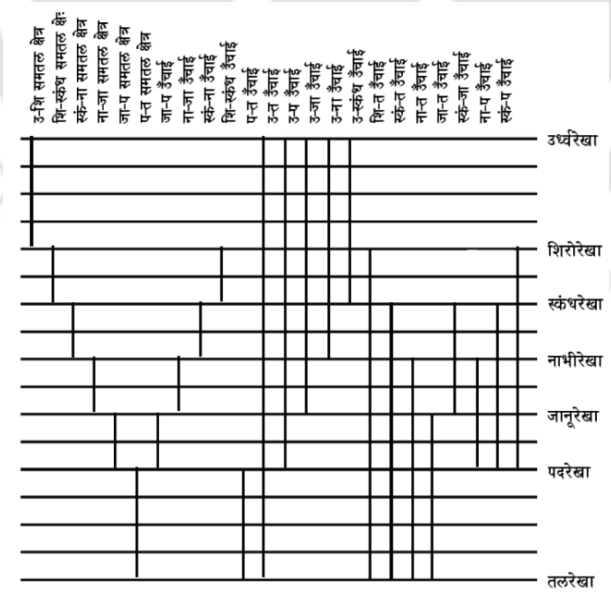


Fig. 2.4: Gridlines of Devenagari (Dalvi, 2009, p. 32)

S. K. Mohanty (1998) describes several factors and parameters for typeface design for Indic scripts. It describes the grid system as well as design strategies for Indic typefaces. Each letter of every script has a different shape, structure, proportion, and the way they combine with various consonants to create diversified visual patterns of letterforms. The author's designation of the aesthetic quality of a font is prior to any other factor and it depends on several factors such as the combination of the various strokes within a letterform, individual strokes, the shape of starting and finishing off a stroke, stroke path, thickness, texture of strokes, inter-line spacing, inter-word spacing and inter-character spacing. The author also explains the calligraphic nature of Indic script due to use of multiple drawing tools. Based on practice, each script has been developed with a unique way of writing the letterforms. Like a nib with a flattened tip cut at an angle of forty-five degrees towards the right is mostly used in Devanagari, whereas pointed tip tools are used for Oriya script. Despite such differences, most of north Indian scripts like Devanagari, Gurumukhi, Gujarati and Bengali have solid horizontal and vertical lines blended with curves.

2.1.4. Bengali Typeface

The Bengali letterforms are sinuous and twisted with many complexities. Fiona Ross (2009) in her book *'Printed Bengali Character'* explains the anatomy of Bengali script (Fig. 2.5). The script consists of twelve vowels and thirty-nine consonant letters. Apart from it, there are diacritics[6] or vowel signs that are placed around four positions of letters above-glyph, below-glyph, pre-based and post-based vowel signs. There are conjuncts that are a fusion of the two or more letters. Often three letters join vertically with each other to form a conjunct which is the most complex letters to design.

[6] Diacritics is a glyph added to a letter, or basic glyph that changes sound of letter or basic glyph to inherited sound.

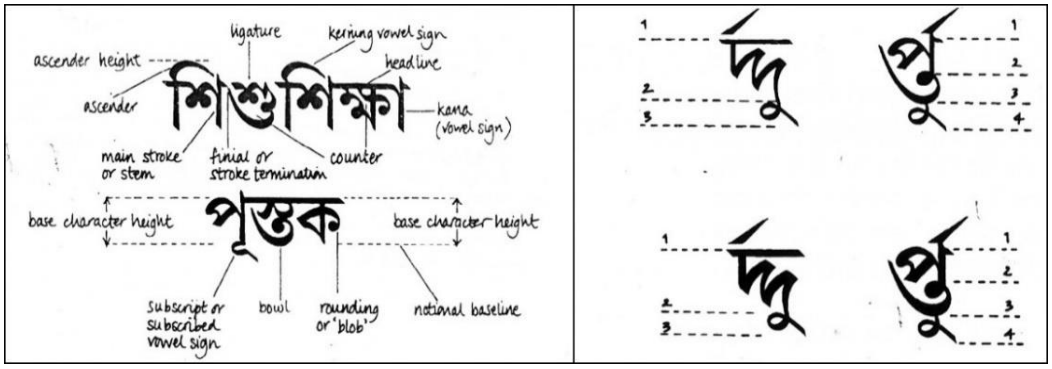


Fig. 2.5: Anatomy of Bengali (Ross, 2009, pp. 9, 129)

The work by F. Ross (2009) identifies few anatomical letter-parts with nomenclature (see Fig. 2.5). The identified anatomical features are Stem, Knot, Headline, Kana, Finial or Terminal, Bowl and Rounding their characteristics are Ascender height, Base character height and Counter (Ross, 2009). The study does not identify all possible anatomical features considering all letterforms which are a concern. The study discusses many complexities of Bengali script but does not define anatomical features in concrete terms. In another article, Ross explains that currently there is no standard terminology for discussing further type forms in Bengali script and those used in Latin are at times inappropriate (e.g. x-height) and fails to describe the letterforms that are peculiar to the Bengali script (Ross, 2013). It also fails to explain consistency throughout all letters including conjuncts. The vertical ratio of each letter and its body parts are different for each case (see Fig. 2.5).

There is not much anatomical study of Bengali letters except the literature authored by F. Ross. The available nomenclatures of Bengali are mostly borrowed from the Latin script (as in Fig. 2.5). However, they are two completely different scripts with different styles in letter composition. The Latin letters usually never touch one another in word formation. In case of Bengali, the Matra of each letter touch each other in word formation. There is no any concept of uppercase or lowercase letter in Bengali script. Thus, it is necessary to examine the anatomy of Bengali letters holistically.

2.2. Anatomical considerations for type design

The anatomy of Latin typeface has been developed due to a need in practice domain. It has been randomly developed without any standard procedure nor being based on any particular parameter. However, existing anatomy of Latin letters is useful in design process of letterforms. The anatomical development has been done in two aspects –

1. Anatomical Features – It is the components of letter construction. The composite form of features creates the identity of the letter (Naik, 1971; Mohanty, 1998; Cheng, 2005; Noordzij, 2006; Coles, 2012).

2. Anatomical Parameters – It is the design specification of anatomical features (Ghosh P. K., 1983; Cheng, 2005; Noordzij, 2006; Coles, 2012).

Pelli et al. (2006) conclude that letter identification is a recognition process for identifying its features. The Gestalt law of grouping plays a significant role in letter recognition through the combination of letter features, position or spatial information of features (Pelli, Burns, Farell, & Moore-Page, 2006; Pelli, et al., 2006). The letter-part that found in different letters repeatedly is the common feature and others are a unique feature. Unlike Latin script, the anatomical features of the majority of Indic scripts including Bengali are underdeveloped (Ross, 2013).

2.3. Methods to define type anatomy: A review

There are few such methods that explain letter anatomy. They are few attempts initiated by researchers and type designers. These methods have limitations in defining process of anatomy holistically. There is barely any literature on the methodology to define anatomy for Bengali letters. Fiona Ross (2009) has attempted to define the anatomy of Bengali letters with limited numbers of letters and it lacks

systematic approach. She explained in an article (2013) that the existing anatomy of Bengali unfits and borrows from Latin script (Ross, 2013).

There is a long history of anatomical development of Latin that makes it resourceful. However, there is hardly any systematic approach available to define anatomy of Bengali letterforms. All the methods that are used by different researchers, most of them lack scientific rigour. Few of them are discussed in following sections.

Legros & Grant (1916) did an exceptional experiment to find out the underlying structure of each letter for best legibility. He selected a few classic typefaces and superimposed them, which resulted in an appearance of a common black region (Fig. 2.6). They measured overlap between similar letter pairs within a typeface and between two typefaces. They found that typefaces which had more common area had lower legibility than typefaces with less common area. They concluded that the dark areas covering all figures are the basic skeleton which has engraved in subconsciousness of reader as an elemental form. The study examines the anatomy of the common region of typefaces. Common letters-parts are considered as anatomy of letters. The anatomy is also useful for understanding the legibility of letterforms. The more common region of the letters, the greater letters are legible.

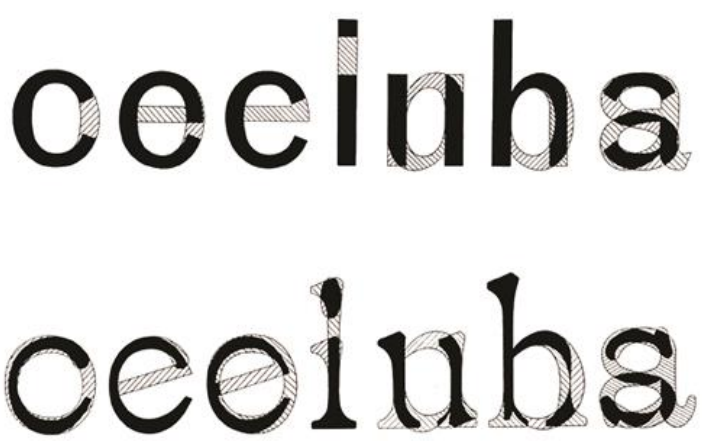


Fig. 2.6: Common region of letterforms

P. K. Ghosh (1983) first attempted to identify different letter-parts of Latin by cutting them separately. The study is not meant to develop anatomy but to define feature for character recognition for OCR systems. The study identifies thirty-seven different, unique letter parts. These letter-parts are structural unit of letters. Any letter can be prepared by combining this letter-parts. (Ghosh P. K., 1983). The study neither proposes any letter-parts nor nomenclature of letter-parts.

Adrian Frutiger (1989) in his book '*Signs and Symbols_Their Design and Meaning*' shows a method to determine the skeleton of letterforms. It is a method of superimposition of letterforms that sculpt out the spine of letter stroke. Sofie Beier (2009), in her thesis, adopts a systematic method to define the central spine of the letters which she refers as anatomy of letter (Beier, 2009). It defines anatomy by considering the common region of multiple superimposed typefaces. The method has a serious issue of consistency since anatomy of letters is here dependable on the structure of typefaces that are limited in their design. Therefore, 'spine' cannot be completely declared as anatomy of letterforms.

Karen Cheng (2005), in his book '*Designing Type*', discusses different parts of letterforms, designs of typefaces and their characteristics. It is a comparative study where utilities and function of typeface over another typeface are objectified by changing their shape. The study also identifies different letter-part and its nomenclature. However, the study does not aim to define letter-parts or nomenclature.

The above methods certainly have different approaches in defining the structural formation of the letterforms. However, none of the methods is used to define letterform anatomy successfully considering all letters, ligatures or conjuncts. They were aimed to define anatomical characteristics, not nomenclature of letterforms. Yet, they reveal that there is a possibility to reconsider them in broader context of systemic approach to define letterform anatomy.

2.4. Anatomy of Bengali – Problems

There are few problems with anatomy of Bengali that are noted down below –

1. Lack of identified letter-parts and their nomenclature.
2. There is inconsistency in existing nomenclature of letter-parts (Fig. 2.7).
3. Existing nomenclatures of Bengali are borrowed from Latin script. The lack of indigenous nomenclature makes letter-parts less practical.
4. There is hardly any systematic method that is useful for defining anatomy of any Indic scripts.

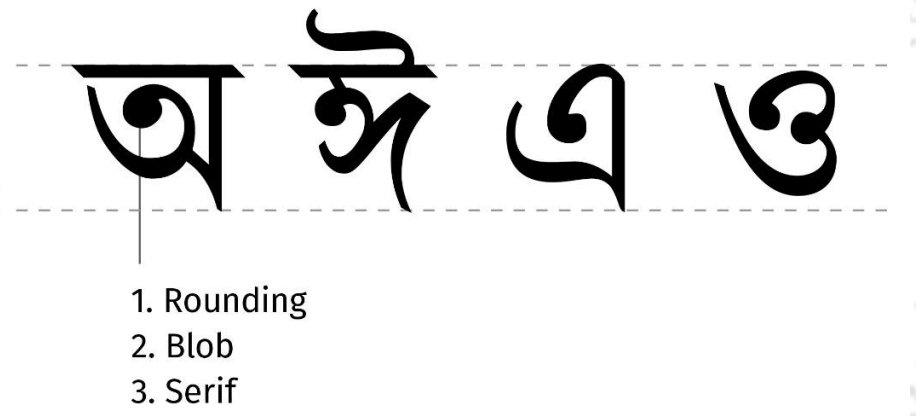


Fig. 2.7: Nomenclatures of Blob

2.5. Conclusion of anatomical study

The letters of a typeface are generally two-dimensional structure or shape, which possesses definite information about the identity of letter. The shapes are written in a combination with strokes that altogether define the letter identity of confined space. Indic letterforms have complex shapes with a higher density of letter-strokes. Retrieving information about the letter-shape is a challenging task and is also a necessity for the typeface designers. In the end, it is crucial for readers to decode the shape information for carrying out the reading task most easily, comfortably and

efficiently. The knowledge of the structural formation of the letterforms is essential to understand the functionality of letter-parts in meaning-making.

The methodology to define Indic typeface anatomy is hardly discussed in any existing literature. In the last century, the extensive research on Latin typeface nurtures the growth of the anatomical knowledge of the letterforms. Only in the last two decades, non-Latin including Indic typefaces are getting attention from the research community. This has made it possible to look into the existing process of defining the anatomy of typefaces from a comparative point of view. Most of the anatomical studies do not follow any standard methodology to establish letter-parts or the nomenclature of letter-parts. In many cases, the anatomical knowledge of Latin typeface is borrowed from the non-Latin or Indic typefaces, which might be inappropriate in the context of Indic typeface.

2.6. Typeface Legibility

The term 'legibility' defines the quality of being clear enough to recognise a character. In the early twentieth-century legibility research became popular in the hand of vision and reading researchers. In the beginning, the legibility research was dominated by the scientists from the domains of Ergonomics, Psychology and Vision Science. Their approach was an empirical scientific approach that dealt with proving hypothesis based on evidence. Moreover, they were looking into the ease of the reading, perhaps the new media and the cognitive process of the brain. The role of letterform design is the missing agenda since the start of the legibility research. This was done without any real knowledge of design aspect of typography. According to Sofie Beier –

> *"A scientific approach is based on examination, and only theories that are testable by empirical methods will be of interest."*

The other approach is design-orientated approach which is an establishing outcome based on practice. It is a widely used approach by typographers and type designers in the field of type research. Typographer Walter Tracy (1986) explains that legibility is the term we use while discussing the clarity of a single letter or character. A character or letter should be recognizable without confusion at a particular distance. Legibility refers to how easily letter identification is performed. It is the ease and accuracy of the human perception with which a reader can perceive the letter or word without any hesitation (Gaultney, 2000). The visual properties of a character or symbol determine the ease with which it can be recognised (Zuffi, Brambilla, Beretta, & Scala, 2007). In typography and type design, researchers explain legibility in many different ways. The few of the definitions are given below:

- Legibility is the term to use when discussing the clarity of single characters (Tracy,1986, p.31)
- Legibility is the measure of reading performance in correlation with visual variables of typeface (Tracy, 1986).
- Legibility deals with the effect of different typographical arrangements on the reader's ability to carry out the reading task most easily, comfortably and more efficiently (Lund, 1999).
- The term 'legibility' is used to measure the speed of reading, continuous text, visibility or perceptibility and familiarity of letters. To achieve the maximum legibility of letters, the varied conditions of such parameters are the major factor of recognition (Beier, 2009).
- Legibility of letters describes the clarity of letters while influenced by typeface familiarity (Beier, 2009).

- Legibility is the quality of type that controls the perceptibility of a letter in the continuous text. In other words, the distinctness of letters that makes perception easy to recognise (Tracy, 1986).

- Legibility is the quality of type being sharp and definite enough to recognise it (Gaultney, 2000).

Legibility is a measure of recognition related to reading. It deals with the visual variables of text. Legibility begins with the glancing process on letterforms and recognizing up to the meaning of it. The most convincing definition of legibility is defined by Slattery and Rayner – 'how easy the letters in a word are to encode' (Slattery & Rayner, 2009). Another author Nadine Chahine defines legibility as 'how easy it is to extract the visual information of a fixated word in order for lexical processing to begin' (Chahine, 2012). The ease of encoding the visual characteristics of letters via their features ensures faster identification within less recognition time. It refers to the easy decoding of letter information and stress-free encoding of letter information to reach to the brain. The 'decode' and 'encode' of the letter information is defined as 'Decode – To extract the underlying meaning from' and 'Encode – to convert a nerve signal into a form that can be received by the brain' (Farlex, 2012). The objective of legible letter design is to do with recognition of letter code or features and making letter information easily accessible to the higher level of cognitive processes. It is about exposing the abstract letter feature to recognize the letter information for the further lexical processing.

The perception of type forms with clarity is one of the essential criteria for legibility measure. Most of the legibility guidelines are established through empirical research and they lack design aspects (Beier, 2009). Few factors like distance of reading, time of reading, colour of typeface, luminosity, reading pattern, eye movement and pixel density in case of the digital typeface are used to evaluate legibility co-relating human vision. Also, many typographical parameters such as type

size, line space, and word count are also measured, previously considering their role in typeface legibility. However, the design issues have been ignored for a long time due to the negligence of designers or inappropriate knowledge of type design among empirical researchers (Beier, 2009). In recent years, it is initiated by design researchers to measure typeface legibility considering design variables. Many type researchers discuss those variables but they were rarely studied rigorously. Few parameters like ascenders, descenders, x-height, contrast, stroke weight & width, counter and stroke path are potential design variables (Zhang Y. , 2006; Beier, 2009; Chahine, 2012; Beier, 2013; Dobres, et al., 2016). There is an effort to understand the role of design parameters on legibility of Latin script. However, such an effort has rarely been devoted to any non-Latin scripts including Bengali. Most rules and guidelines are borrowed from Latin typeface to non-Latin typeface without any validation. The measurement of legibility considering design variables is one of the challenging tasks that designers and researchers are confronting today.

In addition, legibility is sometimes confused with a closely related term called 'Readability'. These two terminologies are most of the times used as overlapped concepts and as a result a lot of confusion is created between them. They both deal with the reading performance, but their objective for successive reading is different. The term readability refers to the issues related to reading performance. It is estimated the word frequency or length, type size, line space and other intricacies of sentences or paragraphs, which are the overall complexity of the writing system. They typically deal with readability formulas and have no direct relation to type design parameters, but deals with the typographic parameters. The typographical arrangement is the issue of readability, whereas design of the letters deals with legibility.

Here, the legibility study will be done from the perspective of type design in the context of Bengali script. There is a need for legibility research on non-Latin scripts that identifies the factors and parameters accountable for legibility. Bengali is

one of the less explored scripts that has a huge number of native speakers (Ross & Shaw, 2012; Ross, 2013). It is one of the most complex scripts according to research by Changizi and Shimojo (2005) considering their average stroke length of 3.91.

Legibility depends on several interrelated design factors (see Table 2.2). If a typeface is designed for a newspaper reading that typeface may not work for screen reading (Gaultney, 2000; Sheedy, Tai, & Hynes, 2009). A typeface designed for the print purpose, may not work for distance reading. Technologies now allow accurate rendering technique for different fonts according to their medium of use (Ross, 2013; Herman & Apple TrueType team, 2002). Hinting is a dependent variable till now and it depends on the design of letterforms.

Table 2.2: Typeface design parameters

Legibility parameters	Reference in literature
Type forms	Frutiger, 1989; Coles, 2012; Ross, 2013
Type characteristics	Gaultney, 2000; Ross, 2009
Typeface familiarity	Beier, 2009
Typeface colour	Carter, Day, & Meggs, 2002; Lupton, 2010
Typeface size	Carter, Day, & Meggs, 2002; Bringhurst, 2004
Viewing distance	Lund, 1999; Beier, 2009
Technological dimensions	Gaultney, 2000; Ross, 2009

The parameters above in Table 2.2 affect legibility in different ways. Altogether, they have significant effects on reading. Reading is a task that is performed with letters, words or continuous text. Based on these three aspects, many researchers apply different meanings to the term legibility by differentiating it into the legibility of (1) letters, (2) words and (3) continuous text. Legibility of letters refers to perceptibility of a letter in isolation. It denotes not only legibility of letters within it but also the word structure which becomes more influential factor apparently, known as 'word superiority effect' (Baron & Thurston, 1973; Spector & Purcell, 1977). But, later studies show letters are key to any word or text recognition. Word context plays an additional role in it (Fig. 2.8). The case of letter superiority is

also disused by James E. Sheedy (2005) and other researchers (Sheedy, Subbaram, Zimmerman, & Hayes, 2005; Rayner & Pollatsek, 1989).

Fig. 2.8: Similar shape words

Sofie Beier (2009) first measures legibility of letters by describing legibility as clarity of letters while influenced by typeface familiarity. She refers 'familiarity' as the collective influence of previous exposure and the level of common letter features in words. She describes legibility of letters as visibility which is the legibility of letters in isolated condition without influence of typeface familiarity. The major finding of her study is the level of letterform distinctiveness that is essential for letter legibility. Simultaneously, familiarity is also necessary when letters are coming together as a word (Beier, 2009; Beier & Larson, 2013). In this thesis, the legibility is considered as the clarity of letterforms to identify letters without hesitation; since Bengali letterforms are complex and previous research have not been performed on it. The clarity is of letterforms are much necessary to identify the intricate letter-parts.

The process of typeface design involves single letter design at a time. The detail process is explained in 1.3.1 where it is discussed that it is a tedious process to design individual letter one by one. Thus, it is certain that knowledge of individual letter legibility is an advantage during design. In such a context, designing legibility of single letter is crucial. Though, in later stage, designers test the designs in word or text format to confirm the familiarity of letterforms and aesthetic quality of text. Even so, a guideline or information about achieving legibility can be useful during design of individual letter.

2.6.1. Letter Identification

There are two central theories of letter identification, template matching and feature detection. The template matching is a holistic approach where letters are perceived as a whole. The complete framework of letters is compared and identified through recognition process. The feature detection is a more analytical approach of separating the letters into different parts in the process of identification.

We are constantly getting exposed to letters from many sources. This process starts with our childhood and continues to do so till old age. As a result, templates of every letter are already stored in our brain. If we perceive a new shape, it goes through a sequence of templates to find the best match. A shape identifies as a letter only if the best fit or nearest match to the template has been found.

A study by Pritchard (1961) shows such letter recognition phenomena very briefly. The investigation was carried out in a way while the eye moved, the image also happened to move simultaneously after successful fixation of the image on the retina. The fixed image, if it is a complex stimulus, sometimes disappeared from the retina and again reappeared as a whole. Also, sometimes letter vanished with fragmented shape. Based on such observation, the experiment supports template-matching theory, but it cannot deny the identification of letter feature in the process.

Template matching

The template matching approach is derived from the assumption that the representative native letters within the long-term memory match a real-world pattern i.e. it has the same structural features as the object of recognition. The problem with template matching theory is that it is not able to explain the extensive variations in the design of typefaces that human brain is capable of perceiving. The theory is incapable of explaining the perceiving process of two dissimilar templates such as Old English Text '𝔄' and Arial 'A'. But, it fails to explain how the brain stores two

templates of 'A' with such variations. It appears that a system like a brain can decide which part of a letter shape is essential for successful identification of letters (Naus & Shillman, 1976; Crowder, 1982; Rayner & Pollatsek, 1989; Smith, 2004). This problem leads to the feature detection theory.

Feature detection

The structural approach of the feature detection theory is the most convenient theory of letter recognition. Instead of perceiving the entire template of a letter, the assumption of feature detection explains that the brain decodes individual features of letter. A study by Urlich Neisser (1964) shows that letter recognition starts with the identification of successful letter features. The recognition will be strenuous if target letter shares a large number of features with other letters. The study concludes that identification of targeted letter in the matrix of letters is less difficult with different distinctive features. In another way, a letter in a matrix with many features in common with other requires a longer time for identification with several mistakes (Neisser, 1964). Here the definition of distinctive feature is the particular shape or characteristics of the common structure that differentiates one letter from another.

Thus, it can be concluded that the letter recognition is a complex coordination of both template matching and feature detection processes. In recent years, letter recognition is explained by many neural models. The Parallel Letter Recognition (PLR) model is one of the fundamental model. PLR model activates the processes from feature detection to visual word recognition. Words provide a context to recognize letters more efficiently. The model consists of four-layer with stimulus, feature, letter and word detectors from bottom-up manner. At bottom feature, detectors activate information for letter recognition. Letter detectors collect such information to detect the letter as a complete template. Same way word detectors gather information from letter detectors to complete the process. A single letter is identified by information received from the letter detectors whereas words receive

information from both the letter detectors and the word detectors. Therefore, apparently, words will have a higher recognition rate than single letters (McClelland & Rumelhart, 1981; Rayner & Pollatsek, 1989). Therefore, letters need precise attention during design which makes letters easily recognisable.

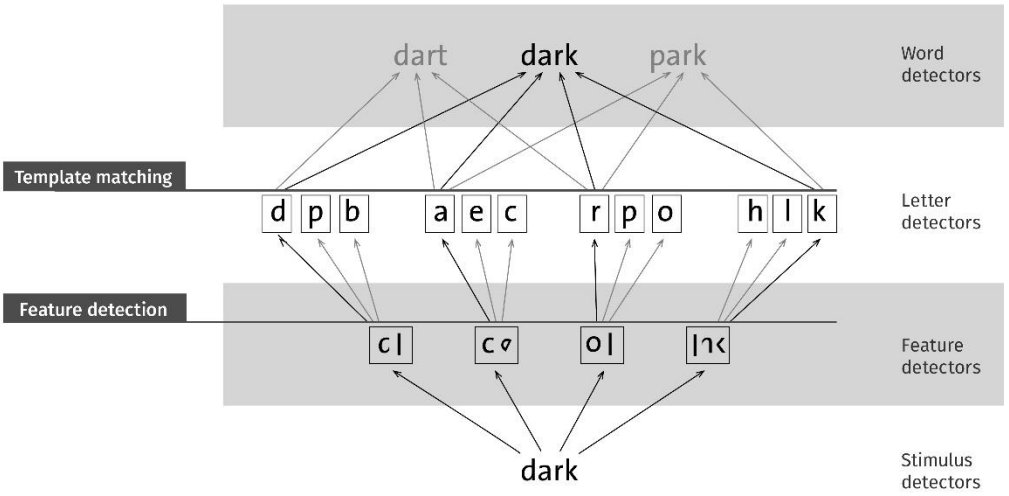


Fig. 2.9: PLA Model (McClelland & Johnston, 1977; McClelland & Rumelhart, 1981)

In recent decades, theories have been developed to understand the letter recognition process. The PLR Model is one of them where first importance of letter features (the horizontal, vertical and diagonal strokes, etc.) is described (Nedeljković, Puškarević, Banjanin, & Pinćjer, 2013). These features are key aspects of letter and word recognition (Davis, 2010; Keage, Coussens, Kohler, Thiessen, & Churches, 2014).

2.6.2. Reading Letters

There are many models such as E-Z reader, SWIFT dynamic model which explain reading very efficiently (Reichle, Rayner, & Pollatsek, 2003; Engbert, Nuthmann, Richter, & Kliegl, 2005; Keage, Coussens, Kohler, Thiessen, & Churches, 2014). But at the heart of reading, letter recognition is the vital aspect of word identification which is widely discussed. Duel-Route Approach to reading is one such model that

explains the role played by letter features to speech conversion. It is the most accepted model to explain the reading process.

Duel route cascade model

In recent times, many reading models have come into picture but the most preferred one is the Duel-Route Channel (DRC) reading model (Finkbeiner & Coltheart, 2009; Coltheart, Curtis, Atkins, & Haller, 1993). The dual route model explains how human brain identifies feature unit to initiate reading processes. It explains from the beginning of letter feature identification to speech expression of words. It is a viable model that rigorously explains any skilled reading and learning to read process. The model is described in Fig. 2.10 (Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Perry, & Ziegler, 2001).

The letter identification in the Dual-Route Cascade (DRC) model describes the process of text to speech by taking two paths in the recognition process (Coltheart, Rastle, Perry, & Ziegler, 2001). One path is concerned with semantics of text and another route is phonological channel. According to the model, semantic and phonological routes are initiated by identifying letter unit. The letter unit is recognized by the visual features unit that is perceived at the beginning of letter processing. Thus, legibility of the letter features is essential to discriminate letters.

The model consists of two paths of a visual letter to speech with all six layers of intermediate brain process. This model clearly indicates the importance of visual feature recognition at the very beginning stage that leads to successful letter identification. First two layers of this model are crucial to identify any readable character. Thus, legibility of visual feature unit and altogether the letter unit are a major factor for recognition task (Woodhead, Wise, Sereno, & Leech, 2011).

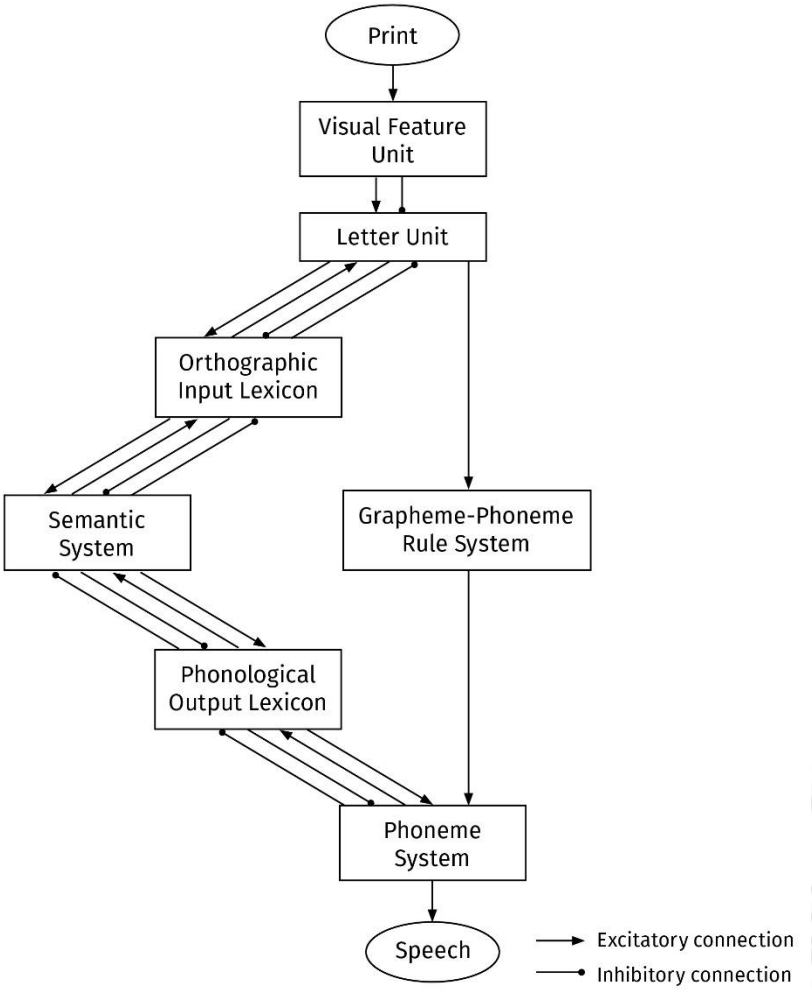


Fig. 2.10: DRC Model (Coltheart, Rastle, Perry, & Ziegler, 2001)

The context of reading is a major factor to discuss when we are discussing the importance of reading letters. Reading mostly involves pronunciation of words; we hardly read letters. We have already discussed that word superiority in reading explains the role of letter shape in reading. The reading does not happen with each letter of text. Many eye-tracking studies show that fixations occur in one or few letters of a word and there are saccades or jumps between two letters. These letters further recognised (as described in DRC model) explains the role of features in identification. The DRC model explains the importance of letter features in the reading process. A study by Sheedy et al. (2005) shows that individual letters play a large role and word shape plays a smaller role in word identification at a threshold

distance which is known as letter superiority effect (Sheedy, Subbaram, Zimmerman, & Hayes, 2005). There is context of reading like 'reading at a distance (Fig. 2.11)' where letter superiority effect is apparent.

Fig. 2.11: Reading at a distance - Signage

2.7. Measure of typeface legibility

The objective of legibility studies is to measure the impact of reading by maximising the chance of getting recognised (Gaultney, 2000). A single letter is nothing but a visual form, and the construction of that letterform is explicit. 'Letter recognition' is the process of finding the existence of letters, whereas 'letter identification' is the process of finding the proof of the letter. The approach to legibility research is to measure the ease of letter identification. The measurement methods that are commonly used are reading speed, comprehension, visual search task, eye movement (Lund, 1999; Beier, 2009; Chahine, 2012). Researchers have also used various other methods to study the legibility of typefaces. The following methods are popular among them and frequently used as described below –

Naming

This method usually involves the presentation of a word or non-word either in the fovea or para-fovea. The faster or more accurately the words are named, the more legible the letters are.

Threshold visibility

This is another form of naming test. The threshold can be an exposure time (the stimulus is presented for a very short period, and then masked) or distance (the stimulus is presented at a distance from the reader). The shorter the exposure rate or, the farther the distance, the more legible a letter is supposed to be (Lund, 1999).

Eye tracking

The use of eye tracking to test legibility gives very accurate speed tests. When looking at global reading measures, a more legible design is characterised by shorter fixation times, longer saccades, and a smaller number of fixations (Slattery & Rayner, 2009).

Search tasks

The reader is given a search task to complete and the faster that is, the more legible in design of letterforms (Lund, 1999).

The eye tracking method is used to measure the efficiency with text setting. It can also be used to measure the legibility. Naming and threshold visibility is used in the identification of letters or words. These methods do not involve higher level of cognitive processes and they are therefore pure measures of legibility (Beier, 2009). If non-words are used, they neutralise the effects of word structure. However, the distance threshold test is a test of visibility and how a typeface degrades over distance. It is then very different from the typical reading process in the fact that both type size and distance are quite distinct in these settings.

2.8. Research Clarification

The objective of making typeface legible is to achieve the process of reading as easy, comfortable and effective. Few studies have focused on easy and comfortable reading

with Bengali text. Literature on letterform legibility of Bengali for effective reading hardly finds any existence. This research focusses towards the anatomy of Bengali letterforms and the role of anatomical features in letterform legibility.

This research also highlights the lacuna in letterform anatomy, legibility and their relation. A thorough inquiry of design parameters is required to propose a new approach to the legibility of Bengali script. Here, the observations are drawn leading to the need for research in anatomy and legibility of Bengali letterforms.

Legibility in Latin script is extensively studied in the last century. There are many definitions of legibility available throughout the literature and these definitions vary significantly. It happens due to the engagement of different domain like ergonomics, vision science and psychology etc. that measure legibility based on the dominating factors in their respective field. The measurement methods commonly used in such studies are reading speed, comprehension, visual search task, and eye movement. Each investigation redefines legibility according to the need of study and such definitions create problematic consequence to define a standard one. In reality, there are too many variables that influence legibility to determine the outcome.

The operational factors of legibility are visibility (recognizability of a single character) and familiarity (perceptibility or distinctiveness from other letters in the group). The visual factors like recognizability, distinctiveness, and clear appearance are the measure of legibility. The measurement of such factors is proven to be dependent on anatomical features and typographic parameters such as ascenders, descenders, x-height, contrast, stroke weight & width, counter, and stroke path (Dobres, et al., 2016; Beier, 2013). Many times such inferences have been adapted to define legibility of Indic scripts without validation. Such adaptation of framework is a required explanation to establish the knowledge of legibility with respect to Indic scripts that may or may not be the same.

Legibility is a kind of reading research where visual and cognitive factors deal with typeforms. A single letter of a script is nothing but a visual form and the construction of that letterform is explicit (Frutiger, 1989). Each visual form is an association of global and local features that confines the letter-shape at a certain point. Therefore, approach to the legibility of the letterforms across all scripts may or may not be similar since letters from all across scripts are combination of indefinite numbers of anatomical features. Legibility considerations cannot be similar for all scripts considering their script composition and stroke density of the letterforms.

Legibility of non-Latin typefaces is not a widely discussed topic in the research community. Most of the rules and regulations are adopted from Latin. It's only in the last few decades that researchers have started empirical research on non-Latin scripts which has little literature.

The visual form of a letter conveys the complete sense of type construction and communicates a specific sound as its meaning. Every letterform is a collection of certain letter stroke, also known as letter features. The combination of such features completes the identity of letters. The process of letter identification follows the Gestalt law of good continuation that involves grouping of features (Pelli, et al., 2006). The legibility researchers have also argued that most of the legible letters of the different typefaces which are considered to create a word structure might not be the best solution (Gaultney, 2000; Larson, 2004). The effective legible text may be created by introducing letters belonging to same typeface family. A comparative visual analysis of groups of common letterform of any two scripts can provide the insight about the difference between these scripts. Fig. 2.12 illustrates the grouping of common letterform in Latin and Bengali scripts. A single group (such as 'Round forms' or 'Diagonal forms' in Fig. 2.12) is not enough for both Latin and Bengali scripts to fit their letters due to the varied construction of letterforms. A different approach to Bengali letter construction such as 'Grouping of Common Structural Letterforms' would be a more reliable approach than adopting the existing grouping

approaches. Such unlikelihood raises doubts about the adaptation of legibility rules in Latin.

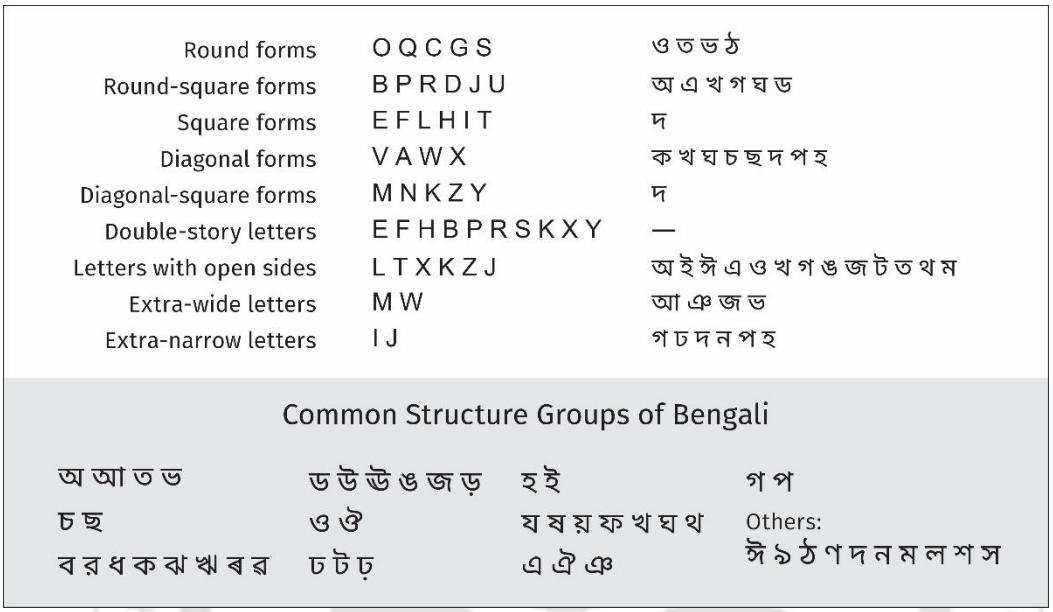


Fig. 2.12: Comparison of grouping between Latin and Bengali

2.9. Parameters Affecting Legibility

Legibility is measured by reading speed, visual search task, eye blink and few other techniques. Such studies have been done in ergonomics, vision science, and other areas. But, those studies hardly consider the design variables such as Gridlines, Stroke Width and Weight, Stroke Path and Treatment, Stroke Density, Terminals, Optical Size, Stroke Contrast, Proportion, Structure, and Counter (Carter, Day, & Meggs, 2002). The lack of awareness of the type design domain could be one of reason. Researchers from other domains lack understanding of letter structure and legibility related to it. They focused on reading comfortably and text arrangements (Beier, 2009; Chahine, 2012). Recent studies are now focusing more on such factors through tests like short exposure test and distance threshold test (Beier, 2009). However, such tests have hardly been applied to non-Latin typefaces to measure legibility. There are certain design considerations for print and digital Latin typefaces, but there is no such guideline for non-Latin typeface.

2.9.1. Unique features of Indic scripts

Conjuncts

Conjuncts are the single letterform of two or more consonants and/or vowels connected vertically and/or horizontally (Fig. 2.13). The conjuncts of Indic letterforms are mostly two or more tier design which is uncommon to Latin letterforms (Ross, 2009). The height is a crucial factor considering the multi-tier structure of letters. If the vertical or horizontal clearance of letters is not enough, they could touch the next (or previous) or below (or above) character (as in Fig. 2.13). Few of Bengali conjuncts are too long due to more than two letters appear in single form. This is one long-standing issue with Bengali that needs a solution.

Conjuncts are not similar to Ligatures[7] in Latin but they achieve a certain sound. Sometimes, their combined form may appear in completely different form. Therefore, the perception of those conjuncts is completely different from ligatures in Latin, although they appear as a single glyph. Such letterforms need a systematic study to establish distinctiveness and legibility.

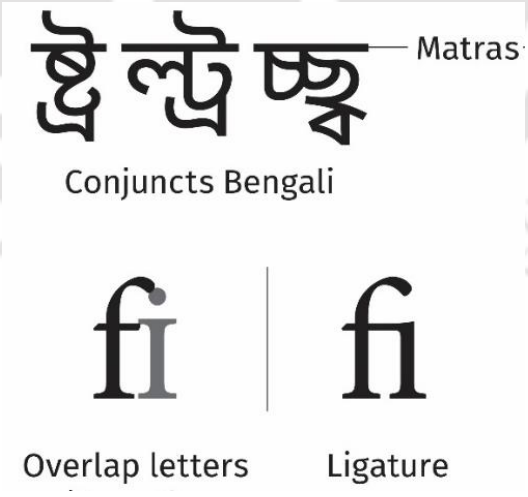


Fig. 2.13: Conjuncts of Bengali & ligature in Latin

[7] Ligatures are the juxtaposed single glyph of two or more letters in case of Latin. It consciously designs to eliminate the 'crowding' of two or more like 'fi', ffi' or 'ffl'.

Matras

A Matra in Bengali is a horizontal stroke that appears on the top of letters. Almost every letter and conjunct have Matras from which the main body of the letter hangs below (Fig. 2.13). This feature is scarcely considered as a major feature to analyse letterforms. It may provide insights about the legibility issues of Bengali.

Gridlines

In type design, the gridlines are an arrangement of fundamental horizontal lines that construct the size and vertical proportion of the letters (Fig. 2.14). The standard Latin grid system consists of five major lines i.e. ascender, cap-line, x-height, baseline, and descender. Their ratio of (distributed) height defines the purpose of the typeface. The display typefaces have a larger x-height that enables readers to read lowercase letters more efficiently. Now, such gridlines are used for any typeface irrespective of Latin or non-Latin across font development software. This adaptation of gridlines for non-Latin typeface may not be an effective approach. Indic scripts do not have any ascender or descender instead they have 'Matras' and dependent vowel signs. Also, they do not have any concept of uppercase and lowercase letterforms. Altogether, the concept of cap-line and x-height is completely misinterpreted in Indic typefaces that affect the letter proportion and further the quality of typeface. Therefore, the question of recognisability or visibility of such letters can arise.

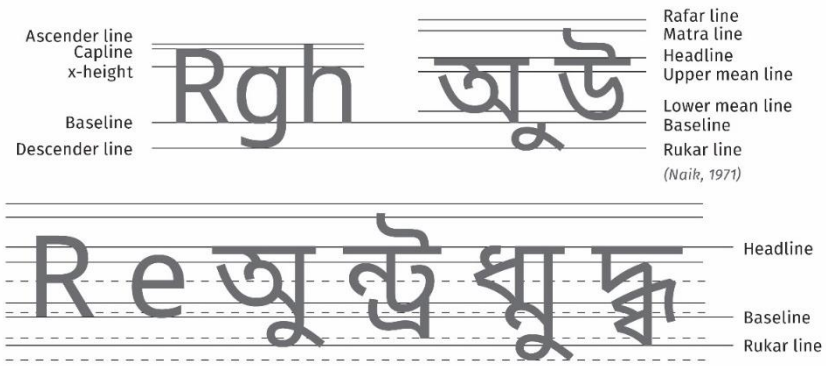


Fig. 2.14: Comparison of Gridlines

Naik (1971) proposes a grid system of Devanagari scripts. It identifies seven different grid lines according to structural formation and body proportion of letters (Naik, 1971). But the vertical proportion of the letters varies significantly with respect to these gridlines (in Fig. 2.14). Mostly, the proportions of every letter change accordingly. Thus, maintaining a constant ratio among these gridlines is a problematic one (like Harsh-U', last one in Fig. 2.14). In addition, the Latin letters stand on a baseline whereas the Bengali letters hang from their 'Siro-rekha (Matra line)' (in Fig. 2.14).

2.9.2. Letter Stroke

Letter strokes are the unit of letter construction. It is the 'brick' that construct a letters by combination of many strokes and crucial for letter identification. The distinctiveness of letterforms occurs due to combinations of stroke or the combination of stroke joinery. Strokes and joinery both together make letterform distinct and identifiable by its own character. Considering the significance, variables related to stroke are discussed in below section.

Stroke Path and Treatment

The stroke path is the identifying characteristics of letter whereas treatment is the design specification of the letter stroke (Fig. 2.15). Both together enable the readers to identify the letters and the family that the letter belongs to. Both stroke and treatment are contextual and culturally rooted. The history of script has great impact on design development of typeface. Indic scripts are largely dominated by writing tools. The impression of the tool is clearly visible in the construction of the letterforms. Without knowing the blending of the tool and cultural practice, the design of letterforms may not achieve desired quality or richness. This is further discussed in the context of the influence of native and non-native designer in the type design process (Dyson & Scott, 2012) in the sub-context of multilingual typeface design and legibility of typeface.

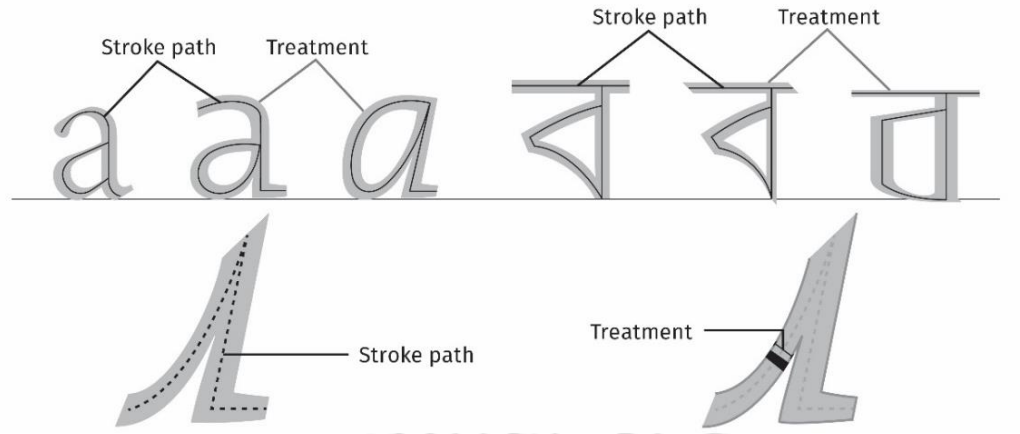


Fig. 2.15: Stroke Path and Treatment

Stroke Contrast

Stroke contrast is the ratio of thinnest to thickest stroke. One can find typefaces with very high contrast to mono-linear (Fig. 2.16). High contrast typefaces are traditional designs primarily used in print media. Mono-linear typefaces developed in the digital era targets screen reading (Carter M. , 2014). Bengali script is dominated by writing tools like cut nib, flattened nibs angled towards left and right, square and oval tips, split point nib, calligraphic brush and etc. (Mohanty, 1998; Ross, 2009); the high contrast stroke feature is part of these scripts. The development of monolinear design for such typeform may need an explanation. At the same time, design validation of such typeform is also needed in comparison to its original form.

Fig. 2.16: Variations of stroke contrast

Stroke Density (Visual Density)

The stroke density (Gaultney, 2000) of Indic scripts is higher than Latin and it becomes much higher in the case of conjuncts. The letters are sinuous with complex structure. Every letter has to design within a given space allocated in font design tool, also known as 'letter space'. It is fixed horizontally for all letters within a font but only vertically adjustable. The space management for a letterform is a critical issue with non-Latin scripts since most of the font design tools are set in Latin specification.

Stroke Width & Weight

The stroke width is another issue that needs attention since the stroke density of Indic scripts is higher. To maintain familiarity within all letters, the stroke width has to be at optimal size by which every character can be designed without any distortion. Also, the linear or exponential increment of stroke width (every instance of stroke width is a single weight) is possible that will further lead to the creation of type family (Fig. 2.17) (Ross, 2013). Such complexity of design leads to limit the design for only single weight or few variations in weight in contrast to Latin type families.

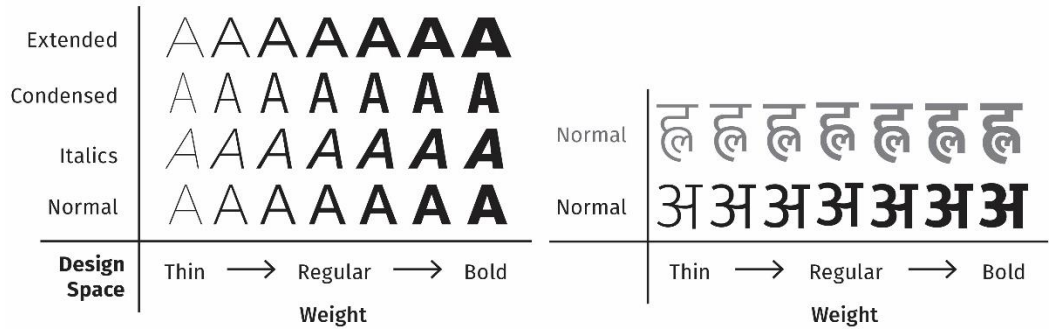


Fig. 2.17: Distribution of stroke weight in Latin and Devanagari with conjunct

2.9.3. Terminals

Fiset et al. (2008) conclude that the terminals are most important features for letter detection (Fig. 2.18) (Fiset, et al., 2008). However, this study and few others are based on Latin script. The letters with terminals and their 'Finial (appearance of the terminal)' are few in Latin like 'a', 'c', 'e', 'f' and variations of terminal are also less. In the case of Bengali; there are many letters with terminals that end in different directions. Therefore, the significance of terminals and its importance in the legibility of these scripts are needed to be investigated further with appropriate context.

Fig. 2.18: Terminals of Latin and Bengali scripts

2.9.4. Optical Size

The Latin letterforms are mainly geometric (Fig. 2.19). They are based on three basic shape triangle, square, and circle. The tip of the triangle is called 'Apex'. The most upper and lower extended point are called Overshoot (exceeding cap-line or x-height) and Undershoot (exceeding baseline). The over/under-shoots are 3-5% prolonged to compensate optical illusion (otherwise, it will be looking smaller than others) (Fig. 2.19) (Cheng, 2005). The construction of Bengali letterforms hangs from a headline or 'Matra' (Fig. 2.19, left two letters). Therefore, the optical balance of such letters should be done considering 'Matra' and other letter-part. A refined study requires to establish optical balance and rules for these letterforms.

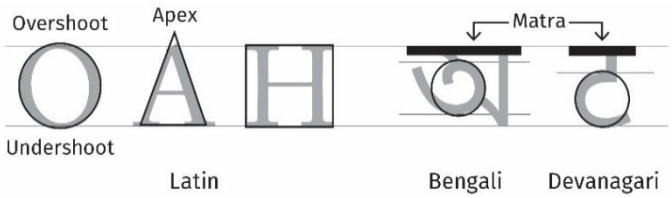


Fig. 2.19: Basic structure of Latin, Bengali, and Devanagari

Legibility measure is a systematic approach by considering the design, visual and cognitive factors together to maintain a certain quality of typefaces. Considering the above discussion on Latin and Bengali, it can be concluded that legibility of Indic letters depends on the letter composition or structural formation, letter cognition and as well as the medium of text displayed or represented. It is also clear from above study that legibility depends on physical parameters of letterforms and is influenced by the evolution of script and design process of letterforms. Here, the lacuna in the current literature is highlighted in the context of legibility study in non-Latin scripts. A thorough enquiry of design parameters with various cognitive aspects is required to study legibility of Indic scripts.

2.10. Research Gap

Through the literature survey, we find following research gap:

- Many researchers discussed typeface anatomy, but there was no such systematic way/ standard method followed to define it.
- The anatomy of Indic scripts is rarely studied by researchers. The existing literature is primarily focused on Devanagari script. Other Indic scripts are yet to be explored.
- Anatomical nomenclatures of Bengali are mostly borrowed from Latin script to identify letter-parts. Adaptation of such nomenclatures needs appropriate justification in context of Bengali.
- Also, the design variables of the Indic script have barely identified previously, and further its influences are thought of in many studies.
- The existing literature suggests that the structural grid lines are not fully defined in Bengali. Practitioners do not follow any standard gridlines in the process of type production. There are possibilities to identify more grid lines

that segregate a letter vertically in rational order for better understanding. The complexities of type design process and existing literature indicate that there is a need for fine-tuning the core letter parts of letterforms. Ross identifies only five features from five letters (as shown in Fig. 2.5). The research gap leads to an investigation on the nomenclature of different letter parts of Bengali letters. A standard anatomy helps to identify individual parts that result in better understanding and improvement in the field of type design. The knowledge of every distinct letter-part benefits designers and font users to understand its structural formation and its purpose (Mohanty, 1998; Coles, 2012; Ross, 2013).

- There are very few studies on typeface legibility of Indic scripts. There is no attempt in defining one singular holistic approach to provide legibility consideration for it. There are parameters to measure legibility of Latin text based on anatomical features and other parameters. Inferences of such empirical studies done with Latin script are many at times adapted to define legibility of Indian scripts without validation.

- Fiset et al. (2008) find out letter features that are necessary for recognition especially terminals, but the study does not described the role of letter features in typeface legibility which is a primary concern for type designers. There are few studies in Latin script that discusses the relation among typeface anatomy, recognition and its legibility. This kind of study is hardly done in Indic script. It is necessary for Indic scripts because most of the letter structure is complex and sinuous.

This research has been conducted from the perspective of type design where design and structure of letterforms are considered as means of communication. Here, the standpoint of typography leaves out an account where issues related to

letter/word/line spacing, continuous text, reading speed and time are considered. However, there are overlaps between them and debate about their interactions.

The study shows the dependency of legibility on anatomical constructs (features or parameters). The study indicates a substantial gap in the study of legibility considering anatomical parameters. The relation of anatomy and legibility can be a crucial aspect to understand legibility of Bengali script. This research will look into the anatomical factor and its role in Bengali typeface legibility.

2.11. Research Question

Considering the research gap, it is clear that the lacuna remains in the anatomical study and broadly in the non-Latin script including Bengali. Creating knowledge of type anatomy may help to improve the legibility of the not only of the letterforms but also typefaces. Here, we are assuming that (in Fig. 2.20) the understanding of the anatomy of letterforms may increase the knowledge of legibility that further provides us with enough information to access legibility. We already know that anatomy of a letter is explicit. Structural distinctiveness of anatomy exposes identity of letter. Successful identification of letter implies that they are legible enough for identification task. Therefore, the primary question of the research is – 'what is the role of anatomical features in Bengali letter legibility?'

Fig. 2.20: Impact model, [A] = statement is an assumption

To answer the research question, we need to go through the available data in literature. At research clarification stage (Fig. 2.21, from phase I of research methodology by Blessing & Chakrabarti, 2009 as in Fig. 1.15), we have found two major issues in literature that is stated below –

1) There is hardly any anatomy for Bengali script and

2) There is no such methodology for defining the anatomy of letterforms. There is hardly any method in Latin also that describes all letter-parts of it.

Fig. 2.21: Research clarification

Anatomy is the fundamental knowledge of structure at the heart of design process. It subconsciously plays a role in designers' mind. To achieve letter legibility by accessing the structural information of letters, the anatomy of letterforms is a basic requirement (Fig. 2.22). Without specific details of anatomy and its features, problems cannot be identified in context of legibility. Based on this fact, we set first two research questions of the study –

sq1. What is the method to define letterform anatomy?

sq2. How to validate the anatomy of Bengali letterforms?

These two research questions are categorised as sub-questions of research that will further help to answer the primary research question of the study.

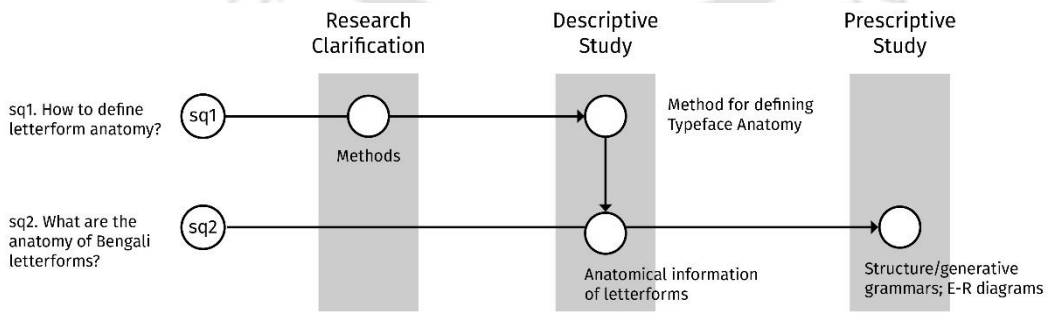


Fig. 2.22: Formulation of first two research questions

The formulation of these two research questions is key to look into the legibility of Bengali which will be done based on letter structure. Consequently, important letter feature will be determined after confirming the role of anatomical feature in letter identification process. The confirmation of role of letter features in identification process is a significant aspect of research. It will determine the involvement of different anatomical features in letter legibility. Thus, the research questions of the study are following –

sq3. How to determine the involvement of letter feature in Bengali letter legibility?

sq4. What is the relation between anatomy and legibility?

The research sub-question three and four (sq3 and sq4) will lead us to determine the role of letterform anatomy in letter legibility. The objective here is to identify the letter-parts that are crucial for recognition task. The outcome of these research questions will determine the important letter-parts and further a guideline for the designers. The result will be synthesised for the designers to understand identification process and critical issues with letters. Such information can be useful for designing of letters to take care of the legibility aspects of letters.

2.12. Aim and Objective

The research is aimed to identify the legibility of Bengali letterforms by providing a guideline for designers. The research sub-question one and two have been set to determine the anatomy of letterforms and rest of the questions determine the role of anatomy in typeface legibility. Accordingly, the aim of the research is as follows:

Aim

- To provide a guideline for type designers to achieve legibility based on Bengali letter anatomy.

The objectives of the research are following –

Objective

- To identify the anatomy of Bengali letters.
- To determine the anatomical features[8] of Bengali letters important for letter identification.

2.13. Conclusion

The literature suggests that there is a lacuna in anatomy and legibility study. Letter anatomy is one of a construct of legibility. The structural formation of letters is crucial for identification of a particular letter. Here, we have looked into anatomical features that responsible for letter legibility by making it easy for recognition in design process. The research is aimed to determine the anatomy of Bengali, important anatomical features and a guideline for the type designers to achieve legibility based on letterform anatomy.

We are examining the role of letterform anatomy in letter legibility. The research method adapted for the study is a 'Design Research Method or DRM: Type 2', proposed by Blessing and Chakrabarti in 2009. It is a comprehensive study of letter anatomy to improvise the typeface legibility. The method comprises three stages, research clarification, descriptive study and prescriptive study (Fig. 2.23). The research clarification is a review-based study which has been done in this chapter. A descriptive study of letterform anatomy of Bengali will be done in the next chapter.

[8] Anatomy or Letter-parts are the individual anatomical components of a letter. Anatomical features are the anatomical component or a specific portion of anatomy.

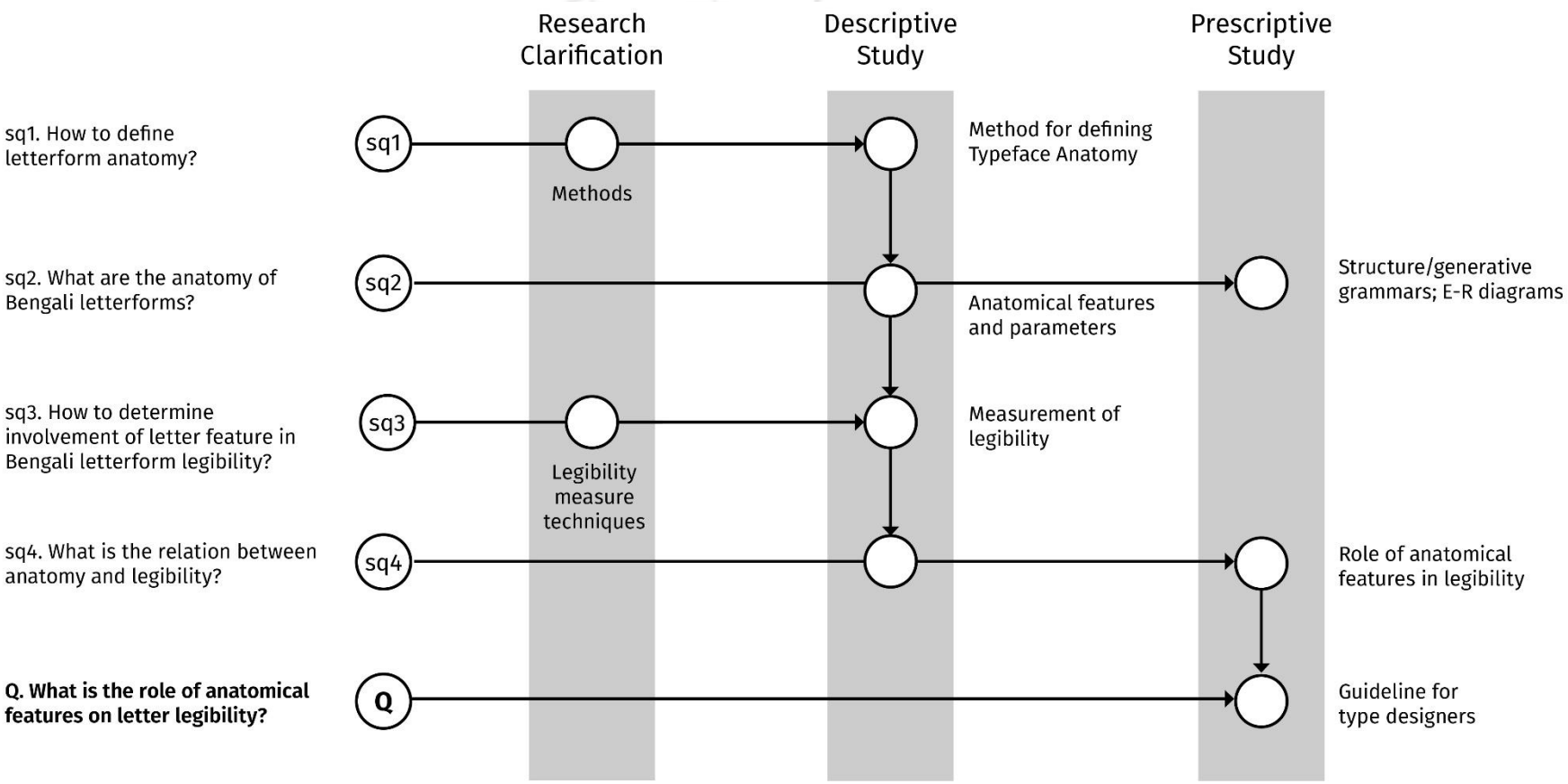


Fig. 2.23: Research Questions

Chapter Three

Anatomy of Bengali Letterforms

Introduction

As stated in the previous chapter, the research objective is to find a method to define the anatomy of Bengali script. It is concluded from the literature review that anatomy of most of Indic scripts including Bengali is not defined adequately. The anatomy of letterforms is very common in design and sounds very minor. Anatomy is a mundane and ever existing but essential for typography and type design studies. The literature available on anatomy of Bengali letterforms shows gaps in theory and practice. The research problem we are trying to solve here is not only routine design practice but also developing a method to define anatomy.

This chapter proposes the anatomy of Bengali letterforms by using a systematic method. Existing literature on typeface anatomy is limited to Latin letterforms and very few nomenclatures exist in Bengali script. This chapter demonstrates the empirical approach to define typeface anatomy in a structured way. The analysis of the anatomy has been carried out using a combination of semiotic methods that leads to identification of letter parts with nomenclature. The study also proposes different letter groups that will be helpful for further study.

3.1. Letterform Anatomy

It is unclear from the literature that whether there is any standard methods or a systematic way to define typeface anatomy. Different scholars discuss a distinct method to identify different letter-parts with their nomenclature. The objective here

is to create a model for defining typeface anatomy in the context of Bengali script. The anatomy of Latin has almost entirely been defined by designers and researchers. In last two decades, non-Latin scripts are getting more attention from the research community. More than sixty percent of the global population is dependent on non-Latin scripts that include Indic scripts. It is globally used in education, politics, economics and cultural purposes. There are many print media like newspaper, hoarding, and posters that are regularly printed using non-Latin scripts. Even non-Latin internet users are increasing day by day (Ross & Shaw, 2012).

3.2. Syntactic Analysis

The systematic analysis is the study of the principles underlying the organisation of the various sciences and conduct of scientific inquiry. Bengali has a wide variation of letterforms in use and their structure vary significantly. The objective here is to determine anatomical parts and provide a nomenclature for Bengali script. Thus, the process involves following two steps –

1. Letter-part identification
2. Naming of letter-parts.

To identify the letter-parts, we have taken few letters and disintegrated it into smallest stroke units of letter construction (as in Fig. 3.1). It is noticed that Bengali has groups of letterforms that have similar structure with minor variants. But few letters are completely different from others. By identifying the letter-parts, it is necessary to go through same parts with other letters. A consecutive repetition is required until all similar and unique parts are identified.

Fig. 3.1: Disintegration of letters

To create a logical entity out of that structure, a normalised approach has been introduced that breaks down all the complex feature in a single unit for further analysis. Following the same steps as a general approach of analysis, all the letterforms have been taken into account. Iterative analysis and semiotic approaches are employed for meaning-making of letter-parts. The process followed here is an adaptation of syntactic and semantic analysis of letter-parts. The syntactic process enables us to identify letter-parts, whereas the semantic process is in the meaning-making and naming of letter-parts (Barthes, 1977; Chandler, 2007).

3.2.1. The letter features: stroke unit

The preparation of stroke unit has been done with Lohit Bengali typeface, designed for the screen display. All the letter parts are cut into unit stroke based on their spatial information such as vertical line, horizontal line, junction or single curve (Fig. 3.2). The operation has been performed on each Bengali letter and details are given in Appendix I.

Fig. 3.2: Separation of letter-parts

A syntactic analysis was done on disintegrated letter-parts. The dissection of letter-parts has been done considering nature, position and function[9] of stroke. The similar letter-parts are grouped together with a nomenclature (Fig. 3.3). The categorisation has done with respect to the nature of strokes. Total thirty anatomical feature groups were formed by the analysis. The detail stroke analysis is given in Appendix II.

3.3. Semantic Analysis

The enquiry of Bengali typeface anatomy and their nomenclature is prepared based on semiotics approach. The disassociation process has been done in the Syntactic analysis. The semantic process is used for identification and naming of letter-parts. The method comprises two stages Syntagmatic analysis and Paradigmatic analysis. Syntagmatic analysis is used to identify letter-parts with nomenclature for a single typeface. Paradigmatic analysis is used to validate letter-parts and their nomenclatures across multiple typefaces. The paradigmatic analysis plays a key role in anatomical identification by establishing a letter-part which is necessary for letter construction and available for all typefaces. The graphical model of syntagmatic and paradigmatic analysis is given in Fig. 3.4.

[9] Nature, position and function denote structural formation, association, initial and terminal of stokes in letters.

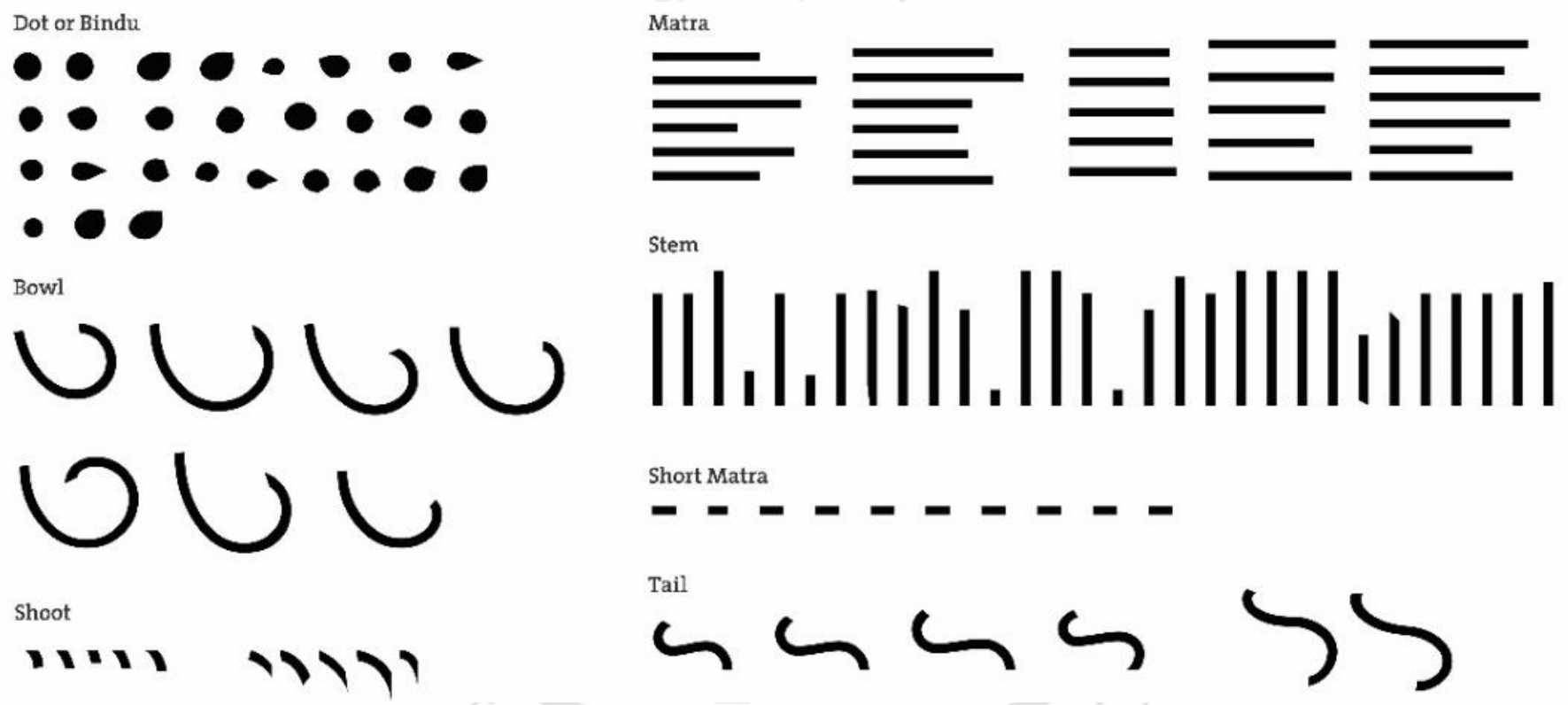


Fig. 3.3: Groups of letter-part

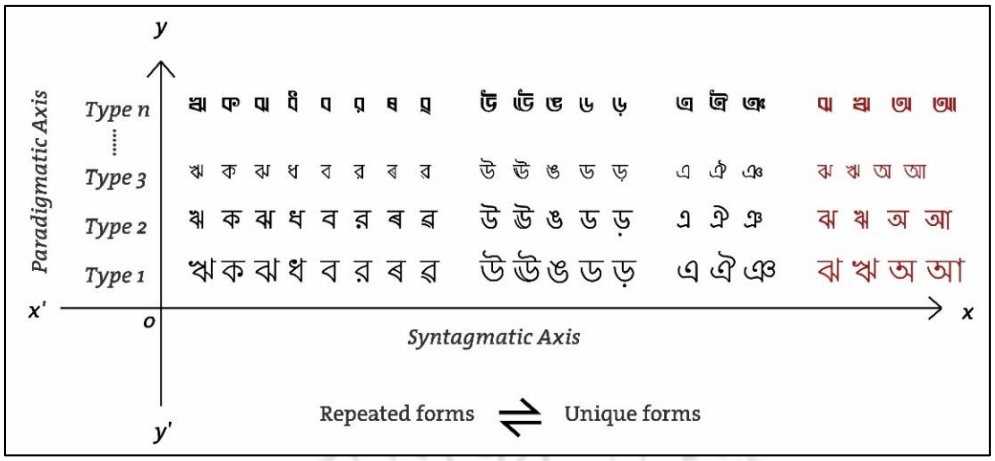


Fig. 3.4: Syntagmatic & Paradigmatic analysis axes

The structural formation of a typeface is investigated using Syntagmatic analysis. The syntagmatic process is useful for making sense out of the letter-parts (Fig. 3.5). The distinct shape of letter parts is named by new terminologies or borrowed from Latin or non-Latin scripts based on the appearance of the stroke characteristics. Most of the terminologies in Latin letterforms are based on human or animal anatomy like eye, ear, shoulder, leg, tail etc. (Cheng, 2005). Here, both plant and animal anatomical nomenclatures are identified and used to classify letter-parts like stem, shoot, bud, knot, shoulder, leg, tail etc.

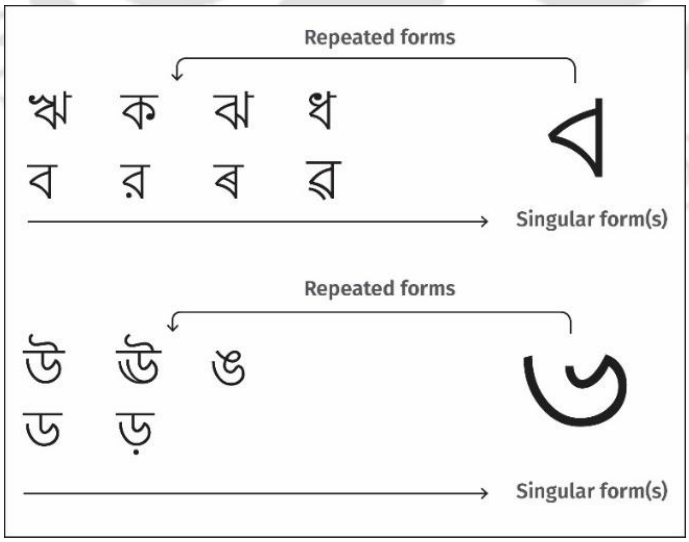


Fig. 3.5: Singular – Repeated forms

3.3.1. Syntagmatic Analysis

The syntagmatic analysis is a method to study the surface structure of an object (Chandler, 2007). This method is used here to identify different anatomical features of letters of a single typeface and to define its nomenclature. The analysis is carried out considering two facts, first the repeated forms among all letters and second the unique form of the individual letter using prepared illustration as in Fig. 3.5. Then, a terminology is provided for each common form that comes out of the analysis of repeated form. The process of feature analysis has been done on vowels and consonants only using repeated forms. Rest of letter-parts are kept for unique identification.

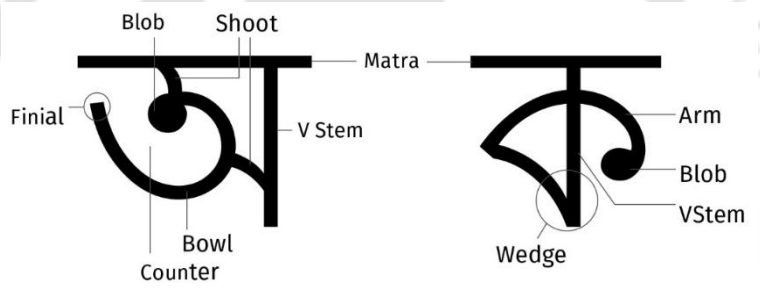


Fig. 3.6: Syntagmatic analysis

The analysis process involves identification of letter-parts by means of characteristics, stroke path and nature of strokes. In Fig. 3.6, the analysis method is shown with vowel letter 'A' and consonant letter 'Ka'. The Horizontal lines at top are named as 'Matra', both of them have 'VStem'. Bowl, Finial, Blob and Shoot are the anatomical feature of 'A' whereas Delta, Wedge Arm and Blob are the features of 'Ka'. There are different arrangements (or stroke path) of curves in Bengali. They are named Arm, Lobe and Bowl, and depend on their spread across a circular periphery as in Fig. 3.7. 'Arm' is a curvilinear stroke within thirty to ninety degrees approximately. 'Lobe' is a curvilinear stroke within ninety to one hundred and eighty degrees approximately and 'Bowl' is a curvilinear stroke about three hundred sixty degrees round approximately.

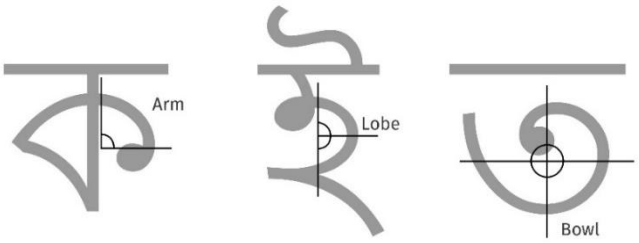


Fig. 3.7: Defining Arm, Lobe and Bowl

There are also different types of 'Blob' feature in Bengali. The identification is done on the basis of placement of the feature. The same letter-part is called as 'Bud if it is coming at the beginning or at the end of a stroke. If the letter-part is coming in-between two strokes it is named as 'Knot'. The Blob feature that does not connect to any stroke is named as 'Dot' or 'Bindu'. The details are shown in Fig. 3.8.

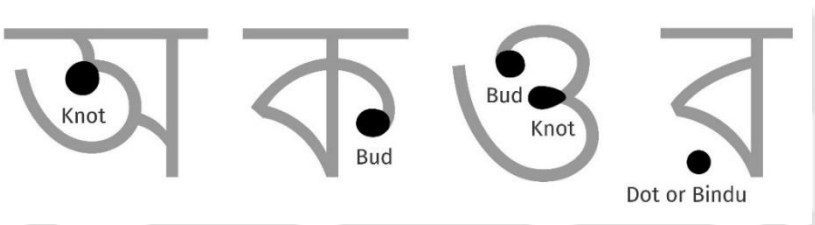


Fig. 3.8: The Bud, Knot and Bindu of Bengali

The feature 'Delta' and 'Wedge' are differentiated by total number of strokes and their formation. A 'Delta' is a triangular formation of three strokes whereas 'Wedge' is a junction of two strokes like 'V' shape (see Fig. 3.9). A 'Delta' is like triangular shape with combination of three strokes. The bottom junction of Delta has common characteristic with Wedge.

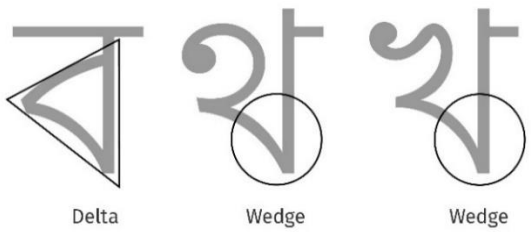


Fig. 3.9: Delta and Wedge features of Bengali

Similarly, Crossbar, Stem, Half-Stem, Leg and Shoot are defined based on visual form and semiotic connection that are meaningful. The details of these visual features have been explained in Fig. 3.10. The complete analyses of all letterforms are given in Appendix III.

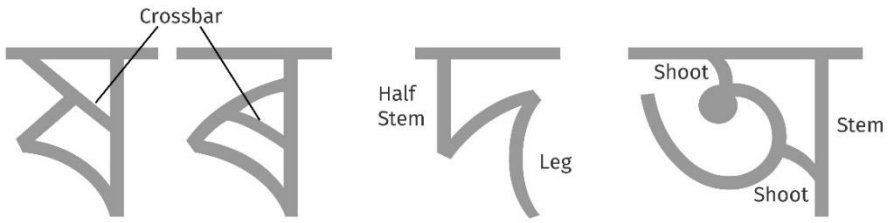


Fig. 3.10: Letter feature Crossbar, Stem, Half-Stem, Leg and Shoot

3.3.2. Paradigmatic Analysis

The paradigmatic analysis has been done on four typefaces Lohit Bengali from RedHat Project, SolaimanLipi from OmniLab, Vrinda from Microsoft and Rupali from Ekushy Bangla. These typefaces are selected on the basis of variation in their application context. Lohit Bengali is used for androids and PCs, Vrinda is used in PCs, Solaimanlipi and Rupali used for digital displays.

Fig. 3.11 is the detailed study of letter 'A' and 'Ka'. Only 'A' of Lohit typeface (first one) has Knot feature and rest of all have Bud due to the presence of 'Shoot' from the Headline. The terminal cuts are distinct in each typeface. The Aperture between Finial and Matra also varies for each typeface. Similarly, the letter 'Ka' in Fig. 3.11 (lower row) has Bud at the end of Arm in first three typefaces Lohit, SolaimanLipi and Vrinda. But in the case of Rupali typeface (last one), there is no Bud feature at the end of Arm. Here the Arm visually becomes a 'Lobe'.

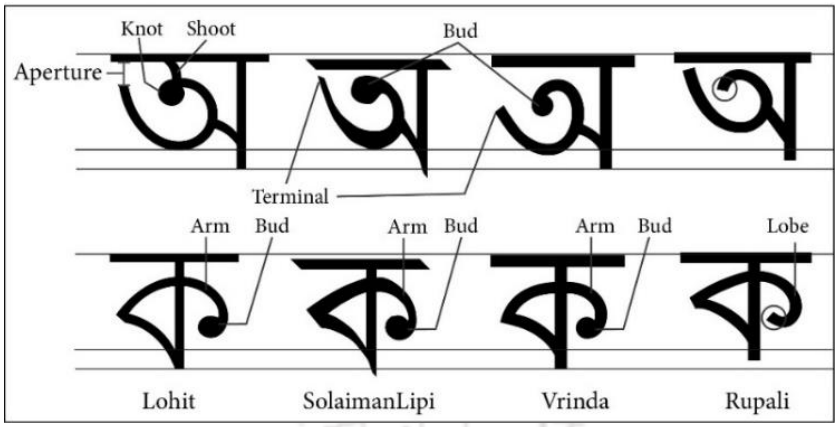


Fig. 3.11: Paradigmatic analysis of letter 'A' and 'Ka'

The feature 'Blob' is segregated further into 'Bud' and 'Knot'. Bud is connected at single end of a curve in letter, but Knot is positioned in joinery of two curves in letters like 'A', 'E' and 'Ma'. Similarly, the 'Delta' feature is a combination or triangular formation of strokes in letterform as the main body element of letters 'Ka', 'Ba', 'Ra' etc. There is a 'V'-like joinery named as 'Wedge' which is a combination of a 'Stem' and 'Shoot' that started from the end of Stem in letters 'Ka', 'Kha', 'Tha' etc. The unique forms of an individual letter are also identified and named accordingly such as 'Loop', 'Nose' etc. All letters are examined in the same way, and Table 3.1 is prepared with all possible nomenclature of vowel and consonant letters. The detail analyses of letterforms are given in Appendix III.

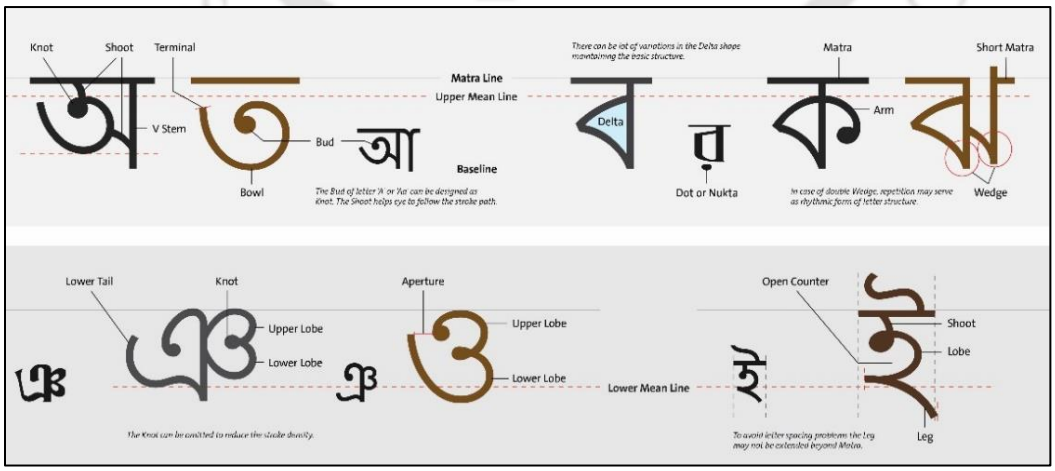


Fig. 3.12: Syntagmatic analysis

Table 3.1: Letter anatomy table

Terminology	Borrowed from	Description	Letterforms
Aperture	Latin (Cheng, 2005)	Opening of two nearest stroke	অ উ ত
Arm	Latin (Cheng, 2005)	A curvilinear stroke within bound of ninety degree	এ ঈ ক
Bindu	Latin (Cheng, 2005), Devanagari (Naik, 1971)	A Dot feature like in letter 'j'	র ড় য় ঢ়
Bowl	Bengali (Ross, 2009)	A curvilinear stroke about three hundred sixty degrees round	অ ত ড
Bud	*	A blob feature connected to end of a stroke	অ ঋ ক খ ত
Curl	*	A stroke that holds shoots	ঋ খ
Delta	*	Formation of three connected triangular strokes	ব ক ঝ
Finial or Terminal	Latin (Cheng, 2005)	End of a stroke	অ উ ত
Half Stem	*	Short vertical stroke	উ ছ
HStem or Matra	Bengali (Ross, 2009), Latin (Cheng, 2005)	Horizontal stroke	অ ক চ ন র ৱ
Initial	Latin (Cheng, 2005)	Beginning of a stroke	ত
Knot	Bengali (Ross, 2013)	A blob feature connected to two continuous strokes	ম ই
Leg	Latin (Cheng, 2005)	A finishing stroke that balances body of a letter	ই ঈ দ
Lobe	Latin (Cheng, 2005)	A curvilinear stroke within bound of ninety to one hundred eighty degree	ই গ ও
Loop	Latin (Cheng, 2005)	A round formation of a stroke	ঙ
Nose	*	A junction of two curves	উ ঊ ড
Shoot	*	A stroke comes out from a stroke	অ জ
Tail	Arabic (Abulhab, 2008), Latin (Cheng, 2005)	A stroke comes out from body of a letter.	উ ই ঈ ঐ
VStem	Bengali (Ross, 2009), Latin (Cheng, 2005)	Vertical stroke	অ ক চ ন র ৱ
Wedge	*	A 'V' shaped angle at bottom part of letter	অ ক থ

* This term is introduced for the first time.

3.4. The method involved in anatomical analysis

The effectiveness of any method is to define outcome accurately. Here, we are using a regulated iterative process (looping) with logical order. The letter-parts that we are identifying are generic. But few of letter-parts are typeface specific. Overall the method is attempted in the following order –

1. Disintegration of letter parts.
2. Identification of unique letter features by repeated measure.
3. Syntagmatic analysis of letters within a typeface.
4. Formation of letter group based on structural characteristics.
5. Paradigmatic analysis of letters among typefaces.

The steps involved in the systematic study are a collection of standard processes that is proclaimed by many authors in other domains of study. The syntagmatic and paradigmatic examinations are not only helping with letter-part identification but also validation of them. The paradigmatic process is a cross verification technique of letter-parts across multiple typefaces. The complete framework is shown in Fig. 3.13 and Fig. 3.14. The order that followed against the methodological framework is given in Fig. 3.13. Here, the method has been used in Bengali script, but it can be further examined with other scripts.

Semiotic Analysis
Syntactic Layer
1. Disintegration of letter-parts
2. Identification of unique letter features by repeated measure
Semantic Layer
3. Syntagmatic analysis of letters within a typeface
4. Formation of letter groups based on structural characteristics
5. Paradigmatic analysis of letters among typefaces (Validation)

Fig. 3.13: Analysis method of anatomy

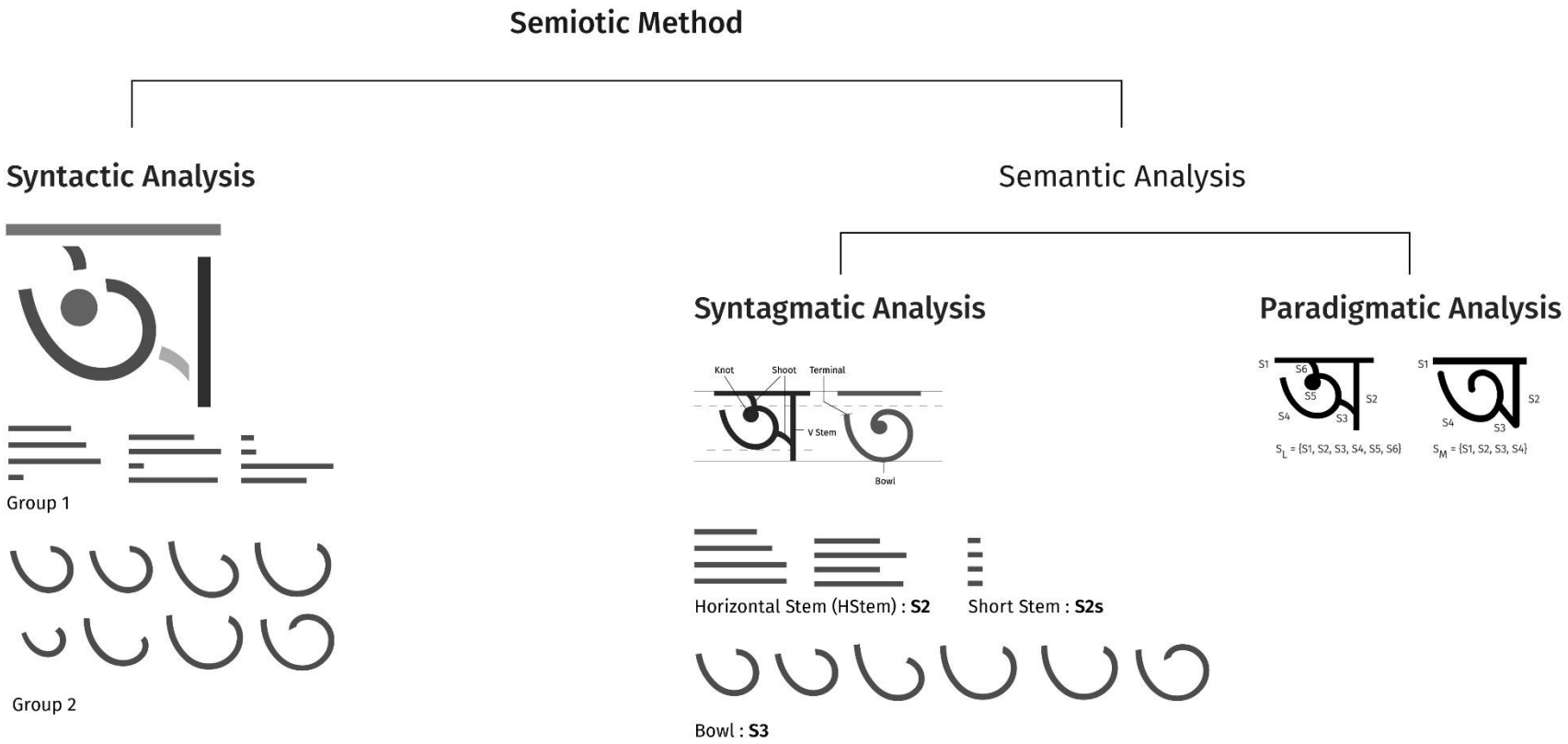


Fig. 3.14: Diagram of semiotic analysis

The paradigmatic analysis is used as a validation method for typeface anatomy. This method enables us to understand the structural formation of individual letter with minimum stroke requirement to identify a letter. The Bengali letters can posses with many extra letter-parts. Such letter-parts donot deface the identity of letters. They are auxiliary letter-parts. To understand, here, we consider four different typefaces of a single Bengali letter 'A' as in Fig. 3.15. The typefaces are Kalpurush as S(K), Lohit as S(L), Noto Sans Bengali as S(N) and Mukti as S(M). Here, the letter-parts are marked considering common identity of feature based on spatial information.

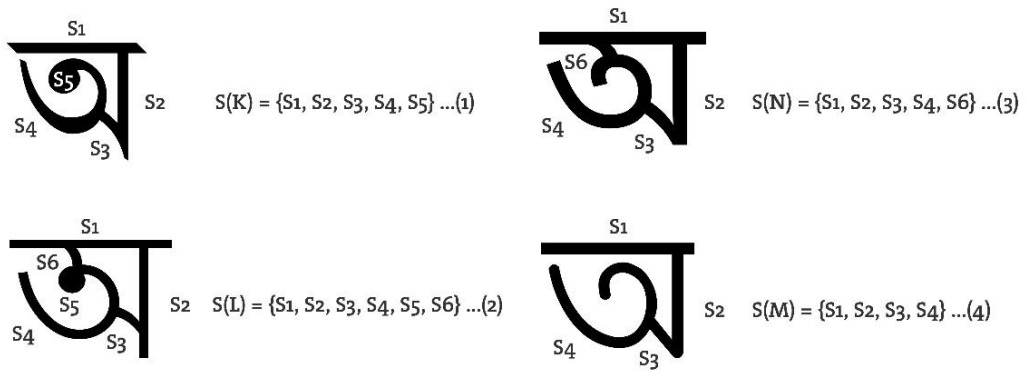


Fig. 3.15: Paradigmatic analysis of letter 'A'

Now, comparing the four typefaces, we can say

All anatomical features of letter 'A'

Equation 3.1: Sm = S(K) ∪ S(L) ∪ S(N) ∪ S(M) = {S1, S2, S3, S4,S5, S6}

Least set of Anatomical features of letter 'A'

Equation 3.2: Sn = S(K) ∩ S(L) ∩ S(N) ∩ S(M) = {S1, S2, S3, S4}

Auxiliary anatomical features

Equation 3.3: Smn = Sm Δ Sn = {S5, S6}

Here, Equation 3.1 is the collection of all possible features minimum stroke requirement and auxiliary features. Equation 3.2 is the representation of structural formation that has to be there to identify a particular letter and Equation 3.3 is the

collection of auxiliary features only. Similarly, all letterforms have been analysed and Table 3.2 is prepared with anatomical features.

Table 3.2: Anatomical features of Bengali letters

Letter	Anatomical Features
অ	Matra, Bowl, VStem, Bud/Knot, Wedge, Shoot
আ	Matra, Bowl, VStem, Bud/Knot, Wedge, Shoot
ই	Matra, Bud/Knot, Tail
ঈ	Matra, Bud/Knot, Tail
উ	Matra, Bowl, Tail, Nose
ঊ	Matra, Bowl, Tail, Nose
ঋ	VStem, Wedge, Shoot, Arm, Curl, Delta
এ	VStem, Bud, Lower Tail
ঐ	VStem, Bud, Tail, Lower Tail
ও	Bowl, Bud, Knot
ঔ	Bowl, Bud, Knot, Tail
ক	Matra, VStem, Bud, Wedge, Arm, Delta
খ	VStem, Bud, Wedge, Arm, Curl
গ	VStem, Shoot, Lobe
ঘ	Matra, VStem, Wedge, Curl
ঙ	Bowl, Loop, Nose
চ	Matra, VStem, Curl
ছ	Matra, Short VStem, Shoot, Leg
জ	Matra, Bowl, Shoot, Leg
ঝ	Matra, Wedge, Shoot, Delta
ঞ	VStem, Bud, Lobe, Lower Tail
ট	Matra, VStem, Bud, Tail
ঠ	Matra, Tail, Curl
ড	Matra, Bowl, Short VStem
ঢ	Matra, VStem, Bud, Curl
ণ	VStem, Bud, Lobe
ত	Matra, Bowl, Bud/Knot
থ	VStem, Bud/Knot, Wedge, Lobe
দ	Matra, Short VStem, Curl, Leg
ধ	VStem, VStem, Bud, Wedge, Shoot, Delta
ন	Matra, VStem, Bud, Lobe
প	VStem, Lobe, Curl, Crossbar
ফ	Matra, Bud, Wedge, >
ব	Matra, VStem, Wedge, Delta
ভ	Matra, Bowl, Bud, Arm

ম	Matra. Knot/Loop, Curl/Shoot, VStem
য	Matra, VStem, Wedge, >
র	Matra, VStem, Dot, Wedge, Delta
ল	Matra, VStem, Bud, Lobe, Arm
শ	VStem, Double Knot/Loop
ষ	Matra, VStem, Wedge, Crossbar, >
স	Matra, VStem, Curl/Shoot
হ	Matra, Bud/Knot, Lobe, Leg
ড়	Matra, Bowl, Dot, Short Stem, Nose
ঢ়	Matra, VStem, Dot, Curl, Bud
য়	Matra, VStem, Dot, Wedge, >
ৰ	Matra, VStem, Wedge, Delta
ৱ	Matra, VStem, Wedge, Delta, Crossbar

3.5. Categorization based on Anatomy

The objective of categorization is to understand the resemblance among letterforms. It is information that can be helpful for designing typefaces. It enables to understand the rhythm and balance of letterforms. The categorisation has been done based on two parameters proposed by Mohanty (1998): common character and common structure. The groups of the letter are prepared with respect to the appearance of common features or a combination of features.

3.5.1. Common character parameter

Common character parameter identifies the groups of letter according to the appearance of a single feature within a typeface. Vertical Stem, Delta and Bowl are most common features of Bengali typefaces, encountered during feature analysis. The letterforms can be grouped (as in Fig. 3.16) based on these features in several ways-

1) Vertical stem at right side,

2) Vertical stem at middle,

3) Vertical stem at left side,

4) Letters with wedge,

5) Letters with lobe,

6) Letters with bowl,

7) Letters with leg,

8) Letters with shoot and

9) Letters with half stem.

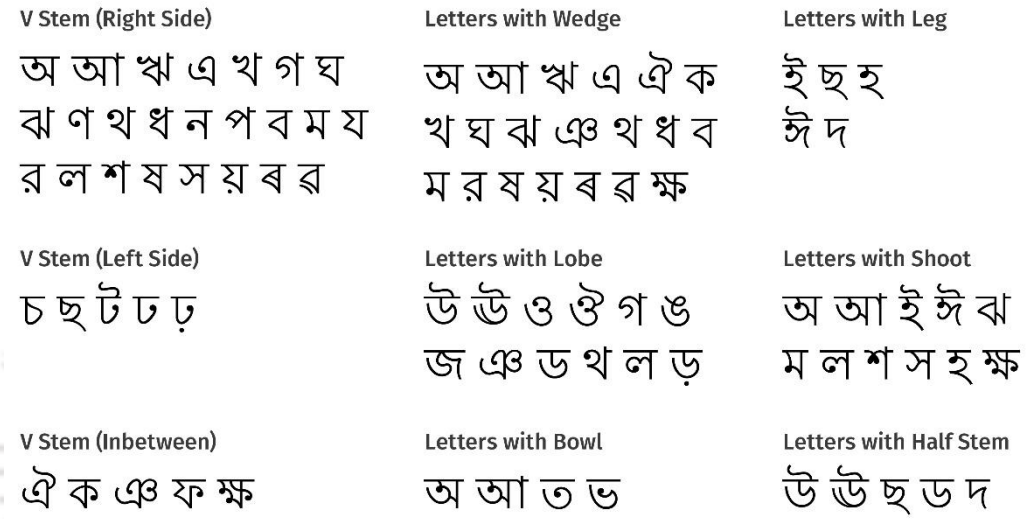


Fig. 3.16: Grouping using common character parameter

3.5.2. Common structural parameter

Common structural parameter similarly provides several groups of letters in combination of strokes or features as a single unit. This category of letterforms is further organised into two sets-

1) 'Strong resemblance category' – the set of letters that have more than one common anatomical features as dominant characteristics, and

2) 'Weak resemblance categories' – that have been created with the letters having only one anatomical feature in common.

1) Strong resemblance letterforms and their categories:

The letters in this category have major structural similarity among themselves. The common letter-parts are dominant characteristics of letterforms. In this group, letters are differentiated by minor distinctive features (Fig. 3.17).

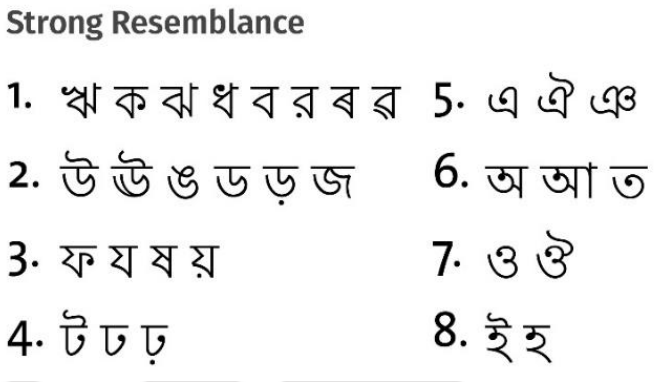


Fig. 3.17: Strong resemblance group of letterforms

2) Weak resemblance letterforms and their categories:

Only few anatomical features are common among letters of weak resemblance groups. There can be many features that can be common across groups. Fig. 3.18 is the categories of different resemblance groups showing few differences in letterforms.

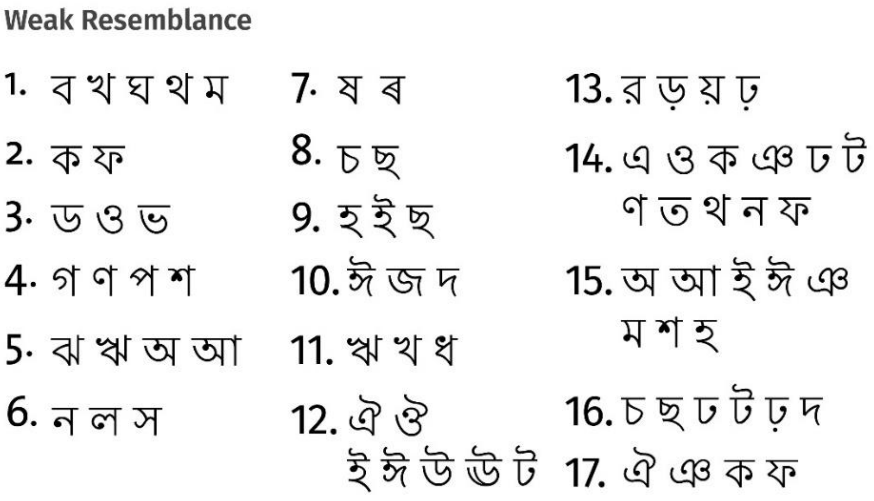


Fig. 3.18: Weak resemblance group of letterforms

3.6. Discussion

The analysis of Bengali typeface anatomy has been done here in a systematic way. 'Lohit Bengali' typeface is used for the analysis and eventually it provides us with enough stroke units that become useful for syntagmatic and paradigmatic study. The study offers a range of nomenclatures to identify different features that may help type designer to achieve rhythm and unity during typeface design. The letterform categorizations are additional inducement in design process. The study proposes twenty distinct features after analysing only vowels and consonants over few features that were identified previously by Fiona Ross (Ross, 2009).

The anatomical study also takes care of the issue with letter-part nomenclature. The study resolves the issue of nomenclature by naming the letter-parts appropriately with respect to their functionality. In general, there is no concept of 'Serif and Sans-serif' typeface in Bengali. But there is a new trend in design practice that is claiming the 'Blob' feature (whether Bud or Knot) as a 'Serif' (Fig. 3.19). Such claim needs extensive study to examine the nature of typefaces. Traditionally, Blob is a feature that expresses the calligraphic nature of the script. It is a trail of brush stroke that remains with the letter. Nowadays, new typefaces like Noto Sans Bengali and Mukti, they do not have such features. That difference raises ambiguity to look into serif and sans serif nature in Bengali script (Tam, 2002; Arditi & Cho, 2005; Vargas, 2007; Josephson, 2011).

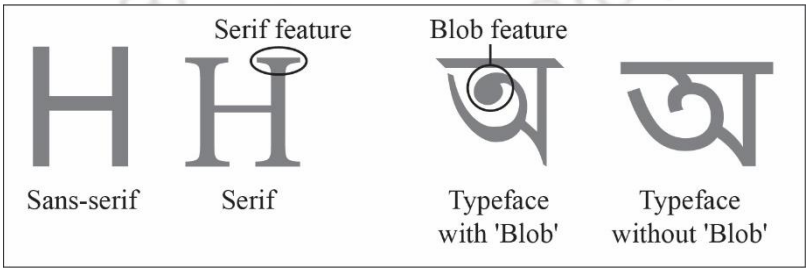


Fig. 3.19: Sans Serif & Serif typefaces

The study also opens a scope for discussing the structural formation of every letter by defining the 'Relationship Model' of letters (Fig. 3.20). The aim of such a study is to generate structural formation based on common features. The model can establish a relational model among all features that further elaborates feature-joinery relationship. Such a model can be useful for OCR systems for letter-identification. A 'stroke-joinery' relationship model is given as an example in Fig. 3.20.

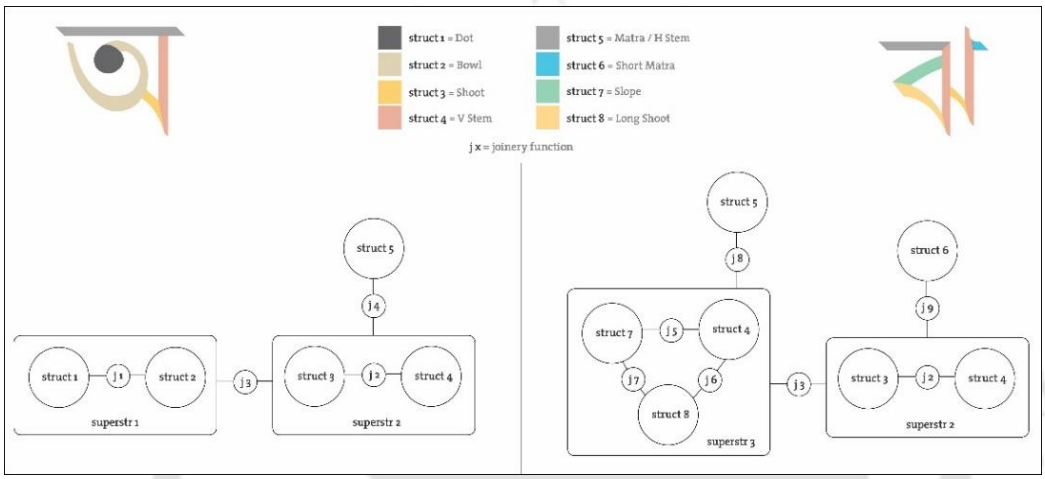


Fig. 3.20: Relationship model of features

3.7. Conclusion

The study offers twenty different anatomical letter-parts of Bengali script and a method to analyse typeface anatomy of Bengali. Other Indic scripts can also adopt this semiotic method for letterform analysis. A study by Changizi and Shimojo (2005) show that letter complexity of each script is different considering the average number of strokes per letter as in Table 3.3. They show that the value of Bengali is 3.91 which is higher than not only Latin (2.08) and also with many other Indic scripts (Changizi & Shimojo, 2005, pp. 268-270). Thus, it can be stated that if a method is applicable for Bengali, it can be useful for other scripts. The application and categorization procedure can vary according to script grammar of that particular script. They also determine the total number of stroke type which is 29 for Bengali. During syntactic analysis, we identified 30 different types of stroke types which is

almost similar to our semiotic study. These features can be useful in OCR systems for detection of letters (Sarwar, et al., 2013; Das, Dasgupta, & Bhattacharya, 2018). The features and their position and shape can accompany to effective design of typeface that can solve the legibility and letter confusion to recognition issues (Fiset, et al., 2008; Chahine, 2012).

Table 3.3: Table of average character length (Changizi & Shimojo, 2005, pp. 268-270)

Script	Average character length	Number of stroke types
Bengali abugida	3.91	29
Devanagari abugida	3.27	30
Gurmukhi abugida	3.20	31
Oriya abugida	2.89	34
Kannada abugida	2.79	34
Tamil abugida	2.74	29
Latin, ancient alphabet	2.67	10
Latin, modern caps alphabet	2.50	17
Gujarati abugida	2.21	32
Latin, modern alphabet	2.08	14

Anatomy, in one way, creates consistency among design features. But, in another way, it makes the difference in the case of common anatomical features come across letters. Similarly, anatomical features can coexist in many letters. Anatomy effectively identifies them, and such features can be designed in different order to reduce ambiguity. Every letter-part or anatomical feature can be identified by their unique spatial information. Such information can be used to identify letters in many recognition systems. Here, we discussed the anatomy of the letterforms. In next chapter, the role of anatomy in letter identification with important letter features will be discussed.

Chapter Four

A. Bengali Letter Identification

Introduction

Anatomy provides the information about structural formation of letterforms that are necessary during designing of letters. In this chapter, the relation between letter anatomy and identification is discussed. Letters are meant for reading in the form of a single letter or word or continuous text. Legibility is a common concern of reading in all these situations. Without it, letters are not perceivable. To discuss the matter of Bengali letter identification, the current chapter is divided into two parts. The role of anatomical features in letter identification has been discussed in part A. In part B, the crucial letter parts are identified which are important in Bengali letter recognition.

Anatomical features[10] are the foundation of a letter stroke and elementary unit of letter construction. They are also components of letterform identification. The process of letter identification is the decoding and encoding of structural information. It is essential to design letterforms maintaining such characteristics that could be easy for readers to encode or decode letter information. The identification process involves recognition of all anatomical features as a whole (Pelli, et al., 2006).

The study has been done to access the letter identification information by recognizing the anatomical feature in Bengali. In order to understand the anatomical feature detection in Bengali, we exposed the letters under visual stress to establish the significance of anatomical features. An eye-tracking study was conducted to understand the letter identification (Haj & Lenoble, 2018). It is already proven that

[10] Anatomical features are the anatomical designation to indicate a specific letter-part.

the letters expose their features under the condition of visual stress (Pelli, Levi, & Chung, 2004; Pelli, Palomares, & Majaj, 2004; Pelli, Burns, Farell, & Moore-Page, 2006; Pelli, et al., 2006). Also, large letters are detected by their edge by revealing the anatomical feature (Majaj, Pelli, Kurshan, & Palomares, 2002).

4.1. Typeface Anatomy and Letter Identification

The letters of Bengali share a large number of common features. Very few distinctive features make the differences in one letter from another. Despite such minimum number, every letter is identified without any ambiguity. Pelli et al. (2004, 2006) examine how readers identify letters.

> *"We compare performance across tasks and stimuli that vary in difficulty by pitting the human against the ideal observer and expressing the results as efficiency. We find that efficiency for letter identification is independent of duration, overall contrast, and eccentricity, and only weakly dependent on size, suggesting that letters are identified by a similar computation across this wide range of viewing conditions. Efficiency is also independent of age and years of reading. However, efficiency does vary across alphabets and type styles, with more complex forms yielding lower efficiencies, as one might expect from Gestalt theories of perception. In fact, we find that efficiency is inversely proportional to perimetric complexity (perimeter squared over "ink" area) and nearly independent of everything else." (Pelli, Burns, Farell, & Moore-Page, 2006).*

The two research papers by Pelli et al. extensively discuss the letter identification under contrast sensitivity. Visual object such as letter recognition can be studied under threshold contrast for identifying letters (Pelli, Levi, & Chung, 2004). Contrast pushes human brain to understand the features of exposed letter under stress condition that reveal the identifiable features of letterforms. Here, Bengali letters have been exposed under contrast sensitivity. Using eye-tracking

methods, it is expected that it could reveal the features that are essential for particular letter identification. The objective here is to determine the involvement of anatomical features in letter recognition process. A repeated measurement method has been used to determine the role of anatomical features in letter identification.

It is known that letters reveal their features under visual stress. Currently, there is no such study with Bengali script that holds the same notion. But it is extensively studied and well-known fact with Latin script. Since the letters are nothing but a combination of strokes, it would be same with Bengali as well. Thus, Bengali letters have been exposed in a similar way to examine their identity and additionally, eye-tracking has been performed. The efficiency of letter identification process denotes that the letterform structure is effectively recognised. The easier the reader perceives the letterforms the easier recognition can take place (Bigelow & Holmes Inc., 2014). It is certain that clear and well-defined structure of letterforms is easily recognisable. Such structural formation can be decoded effortlessly and transfers for higher cognitive processes. In the end, legibility of structural information eases the letter identification process (Bedell, Siderov, Formankiewicz, Waugh, & Aydin, 2015).

An eye-tracking study was executed to understand the reading pattern of Bengali letters. The objective was to make the participants to identify the letters features during reading. Here, we use the low contrast technique to hide letter stroke information that reduces the chance of getting recognised easily at once as well as in the peripheral vision. At low contrast, letters are recognised within fovea. Participants have to read the letters with precise attention to identify them (Pelli, Burns, Farell, & Moore-Page, 2006; Majaj, Pelli, Kurshan, & Palomares, 2002; Pelli, et al., 2006; Pelli & Tillman, 2007).

4.2. Eye movement recording in Reading

During reading, eyes move with stops and jumps, called fixations and saccades. Fixations are the stops where eyes stand still for a short period of time to focus on any object. Saccades are fast movement and shifting from one fixation to another fixation (Rayner & Pollatsek, 1989). The eyes move so quickly during saccades that almost any information can be perceived during the jumps (Brooks, Impelman, & Lum, 1981).

The eye movement explains how the visual system behaves during reading. However, reading is a complex cognitive process and it involves many different stages of lexical processing. According to Schotter et al. (2012), a general overview of cognitive processing of text is below –

> *"Visual information is obtained, and the orthography (letter identity and word length), phonology (sounds), and morphology (units of meaning, grammatical gender, etc.) of the word are analyzed. Then the lexical representation (the abstract representation of the word form) is accessed. Finally, the semantics (word meaning) and syntax (grammatical role) representations of word are accessed and integrated into the meaning of sentence" (Schotter, Angele, & Rayner, 2012).*

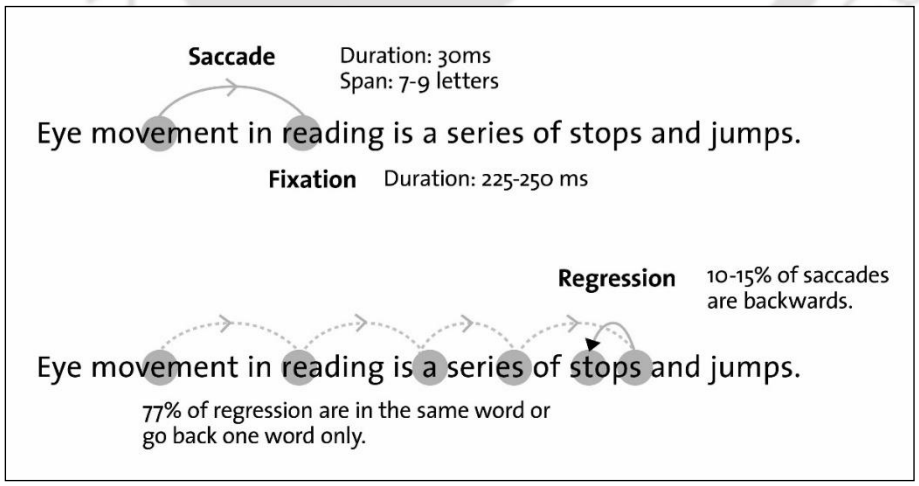


Fig. 4.1: Eye movement in Latin

The approximate span of a fixation in Latin is around 225–250 ms but can vary from 50 ms to 600 ms. The average saccade is 7–9 letters jump but can also range from one single letter to 20 letters or more (Rayner, 2009). The average saccade commences on a 2-degree move and takes around 30 ms to execute as in Fig. 4.1 (Rayner, 1978). These values are averages and can vary depends on various factors of reading (Kwon, Legge, & Dubbels, 2007).

Saccades are forward movements of eyeball and reading stimulus come next to one another into the fovea. Simultaneously, around ten to fifteen percent of saccades are the backward movement which is referred to regressions. Regressions are usually going back due to oculomotor errors. If eyes move too far from last fixation and landed too far that causes an error in connection of reading (Rayner, Chace , & Slatt, 2006). In such cases, the eyes go back backwards to recognise in-between words for comprehension (Rayner, 2009; Brothers, Hoversten, & Traxler, 2017).

The writing system is one of the major factors for the differences in reading measures across different script. For example, the Chinese script is an ideographic writing system where word density is high compared to Latin. The average fixation duration and regression rate of Chinese script are similar to Latin. Whereas, average saccade length is different in case of Latin readers. They move their eyes an average of 2–3 letters in contrast to Latin which is 7–9 letters (Rayner, 2009). Similarly, in Japanese, saccade length is about 2–5 letters (Ikeda & Saida, 1978) (see Fig. 4.2). Katakana script requires the longest fixation duration and shortest saccade length. The Kanji script requires the longest saccade and shortest fixation duration (Osaka, 1989; Osaka, 1992).

The variations in all cases are the effect of increased density of linguistic information (Rayner, 2009). All these results with regards to linguistic information are similar to the findings of Morrison and Rayner (1981). They show that the saccade length depends on number of letters and letter spaces. The saccade length

stays same when the distance from the stimulus is doubled with a constant type size. (Morrison & Rayner, 1981; Bernard & Castet, 2019).

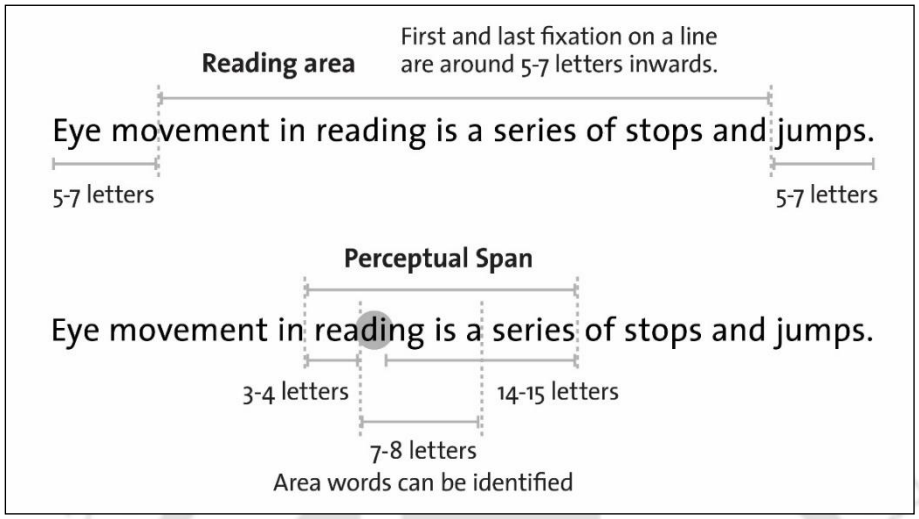


Fig. 4.2: Perceptual span

4.2.1. Attention & Perception in Fovea and Para-fovea

When we look to a continuous text, it appears as if we read the whole line and all of it is in focus. But, we focus on only a part of a line which is known as perceptual span[11] (Fig. 4.2). This field, perceptual span, is asymmetric in Latin. It extends to three or four characters to the left and fourteen or fifteen characters to the right of a fixation (McConkie & Rayner, 1975; 1976). The perceptual span is uneven and biased towards the direction of moving attention (Reichle, Rayner, & Pollatsek, 2003). The reading also depends on the age of the readers (Payne & Federmeier, 2017). Pollatsek et al. (1981) demonstrate that the perceptual span in Hebrew is asymmetric and biased to left rather than to right like Latin. Therefore, it can be considered that reading attention and perceptual span depend on the reading direction, not on the reading habit (Chahine, 2012; Veldre & Andrews, 2018).

[11] Perceptual span is the field of effective vision.

4.2.2. Effect of Orthography

There are many studies that found a significant effect of orthography of word on fixation duration (Rayner, 2009). Drieghe et al. (2005) conclude that, in para-fovea, a longer word leads to shorter fixation duration on instance of current word (Drieghe, Rayner, & Pollatsek, 2005). Another study by Drieghe, Rayner, and Pollatsek (2008) show the evidence for parafoveal-on-foveal effect with result that indicates longer fixation time due to orthographic characteristics. But, there is no direct relation or effect of word frequency on reading behaviour (Drieghe, Rayner, & Pollatsek, 2008).

4.2.3. The Control of Eye Movement

Eye movement is a moving window that controls the fixations and saccades (Rayner & Pollatsek, 1981). The moving window paradigm and the stimulus onset can be controlled with alternative manipulation of these two construct. The fixation duration and saccade length vary independently with the manipulation of these two construct and eye movement are also independent of their control (Rayner & Pollatsek, 1981). The fixation duration and saccade length do not have any correlation. There is also no relation between two consecutive saccades or durations of successive fixation (Rayner & George, 1976). Although, there are cases of regressions and re-fixation that happen due to higher cognitive processes and cause comprehension problem (Rayner, Kambe, & Duffy, 2000).

The extraction of visual information of text is an independent process from lexical processing that is responsible for the reading process of letter, words or text (Inhoff, Eiter, Radach, & Juhasz, 2003). The saccade will be longer if text is longer. Short words or text can result in longer saccades if they skip over (Juhasz, White, Liversedge, & Rayner, 2008). However, Juhasz et al. (2008) have shown that the para-foveal preview of next fixation i.e. word or text directly sends the eyes to the

centre of target word or text (ibid). It allows and shows improved reading performance in many script systems. According to Nadine Chahine (2012) –

> *"Several studies added spaces in between words in script systems that did not usually allow word spaces, and the results showed improved reading measures in these trials, which goes to show that word spaces are beneficial even when they are orthographically illegal (Rayner, 2009). It also results in a disruption of the landing positions; readers are better able to send their eyes to the optimal viewing position when the text includes word spaces (Rayner et al., 1998). This could partially explain the increase in fixation durations. In contrast, using double rather than single word spaces actually improves reading performance (Drieghe, Brysbaert, & Desmet, 2005)." (Chahine, 2012).*

4.3. Effects of the Stimulus

The reading activity involves two physical entities - reader and reading matter. In the previous section, various aspect of readers' attention, perception and cognition during reading activity have been discussed. In this section, the visual characteristics of the reading material and its effect will be discussed including its size, medium of display, and features involved in the process of reading.

4.3.1. Visual Characteristics of Text

The characteristics of reading text can influence the reading process. The reading process is affected by the input text. Reingold and Rayner (2006) concluded that low (reduced) contrast between text matter and background significantly increases the fixation time (Reingold & Rayner, 2006). They conducted a series of tests to confirm the contrast effect and stated –

> *"This faint presentation had a robust influence on the duration of fixations on the target word without substantially altering the processing of the next word."*

This finding is attention-grabbing in context of type-arrangement in our research. The arrangement of text is crucial in every case since reading involves continuous attention in a letter or word comes after one another (Marcet & Perea, 2018; Coates, Bernard, & Chung, 2019). Also, reading is not only about reading material but also the quality of the text. In relation to the quality, we have largely discussed the readability and legibility of text in Chapter Two.

4.3.2. Reading on Screen

In the beginning, several studies have shown that reading on screen is slower than reading from paper (Gould, et al., 1987; Kong, Seo, & Zhai, 2018). Muter et al. (1982) have concluded that reading on a TV screen is 28.5% slower than reading from paper (Muter, Latrémouille, Treurniet, & Beam, 1982). Display screen is direct source of light which is bound by intermittent light. It is difficult for eyes to read in such condition. On the other hand, reading from paper is under reflected light which is continuous in nature. This could be the possible reason for slower reading on screen since frequency of light could create interference with ocular system (Ackerman & Lauterman, 2012).

In recent times, many researches have been conducted. They have concluded that reading in faster on paper but can be achieved as faster as paper on screen (Myrberg & Wiberg, 2015; Mangen, Walgermo, & Brønnick, 2013; Stoop, Kreutzer, & Kircz, 2013) if following factors are met –

- The resolution of screen needs to be high enough for display.
- Vector fonts should be used to meet the quality of paper in CRT displays.

- The font must use anti-aliased[12] hinting to meet paper quality on screens (Gould, et al., 1987).

Increasing pixel density[13] is another factor by which reading on screen can be improved. Increasing pixel density results in better performance in reading in letter identification task. The study concludes that if conditions are met in LCD and CRT screens and paper, there is no main effect on letter identification (Sheedy, Subbaram, Zimmerman, & Hayes, 2005; Sheedy J. E., Tai, Subbaram, Gowrisankaran, & Hayes, 2008). The authors' claim that letter identification is similar in different mediums with these conditions for display screens. But it cannot be stated that it fully relies on those factors with confidence as there is an insufficiency in visual aspects.

Here, the objective of the study is to determine the involvement of letter feature in reading of Bengali letters at low contrast. It is intended here to reveal letter feature and track them simultaneously (Haj & Lenoble, 2018). In order to understand the reading process of a letter, the manipulation of the text matter is essential. According, the need of this research Manipulation is required with presenting text to control the reading pattern and extract the letter information through this process.

4.4. Experiment Design

The experiment was designed to meet the above conditions described in section 4.2 and 4.3. The following experiment is designed to understand the role of letter feature in letter identification. An eye-tracking study was conducted to identify the role of letter features in reading. The test was performed with Bengali script and its letters

[12] Antialiasing is a technique used in digital imaging to reduce the visual defects. Aliasing is the visual stair-stepping of edges that occurs in an image when the resolution is too low. Anti-aliasing is the smoothing of jagged edges in digital images by averaging the colours of the pixels at a boundary.
[13] Having more pixels to render characters on screen.

were exposed in low contrast. It is presumed that the readers will identify the letters by their key structural aspect and such information will be captured by the eye-tracking device.

Letters, at low contrast, are exposed from left to right with a sufficient gap that should not come on fovea during first exposure. After the first exposure of a letter, the second letter should appear in para-fovea by which readers can perceive it but could not recognise or identify it. For identification, readers have to focus on the letter and the letter should come within fovea. During identification task, we assume that readers will look into the specific features to identify the letterforms. In low contrast, it is a known phenomenon that we discussed previously.

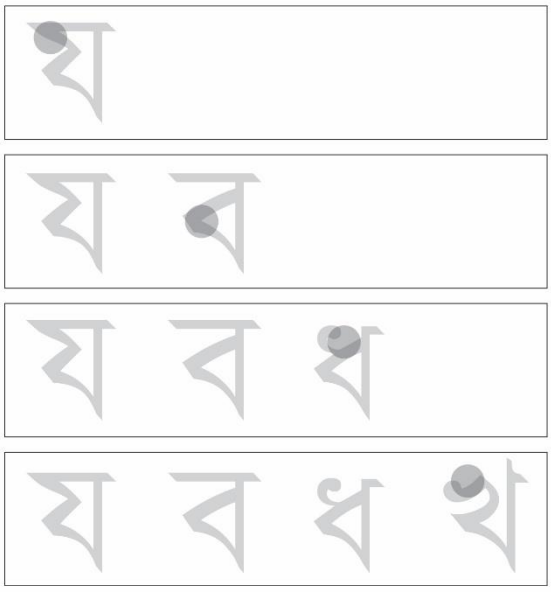


Fig. 4.3: Experiment design of eye-tracking study

4.5. Preparation of Test Materials

4.5.1. Apparatus

1. A 20-inch TFT-LCD monitor was used which had 438 mm diagonal screen with a viewing area of 340 mm horizontally and 276 mm vertically. The screen

resolution was 1280 by 1024 pixels. The screen images were refreshed at a rate of 60 Hz.

2. SMI eye tracker

4.5.2. Exposed Letters

Three or four different letters of 2.5-inch size were prepared and presented horizontally on the monitor (as shown in Fig. 4.3). Each letter was presented in the equal distance of each other. The letters were exposed on the left side to right side of the screen at the centre position of the screen at 1280x1024 (width x height) resolution of 96 PPI (pixel per inch). The colour of the text was light grey (RGB – 235, 235, 235) on white (RGB – 255, 255, 255) background. We placed letters on the screen in two ways –

1) Distinctive letters belong to a different group and

2) Similar letters belong to the same group.

The groups were created during the anatomical study in Section 3.5. The groups of letters are given in Fig. 4.4.

4.5.3. Participants

Six participants volunteered for this study. Their mean age is 26.17 Yrs. (SD= 0.752). All participants have normal or corrected vision. They can read Bengali fluently. They read documents on a computer screen for varying lengths of time in a day.

Fig. 4.4: Group of letters

4.5.4. Experimental setup

The TFT-LCD monitor was placed on a table 65 cm in height with an inclination angle of 105 degrees (Burgess-Limerick, Mon-Williams, & Coppard, 2000; Horikawa, 2001) with respect to the axis of the plane of the table. Participants were asked to get rest position on chin rest. Head-mounted eye-tracker was adjusted accordingly (Fig. 4.5). The office ambient light was maintained. The eye-tracker was calibrated by using five points (four corners and one centre) on the display screen.

4.6. Methods

Exposure text was performed that allowed readers to identify letters. The method was used to expose letter features refereeing DRC model of reading (Coltheart, Rastle, Perry, & Ziegler, 2001). This is a combination of exposure and naming test. The threshold was exposure time of 5 seconds. After every 5 seconds, a new letter appears next to first letter at a fixed distance of 250 pixels (last letter's right-side bearing to next letter's left-side bearding) (Lund, 1999).

The eye tracking device was mounted on the head during the experiment. Trials were taken from the six participants by fixing the position of the paticipants' head by a jaw holder. The eye-movement was recorded by SMI eye-tracker. To reduce their unwanted eye movement, a black point was placed in the centre of the screen before beginning of exposure of letters. The participants were asked to read aloud each letter as quickly and as accurately in that instance of letter appears on the screen. Their eye movement was recorded and heat map of data was prepared later (Fig. 4.7).

Fig. 4.5: Experimental setup

4.7. Results

The video data was collected from the eye-tracking device for analysis. Scan-path (Fig. 4.6) and heat-signature (Fig. 4.7) were determined by using SMI BeGaze software. The fixations on letterforms and heat-map are given in Appendix IV. The captured data was analysed and processed with SMI BeGaze software to determine the eye-tracking information inclusing fixations and saccades. Later, reliability

statistics was conducted considering fixation time and saccades. Further, one-sample t-test and coleration statistics were conducted to validate the results.

The reliability test was conducted and Cronbach alpha values of each paricipants is given in Table 4.1. The data shows that the association of fixation and saccades of is significantly correlated with alpha values more than 0.9. The values signifies that the process of reading of exposed letters was heardly with any interruption.

Table 4.1: Cronbach alpha values of each participants

Paticipant	Cronbach alpha's value
1	0.973
2	0.995
3	0.963
4	0.979
5	0.939
6	0.991

One sample t-test was performed on fixation time with stimulus placement. There is no significant within subject variation observed in fixation time due to stimulus placements ($p < 0.001$). Similarly, one sample t-test was performed on saccades and stimulus placement. There is no significant variations found in saccades and stimulus placement ($p<0.001$). The eyes follow in a similar pattern in most of the cases to identify the letters with specific fixation locations.

The correlation statiscics were performed using Pearson's correlation on fixations time and saccades. The value of all 'r' are given in Table 4.2. The notation 'Fx' identifies the fixations and 'Fx1' is the fixations of first participant and similarly the other fixations 'Fx2', 'Fx3' and so on. Similarly, 'Sa' signifies the saccades and 'Sa1' is the saccades of first participant and similarly 'Sa2' to 'Sa6'. The coreelation within group i.e. fixations and saccades of a participat is determined by the value of

Pearson's 'r'. The results shows that a strong coreelation values of 'r' (between fixations and saccades) which are above 0.9 for all cases except participants five with value below 0.9 but above 0.8.

Table 4.2: Pearson's r correlation values of fixations and saccades

Fixation – Saccades Items	Pearson's r
Participants 1 (Fx1-Sa1)	0.947
Participants 2 (Fx2-Sa2)	0.991
Participants 3 (Fx3-Sa3)	0.930
Participants 4 (Fx4-Sa4)	0.959
Participants 5 (Fx5-Sa5)	0.885
Participants 6 (Fx6-Sa6)	0.983

The inter-item correlation of fixations and saccades were performed to verify the eye movement in a particular pattern. The correlation data of fixations and saccades of participants are given in Table 4.3 and Table 4.4 below. The data shows that a strong correlation among fixation values of paricipants. Similarly, the correlation values of saccades are in higher side for most of the cases.

Table 4.3: Co-relation data of fixations

	Fx1	Fx2	Fx3	Fx4	Fx5	Fx6
Fx1	-	1.000	1.000	1.000	1.000	1.000
Fx2	1.000	-	0.999	1.000	1.000	1.000
Fx3	1.000	0.999	-	1.000	1.000	1.000
Fx4	1.000	1.000	1.000	-	1.000	1.000
Fx5	1.000	1.000	1.000	1.000	-	1.000
Fx6	1.000	1.000	1.000	1.000	1.000	-

Table 4.4: Co-relation data of saccades

	Sa1	Sa2	Sa3	Sa4	Sa5	Sa6
Sa1	-	.976	.985	.993	.988	.996
Sa2	.976	-	.965	.967	.963	.973

Sa3	.985	.965	-	.994	.994	.986
Sa4	.993	.967	.994	-	.993	.995
Sa5	.988	.963	.994	.993	-	.986
Sa6	.996	.973	.986	.995	.986	-

4.8. Discussion

The reliability of the data has established using Cronbach alpha value to determine the consistant gaze pattern of all participnts. Here, the experiment was setup to understand the fixation location of the eye to determine the hot zone of the letters. To validate the fixation locations one sample t-test with within participants and between paeticipants correlation statistics have been performed. The result of one sample t-test shows that there is no significant variations in fixation tine and saccades with the stumulus placement. The eyes follow in a certain pattern in most of the cases without unexpected fixations. Most of the fixation locations remain in same position with no difference in mean fixation count.

Later, Pearson correlation has been performed to determine the consistency fixations and saccades of a participant to validate the fixation location in order to determine the hot zones of letters. This validity has been further extended among inter-item to confirm the consistency in eye gaze among all paricipnts by inter-iten correlation. The data shows a strong correlation among participants with there fixation time and saccades. The fixation locations are important to determine the hot zone of the letters or crucial letter-parts that engage in letter identification alltogether. The information of fixation locations are further processed to determine the important letter-parts that are essential for identification and additionally need careful attention during design of the letterform.

The eye-tracking data has been analysed qualitatively considering the fixation location on letterforms. The heat signatures are considered to determine the fixation on the letter features. It was observed that fixations on a particular letter vary from

three (3) to nine (9) fixations. There was no overlooked letter during the study. The correct pronunciations of all participants were more than 97% correct. Little confusions were identified in group of letters (ঘ, খ, য, থ), (ঋ, ধ, ঝ, ক) and (য, ব, ধ, খ). The Fig. 4.8 shows the mean fixation zone of all participants against the letters. The data suggested that the fixations happen to critical zones through which letter can be differentiated from one another.

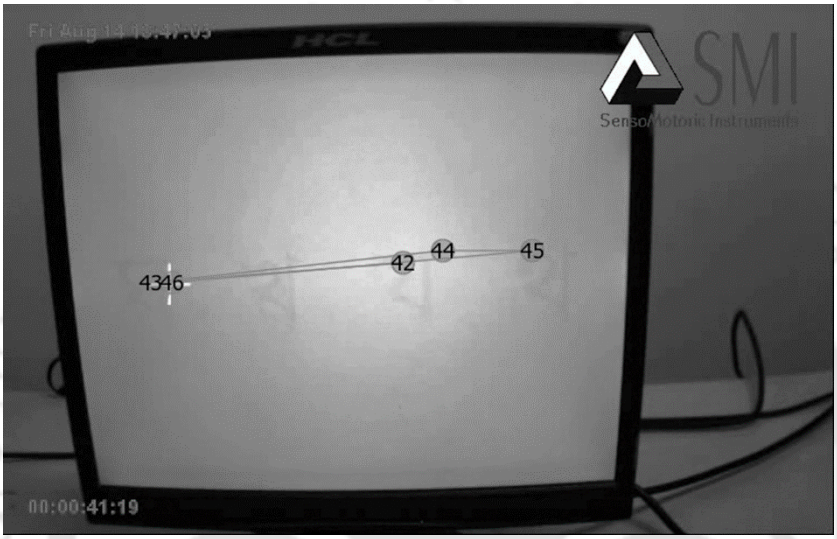


Fig. 4.6: Fixation on screen

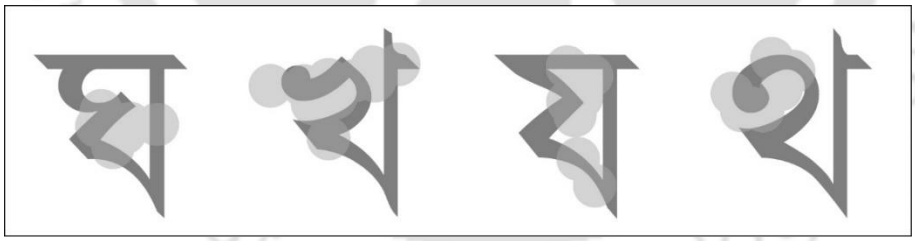


Fig. 4.7: Eye tracking data – scan path

In Fig. 4.7, the heat signature on letterforms is distributed to very specific parts of the letters. These letter-parts are noted down for the important feature identification that contributes to letter recognition. Based on the heat map, the major fixations on letter-parts are listed in Table 4.5. The analysis of letters suggests that the letters were identified by specific anatomical features in each case. The pattern of

identification in each letter is similar for most of the participants. The data enables us to capture the specific letter-parts that play a significant role in the identification process. It leads us to identify the letter features that enable letter recognition process. The important parts of letter further need to be identified that play a critical role in identification task. The confusion in groups (ঘ, খ, য, থ), (ঋ, ধ, ঝ, ক) and (য, ব, ধ, খ) also suggests that the specific letter features like 'shoot of ঘ' or 'Bud & Arm of খ' needs special attention to correctly identify.

Table 4.5: Identified letter features (considering fixations)

Letters - ত, আ, অ	**Letters - ঝ, অ, খ**
• Counter of Matra and Bowl - ত, আ, অ • Bowl - ত, আ, অ • Initial/ Finial - ত, আ, অ • 'T' Junction - আ, অ • Wedge - আ, অ	• VStem and Wedge - ঝ, অ • Initial - খ • Finial - অ • Nose - খ
Letters - য়, ফ, ষ, য	**Letters - ঘ, খ, য, থ**
• Wedge - ফ, ষ, য • VStem and Arm - ফ • Crossbar - ষ • Close Counter - ফ, য • '>' Junction - ফ, য • Initial - ষ • '<' / Nose - য়, ষ, য	• Nose - ঘ, খ • Initial - খ, য, থ • Counter of VStem & Nose - খ • Wedge - য • Short Matra - খ
Letters - ঢ়, ঢ, ট	**Letters - চ, ট, ঠ**
• Terminal/ Finial - ঢ়, ঢ, ট • Dot - ঢ় • Counter - ঢ • Matra & Tail Counter - ট • Arm - ঢ়, ঢ	• Junction of HStem & Crossbar - চ • Matra & Tail Junction - ট, ঠ • Upper Tail - ট • Close Counter - চ • 5-point Cross/ Junction - ঠ • Terminal/Finial – ট
Letters - ঙ, ঊ, ড়, উ	**Letters - জ, ঊ, ঈ, ভ**
• Nose - ঙ • Loop - ঙ • Matra & Upper Tail Junction - ঊ • Finial - ঊ, উ • Dot - ড়	• Nose - জ, ঊ • Shoot & Leg Junction - জ • Finial - ঊ, ঈ, ভ • Initial - ঈ, ভ • Bowl - জ • Diagonal - ঈ • Upper Tail - ঊ, ঈ • Leg – জ

Letters - ঋ, ধ, ঝ, ক	Letters - য, ব, ধ, খ
• Wedge - ঋ, ঝ • VStem - ঋ • Delta & Shoot Junction - ঋ • Arm - ধ • Nose - ঝ • Delta & Matra Junction - ক • Close Counter - ঝ	• VStem - য • Delta & Matra Junction - ব • Arm - ধ • Initial - খ • '>' Junction - য • '<' / Nose - ব • Short Matra – খ

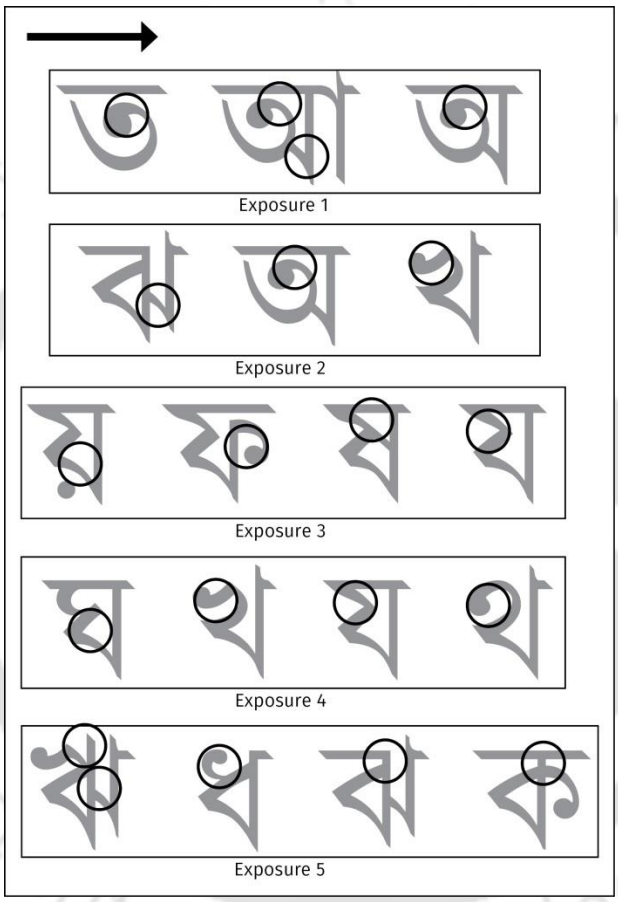


Fig. 4.8: Fixation data

In Fig. 4.8, the fixations are explained in details. In exposure 1 (first row), the eye looks for the wedge to differentiate each letter. The case with 3rd letter may be the 'Aakar' sign of 2nd letter that makes the distinction from 3rd letter in peripheral vision. In Exposure 2 (second row), again the 'Wedge' of the letter 'Jha' is typically identified most of the time. The next letter 'A' is same as previous the negative space

among Matra, Bowl and VStem show effective space in the heat map. The last case letter 'Khya' also shows the heat map on the distinctive feature. Exposure 3 and 4 show the same kind of trend. The distinctive features zones were identified by the participants. In Exposure 4, the data of 2nd and 3rd letters show similar results from Exposure 2 (last letter) and 3 (last letter). Exposure 5 is the collection of distinctive letters except the 3rd letter 'Jha' (previously in Exposure 2, 2nd letter). Here, the 'Wedge' was not recognised but upper junction (junction of Matra and Delta) got noticed. The similarity effect may have been the reason for that. Similar letters may get identified by the distinctive features they possess. Hence the 3rd letter (of Exposure 5) has a common feature with 1st letter (of Exposure 5) the distinctive feature remains the upper part of the letter where one is straight, and another is curvilinear. Considering all letterforms and the fixation on them, there is a tendency to identify the common features as well as the distinctive features of letterforms. The identification process creates a balance during recognition by recognising both features to determine the uniqueness of a letter. The common and distinctive features that are identified during the eye-tracking study are given in below in Table 4.6. The analyses within and among groups of letters are given in Appendix V.

Table 4.6: Letter features, deducted from eye-tracking study

Common Features (detected in more than one letter)	**Distinct Features (mostly unique features)**
• Wedge - আ, অ, ঝ, অ, ঋ, ফ, ষ, য • Initial/ Finial - ত, আ, অ, খ, য, থ, ঢ়, ঢ, ট, ঈ, ভ, ঊ, উ • '<' / Nose - ব, য়, ষ, য, ঘ, জ, ঊ, ঙ • Short Matra - খ • '>' Junction - ফ, য • Matra & Tail Junction - ট, ঠ	• Bowl - ত, অ • Delta & Shoot Junction - ঋ • Delta & Matra Junction - ক • VStem and Arm - ফ, ক • Crossbar - ষ • Arm - ধ • Dot - ঢ়, ড় • 5-point Cross/ Junction - ঠ • Loop - ঙ • Shoot & Leg Junction - জ • Arm - ধ

4.9. Conclusion

The experiment was designed to extract information about the vital letter-parts that involve in letter identification process. The experiment was done through repeated measure without controlling individual letterforms. The exposed letters were kept apart from one another with a threshold distance. The contrast and enviromrntal light were the extraneous variable of the experiment that were controled during the experiments.

The result indicates that there is an involvement of specific letter-parts in letter identification process. Specific letter-parts distinguish letters during letter identification process with common letter-parts. Both together or by combination of common and specific letter-parts make the letter unique in the identification process. Such as 'Bowl-common feature' and 'Wedge-specific feature' make letter 'अ' identifiable. These letter-parts are further need attention during design of letterform. These letter-parts make letters legible enough in letter identification process. This particular experiemtal setup is desiged to determine the important letter-parts. The specific anatomical features are not identified during this study due to limitation of the instrument and experimental setup. The critical parts further need to be evaluated considering 'recognition task' to confirm their role in letter legibility. The few mispronunciations during the study indicate that similar structural letters need more attention during reading. They are differentiated by letter-parts that are not very distinctive by design. The differences in anatomical structure are not overlapped and need precision to differentiate. The study has few limitations that are controlled by the design of the experiment. One of the main effects is the similar structures that appear in fovea one after another. It influences or accelerates the recognition of next letter. To control the similar letter effect, letters were exposed more than one time to nullify the effect of the experiment. In the next part (B) of the section, the important letter-parts will be identified as an extension of the outcome of part A, as well as the second objective of this thesis.

B. Anatomical Features of Bengali

Introduction

Anatomical features refer to letter features with specific characteristics. Any visual letter features indirectly refer to the anatomical features that have a collective effect on letter identification. Here, in this section, the important anatomical features will be determined that are crucial for letter recognition. The goal of the study is to propose a guideline for the designers considering important anatomical features.

In the previous chapter, it was concluded that letter-parts are crucial in Bengali letter identification process. The following study will be undertaken to determine the specific anatomical features of Bengali letterforms. The study deepens the understanding of letter-parts that play a crucial role in letter identification and recognition process. The objectives of the following experiment are –

1. Determine the important anatomical-feature and
2. Understanding of letter processing in Bengali.

Here, we are focusing on the letter recognition behaviour which will reveal the important anatomical feature of Bengali script. The composition of every script is unique. The complexity of construction also varies from script to script. A study by Changizi and Shimojo (2005) is shown that the letter complexity of each script is different considering the average number of strokes per letter (Table 4.7). They conclude that the average character length of Bengali is 3.91 which is almost double than Latin with average character length of 2.08. Also, there are 29 different kinds of

strokes, according to them, which is more than double of Latin (Changizi & Shimojo, 2005). If the number of strokes varies from script to script, the complex nature of letterforms of each script is supposed to vary. Therefore, finding the important letter feature of a script cannot be considered with the same condition and consideration. They cannot be compared in similar condition or variables. Additionally, complexity is apparently diverse across scripts, and important features may change accordingly. These aspects altogether indicate the need to determine the anatomical features of Bengali individually as opposed to Latin.

Table 4.7: Table of average character length (Changizi & Shimojo, 2005)

Script	Average character length	Number of stroke types
Bengali abugida	3.91	29
Devanagari abugida	3.27	30
Gurmukhi abugida	3.2	31
Oriya abugida	2.89	34
Kannada abugida	2.79	34
Tamil abugida	2.74	29
Latin, ancient alphabet	2.67	10
Latin, modern all-caps alphabet	2.5	17
Gujarati abugida	2.21	32
Latin, modern alphabet	2.08	14

Fiset et al. (2008) performed an experiment with the 100 blocks of 260 letters per participants with the total six participants. Each letter is masked on Gaussian holes (also known as 'bubbles') using the Laplacian pyramid. The short exposure test was designed to collect the data from users with a time frame of 494 ms, within that an exposure time of 200 ms for 'bubblized' letters are included. The study concludes with a set of features that are important for letter identification such as Line termination or Terminal, Horizontals, Slants Tilted Right, and Intersections.

Another study by Hannagan and Grainger in 2013 shows the similar result as predicted by Fiset et al. (2008). A computational model, known as Linear Amplifying Model or LAM, is used to categorise the features that are supported by the human detected features in the study of Fiset et al. (2008). Both studies are the example of an empirical study that reveals the important letter-features considering the recognition aspect. Features are nothing but the letter stroke that constructs a letterform. All letters are the combination of features that may be common to many letterforms, also known as global features, which is used to detect of the letters. There are few features that are unique to the letter or known as local features that are used to identify the letters. But, all these studies and identified features are based on Latin letterforms only. The understanding of features is needed to verify their role in letter recognition. An extensive study is required to obtain the visual features and their role in letter identification in the context of non-Latin scripts.

When a letter appears in front of eye, apparently we read it instantly. In reality, there is a time course of letter identification from the first glimpse to identify it. Many studies have been conducted with Functional Magnetic Resonance Imaging (fMRI) to understand the course of letter identification. It is observed that the specific neural cluster actives blood flow just after observing a letter (Baars & Gage, 2013). It happens within a short span of time 300 milliseconds (ms). Many types of research uncover these initial 300 ms and the nature of processing (Keage, Coussens, Kohler, Thiessen, & Churches, 2014). The low-level letter processing takes place from beginning to 100 milliseconds after stimulus onset, i.e. participates realised something has appeared in the visual field. Between 100 to 200 milliseconds, known category is commenced. Within 120 to 180 milliseconds higher level processing like feature detection and essential to letter recognition commences (Keage, Coussens, Kohler, Thiessen, & Churches, 2014). At around 200ms abstract case-independent letter identity representations are activated that transcend specific visual representation and after 300ms participants show behaviour responses indicating the

object is recognized and its meaning processed sufficiently to consciously respond to a task related activity (Rey, Dufau, Massol, & Grainger, 2009; Keage, Coussens, Kohler, Thiessen, & Churches, 2014) (Fig. 4.9).

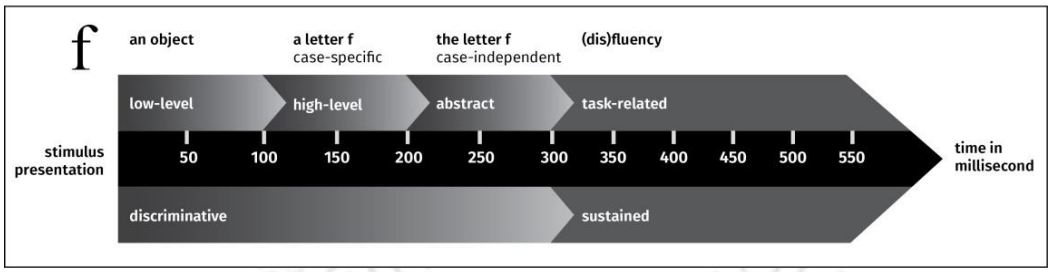


Fig. 4.9: Time course of letter recognition (Thiessen, Kohler, Churches, Coussens, & Keage, 2015)

To test the idea of the importance of letter feature, a 'short exposure test' combining with 'bubble test' was conducted. Bubbles are the open window of information putting a mask on letters. The bubbles or open windows will reveal the letter information that has been generated randomly. These masked letters (with windows) are exposed in front of participants for the letter identification task.

4.10. Experiment Design

The experiment is designed to address the second objective of the research – identification of the important anatomical features of Bengali. The experiment is designed to understand the Bengali letter processing with crucial anatomical features of letterforms. It will help to come up with a design guideline for Bengali letter design considering legibility aspect that is controlled by the letter processing.

To identify anatomical features, the Bengali letters were masked with bubbles by which few anatomical features were revealed by each letter. The masking was randomly created to compensate all possible anatomical features of a letter. These masked letters are then exposed with a time frame of 200 ms which is the processing time of specific letter feature. The 200 ms time frame reveals the letter feature that is

essential for recognition (Keage, Coussens, Kohler, Thiessen, & Churches, 2014). The experiment was designed using MATLAB, HTML and PHP/MySQL.

4.11. Preparation of the Test Material

4.11.1. Instruments

A 22-inch or 566 mm diagonal screen TFT-LED monitor was used with a viewing area of 475 mm horizontally and 276 mm vertically and the display resolution was 1920 by 1080 pixels. The monitor was connected to a workstation with Intel i5 (4570, 3.2 GHz) processor and 8 GB of Ram (1600 FSB).

4.11.2. Stimuli

All letters of Bengali were created in Adobe Illustrator as in Fig. 4.10. The dimension of images were 245x245 (height x length) pixels and the resolution was 72 dpi. The RGB value of the letters was R: 240, G: 240, B: 240 and the background were R: 120, G: 120, B: 120 as in Fig. 4.10. Then, they were processed in MATLAB for the masking.

Fig. 4.10: Letters of Bengali

The steps involved in creating an experimental stimulus are as follows: A letter stimulus was decomposed in five spatial frequency bands which are 128–64, 64–32, 32–16, 16–8, and 8–4 cycles/image (as in Fig. 4.11, first row). The constant bandwidth served as background that was created using the Laplacian pyramid

(Gosselin & Schyns, 2001; Fiest, et al., 2009). The letter information on the five scales was then sampled using an opaque mask with Gaussian holes placed randomly. These holes are called "bubbles" with blur edges to avoid any intruding spatial frequency artefacts. The size of the bubbles was adjusted according to the frequency band from bubble radius 7 pixels to 90 pixels at a constant distance of 10 pixels based on spatial information (Fig. 4.11, second row) available on test images. Because the size of the bubbles increased based on the spatial frequency band of the decomposed image resolution. The number of bubbles differed across scales to keep the size of the sampled area constant across frequency bands. Finally, the information revealed by the bubbles was fused across the five frequency bands together to produce an experimental stimulus (Fig. 4.11, third row). The flowchart is given in Fig. 4.12. The MATLAB code is given in Appendix VI.

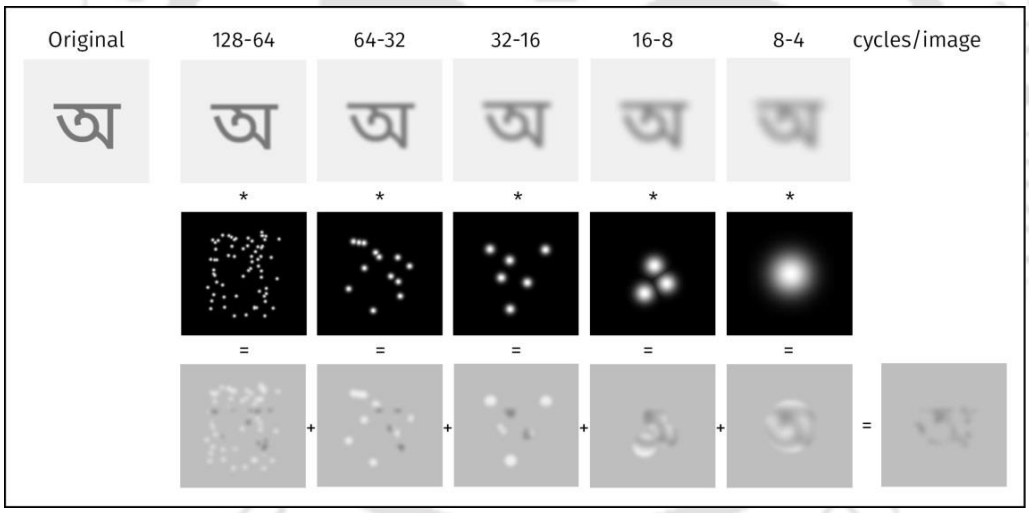


Fig. 4.11: Illustration of the stimulus generation process.

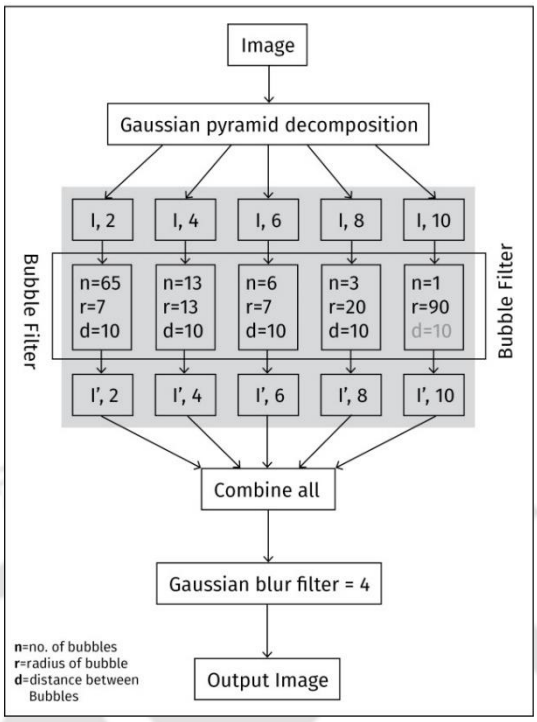


Fig. 4.12: Flowchart - preparation of test materials

Numbers of 47 letters were considered for this test. The stimulus preparation (as explained in Fig. 4.11 & Fig. 4.12) was carried out 100 to 120 times for each letter. Among them, 30 substantial bubbled images were selected based on their window that reveals the features of all different parts as explained in Fig. 4.13. A letter is expressed as 30 unitary blocks based on the window that considered in the study. Therefore, total 1410 (47 letters x 30 masked samples) sample of masked letters has been created for the evaluation. A few samples are shown in Fig. 4.14 and all sample masked images are provided in Appendix VII.

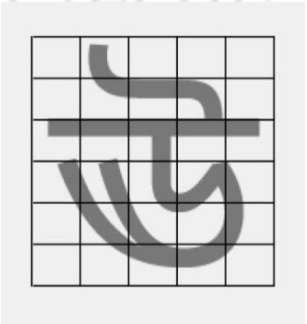


Fig. 4.13: Grid distribution of Bengali letters

Fig. 4.14: Sample of masked images

4.11.3. Preparation for short exposure

The samples were exposed to participants for 200ms (Keage, Coussens, Kohler, Thiessen, & Churches, 2014). The display screen windows were created using HTML and PHP/MySQL. The screen was visually divided into two areas. One side was used for sample exposure, and the other side was used as a fixed keyboard of letters for responses as in Fig. 4.15. All letters were in the sequence of their phoneme order in virtual keyboard. The letters of the keyboard only activate when the identification task has finished. After providing an input, the keyboard went to the inactive mode again and next letter identification task was initiated. For each response, whether data is right (1) or wrong (0) is collected in one table. In another table, the corresponding identified letter responses are stored against the confusion letter value. The backend was designed using PHP/MySQL and codes are provided in Appendix VIII.

4.11.4. Participants

Thirty-three participants from the postgraduate studies of IIT Guwahati volunteered for this study. Among them 26 were male, and 17 were female. Their mean age was 28.273 Yrs. (SD= 1.56, Min age = 26, Max age = 32). All participants have normal or corrected vision. They read documents on a computer screen for a varying period of time. The native language of all participants is either Assamese or Bengali and read the script fluently.

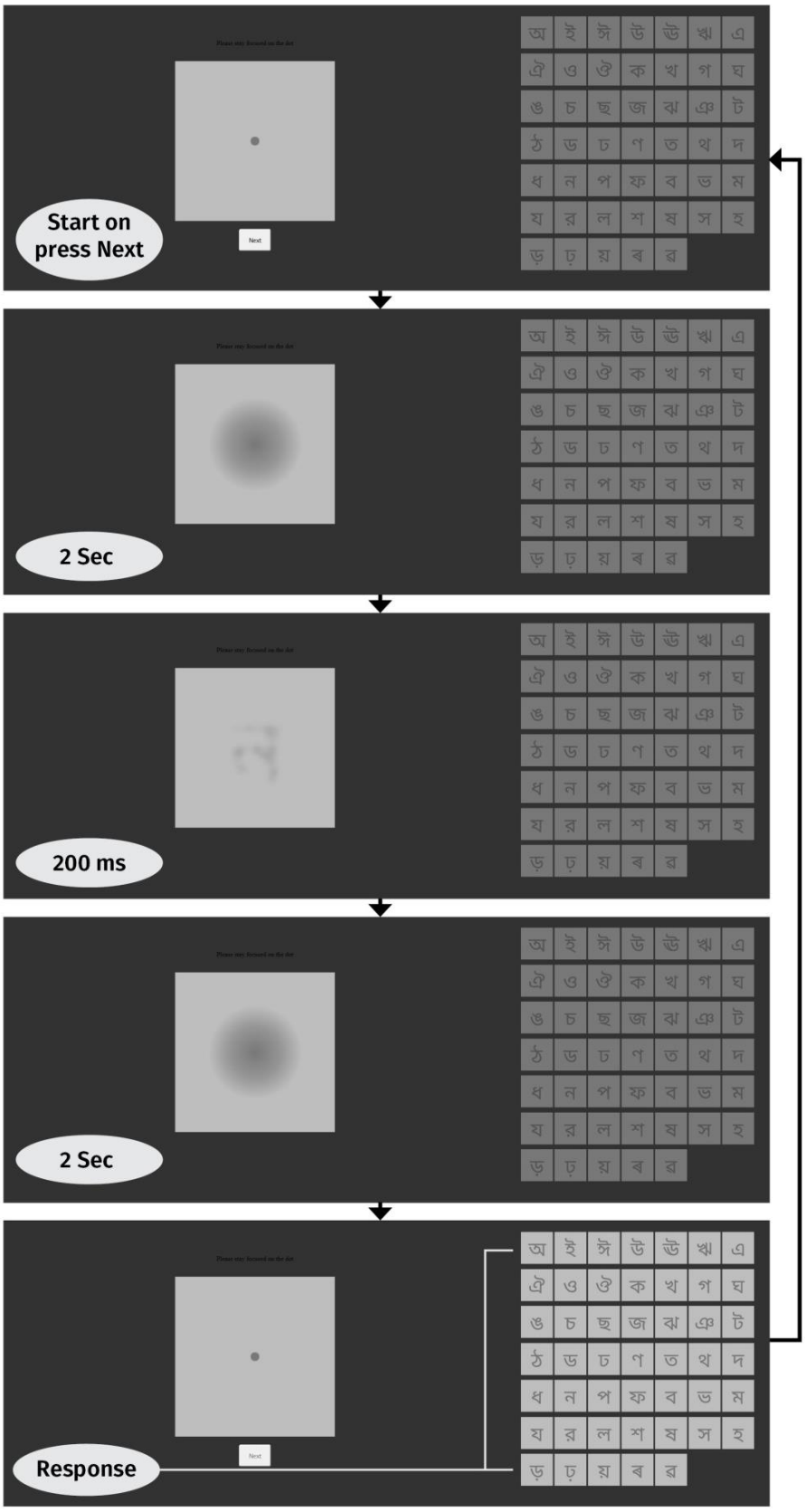


Fig. 4.15: Windows of response loop

4.12. Procedure

Each participant completed 30 variations of 47 letters, total 1410 samples. Participants were requested to sit at a comfortable distance from the computer as they normally practised during regular computer work. An average distance of 650 ± 50 mm from the display screen was measured by the participants during the experiment. The office ambient light was maintained. The monitor angle was 100 degrees (± 5 degrees). Each trial began with the dot displayed at the centre of the frame. Whenever the participants were ready, they were instructed to press 'Next' button to start the task. From here the task started and stayed for 4200ms. First 2000ms for the blurred dot, 200ms for the masked letter and then last 2000ms for the blurred dot to remove the after exposure or residue effect from the retina (Beier, 2009). After the exposure, the keyboard was activated and awaiting for participant's response. Here, they were forced to respond based on the understanding of exposed letter. After the response, the last frame of Fig. 4.15 had a link to the second frame for further responses. The experiment was about two hours long. Participants were advised to take at least three breaks of ten minutes during the experiments (Fiset, et al., 2008).

Before data collection, participants were asked to fill in their personal details. With their concern, the short exposure test was commenced. The data has been collected in two different databases for individual letters. The first database consisted of the information on right or wrong, stored as 1 or 0 (in binary form) against the successful identification of letters. The other database was designed to store the corresponding identified letter if the response is wrong. All tables are given in Appendix IX.

4.13. Result

The data was analysed using Chi-square test. The test was done to validate the participant responses of correct identification, comparing the errors. The test was

performed within individual letters since wrong identifications within a letter are crucial to identify the important letter-parts and design of those letter-parts. The results of Chi-square test of individual participants were performed and the below Table 4.8 is the data set and overall p-value mention at end. Similarly, the test were performed with all thirty three participants and the mean of p was determined. The p-value of overall Chi-square thet is 0.00053 ($p<0.05$); means there is a significant difference in overall wrong identification which can provide enough evidence of letter difference in design of letterforms.

Table 4.8: Chi-square table of short-exposure

Letters	Bengali Letter	Observed Frequency	p Value
L1	অ	25	p<0.001
L2	ই	25	p<0.001
L3	ঈ	24	p<0.001
L4	উ	32	p<0.001
L5	ঊ	32	p<0.001
L6	ঋ	33	p<=0.001
L7	এ	33	p<=0.001
L8	ঐ	14	p<0.001
L9	ও	33	p<=0.001
L10	ঔ	18	p<0.001
L11	ক	6	p<0.001
L12	খ	33	p<=0.001
L13	গ	28	p<0.001
L14	ঘ	16	p<0.001
L15	ঙ	30	p<0.001
L16	চ	33	p<=0.001
L17	ছ	33	p<=0.001
L18	জ	28	p<0.001
L19	ঝ	32	p<0.001
L20	ঞ	28	p<0.001
L21	ট	31	p<0.001
L22	ঠ	20	p<0.001
L23	ড	33	p<=0.001
L24	ঢ	33	p<=0.001
L25	ণ	32	p<0.001
L26	ত	32	p<0.001

L27	থ	32	p<0.001
L28	দ	30	p<0.001
L29	ধ	31	p<0.001
L30	ন	33	p<=0.001
L31	প	31	p<0.001
L32	ফ	20	p<0.001
L33	ব	31	p<0.001
L34	ভ	33	p<=0.001
L35	ম	33	p<=0.001
L36	য	33	p<=0.001
L37	র	33	p<=0.001
L38	ল	18	p<0.001
L39	শ	32	p<0.001
L40	ষ	26	p<0.001
L41	স	18	p<0.001
L42	হ	31	p<0.001
L43	ড়	33	p<=0.001
L44	ঢ়	33	p<=0.001
L45	য়	33	p<=0.001
L46	ৰ	32	p<0.001
L47	ৱ	32	p<0.001
The value of p = 0.0005			p<0.05

4.14. Data Analysis

The Chi-square test confirms the involvement of letter-parts in the letter identification process. The result shows that participants feedbacks are significant ($p<0.05$) to commence further with the post-processing of the participants' inputs. The post-processing is necessary to determine the important letter features that are essential in identification process as well as for the design of letterforms.

To achieve the objectives, the collected data were analysed by two different methods. The first objective was set to determine the important letter-parts responsible for letter identification. The other objective was to understand the letter

processing in relation to significant letter-feature for the recognition purpose. The methods that were followed were:

- Identification and ranking of the letter features
- Calculation of wrong information
- The most confusion letters.

4.14.1. Identification and Ranking of Letter Features

All masked letters were exposed randomly to thirty (30) different variations of each letter. From the first table, all correct identified variations and incorrectly identified variations of responses were grouped together according to each letter. The right identified variations were added together in MATLAB and similarly, the incorrect variations were added separately. All added correct variations were denoted as 'Correct Plane or (cp)', and all added incorrect variations were denoted as 'Incorrect Plane or (ip)' (see Fig. 4.16). Then, Incorrect Planes were subtracted from the Correct Planes to get the leftover that was accountable features for correct identification of letters as in Fig. 4.17. This subtracted plane was identified as 'discrete plane or (dp)'. The 'dp' was further subtracted from the original letter image to create the impression of accountable features on original letter as in Fig. 4.17 (last column) and denoted as (O-dp) plane. The MATLAB Code for creating discrete (O-dp) planes is provided in Appendix X. The images of discrete planes have been processed for all thirty-three participants as in Fig. 4.18.

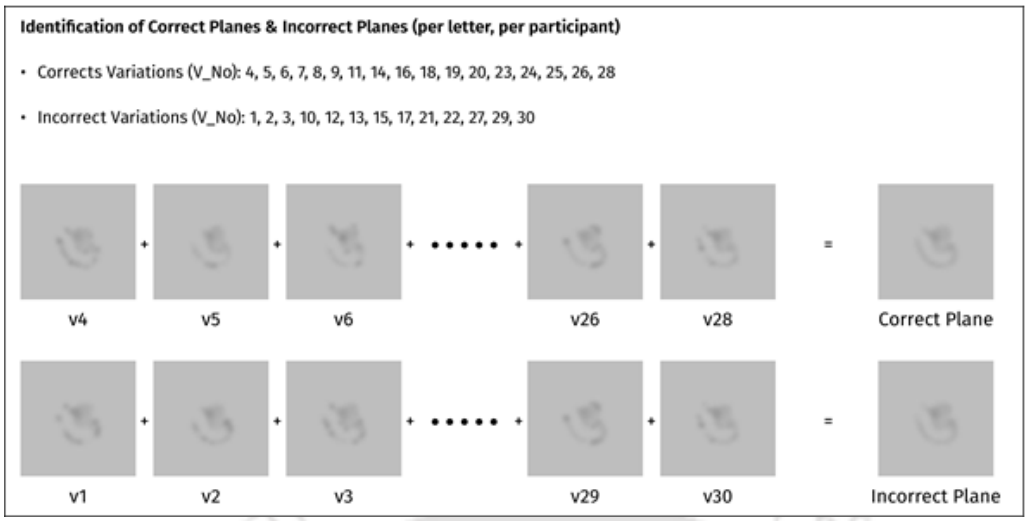


Fig. 4.16: Calculation with Correct and Incorrect Planes

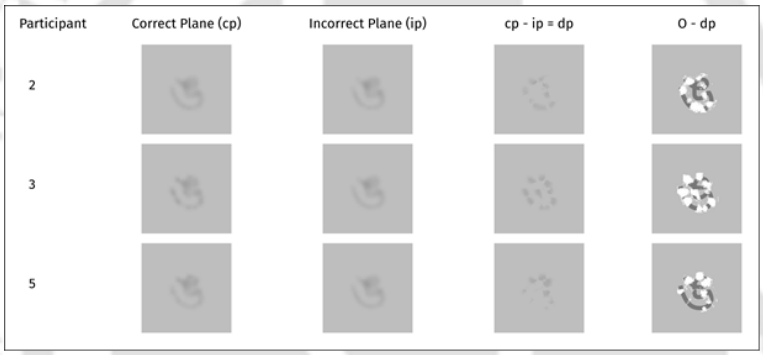


Fig. 4.17: Determining the visual features for each letter

Now, common anatomical features were identified by comparing all discrete (O-dp) planes of a single letter. The frequency of identifying anatomical features of all discrete planes was noted down as in Fig. 4.18. The process has been repeated with all the letters. Finally, Table 4.9 was prepared with all identified anatomical features of all letters.

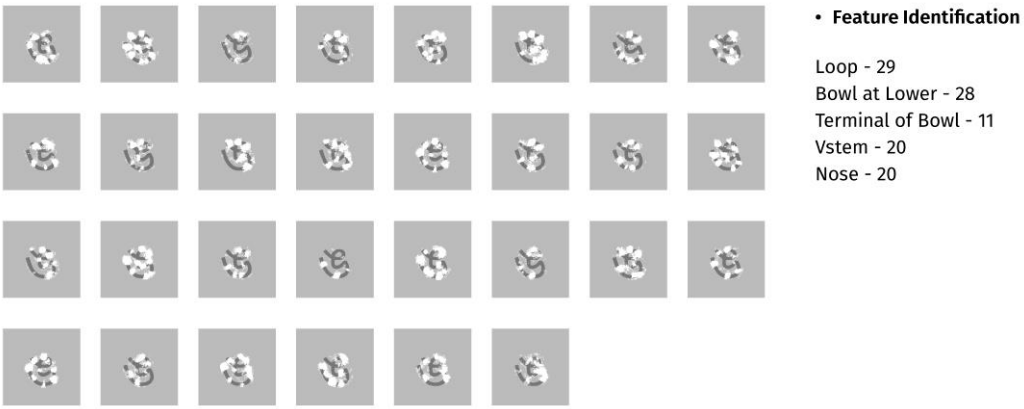


Fig. 4.18: Feature identification from discrete planes

Table 4.4: Identified features

Letters	Right Identification/ Observed Frequency	Matra	Short Matra	V Stem	Short V Stem	Terminal of Bowl	Knot	Double Knot (Left)	Double Knot (Right)	Dot / Bindu	Bud/ Terminal (Initial)	Bud/ Terminal (Finial)	Terminal at Leg	Terminal at VStem	Wedge	Diagonal of Wedge	Diagonal (Others)	Bowl	Lobe	Arm	Leg	Curl	Shoot	Terminal at Arm	Terminal at Curl	Nose	"<" Feature	">" Feature	Delta	Tail (Upper)	Tail (Lower)
অ	25	19		23		23					13				21			17													
ঈ	25										19		24						23		23									25	
ঈ	24	24									14		24				18													23	
ঊ	32	30			16	14												30								18				30	
ঊ	32	23			18	28												27								28				31	
ঋ	33			32							32				21	21											12				
এ	33			27							17									19											32
ঐ	14			9							9									14										14	12
ও	33					24					31								*												
ঔ	18					18					15								*								17				
ক	6	6		5											5					3				6			5				
খ	33			25							16				15	23				25		28									
গ	28			21										10					27				27								
ঘ	16	15		13											12	15	8		14												
ঙ	30					11												28													
চ	33	28		19																20											
ছ	33	31			8								20							32	23	31									
জ	28	26			20	24												23			27		21								
ঝ	32	26		25											21												29		31		
ঞ	28			18							15								*	13											28
ট	31	15		30								31								16										30	
ঠ	20	14																		14		18								20	
ড	33	28			18	13												30								24					
ঢ	33	28		28								20								28											
ণ	32			31							21			32						31											
ত	32	30				23					20							31													
থ	32			16							31				19	16				24											
দ	30	25			25								24				29				29										
ধ	31		20	29								26			23	17				20							24				
ন	33	29		24							20			16						26											
প	31			29													30			22			18								
ফ	20	19		16								9			8					20								20			
ব	31	29		22											28	29											31				
ভ	33	33				23					25							30		27											
ম	33	21		16			30													33			26								
য	33	28		26											26	29												27			
র	33	10		13						33					31	15											6				
ল	18	18		15							13									18			14								
শ	32		17	24				26	24											16		17									
ষ	26	25		14											18	22												25			
স	18	17		13																		17	17		15						
হ	31	29									12		14						31		23										
ড়	33	32	15			20				33								31								26					
ঢ়	33	3		1						33		33								30											
য়	33	13		1						33					33	20												3			
ৰ	32	24		21											12												25				
ৱ	32	24		25											19												21				
Total Features Detected		722	52	611	105	221	30	26	24	132	323	119	106	58	312	207	85	247	95	451	125	111	123	6	15	96	170	75	31	173	72
Total OcF																															
Feature Frequency	282	32	3	31	6	11	1	1	1	4	17	5	5	3	16	10	4	9	4	21	5	5	6	1	1	4	9	4	1	7	3

Table 4.4: Identified features

Terminal at Upper Tail	Terminal of Lower Tail	Junction of V Stem & Nose	Lobe (Upper)	Lobe (Lower)	Extra Tail	Extra V Stem	Extra Wedge	Loop	Crossbar	Joinery of Tail & Bowl	Joinery of Delta & Shoot	Joinery of Arm & Shoot	Joinery of Delta & 2nd Wedge	Joinery of Arm & Vstem	Joimery of Delta & Arm	Joinery of Arm & Curl	Junction of Shoot & V Stem	Joinery of V Stem & H Stem	Junction of H Stem & Arm	Joinery of Curl & Leg	Joinery of Arm & Diagonal of Wedge	Joinery of ">" & Diagonal of Wedge	Joinery of Delta & Matra	Junction of "<"	Joinery of Lobe & Leg	Joinery of Matra & V Stem	Junction of Crossbar & V Stem	Floating Stroke	No. of Features
																												6
																												5
																												5
		22																										7
		28			29					26																		9
											11	29	21															8
	23													27														6
	12																											6
			27	28																								4
			2	18																								5
															3													7
																18												7
																	8											5
																												6
		20						29																				4
																		27	24									5
																				30								7
																												6
						31	24																					7
	16		27	26																								7
27																												6
20																												5
																												5
																												4
														24														5
														24														5
																					16							6
																												5
																												7
														21														6
												18					23											6
																												6
																												5
																												5
								30																				6
																						23						6
																							29	31				8
																	11											6
														13														7
									19													23						7
																	12											6
																									27			6
																												6
																										33		6
																						33				27		8
									27															24			27	7
																								23				28	6
47	51	70	56	72	29	31	24	59	46	26	11	47	21	85	3	18	54	27	24	30	16	79	29	78	27	60	27	28	Max. = 9
																													Min. = 4
2	3	3	3	3	1	1	1	2	2	1	1	2	1	4	1	1	4	1	1	1	1	3	1	3	1	2	1	1	Avg. = 6

Calculation

The frequency of each identified letter features is calculated in Table 4.9. The ranking of letter features is determined by calculating the probability of frequency count of observed, expected and actual frequency.

- **Observed frequency:** is the frequency of a number of letter feature identified correctly.
- **Expected frequency:** is the frequency of expected or number of correctly identified planes/ letter variation.
- **Actual frequency:** is the frequency of projected the letter with feature during the short exposure experiment. The experiment was done with 33 participants. Thus, 33 samples of actual frequency of letters are to be considered.

$$F = \left(\frac{\text{Observed frequency}}{\text{Expected frequency}}\right) \times \left(\frac{\text{Observed frequency}}{\text{Actual frequency}}\right)$$

Based on the probability value (F-number), the value of F has been calculated. The F value is used to rank (probability ranking) the anatomical features. The details are shown in Table 4.10.

Table 4.10: Feature table of Bengali

Ranking	Anatomical Feature	Value
1	Dot / Bindu	1.000
2	Delta	0.910
3	Extra V Stem	0.910
4	Loop	0.837
5	Knot	0.826
6	Joinery of Curl & Leg	0.826
7	Joinery of Matra & V Stem	0.826
8	Extra Tail	0.796
9	Joinery of Delta & Matra	0.772
10	Floating Stroke	0.742
11	Bowl	0.739
12	Tail (Upper)	0.728

13	Joinery of Lobe & Leg	0.712
14	Tail (Lower)	0.698
15	Junction of Crossbar & V Stem	0.690
16	Joinery of ">" & Diagonal of Wedge	0.685
17	Joinery of V Stem & H Stem	0.669
18	Lobe (Lower)	0.663
19	Terminal at Upper Tail	0.656
20	Leg	0.644
21	Double Knot (Left)	0.640
22	Joinery of Tail & Bowl	0.640
23	Junction of "<"	0.633
24	Bud/ Terminal (Finial)	0.580
25	Crossbar	0.553
26	Curl	0.549
27	Double Knot (Right)	0.545
28	Extra Wedge	0.545
29	Diagonal	0.542
30	Matra	0.541
31	Nose	0.537
32	Junction of H Stem & Arm	0.528
33	Junction of V Stem & Nose	0.526
34	Joinery of Arm & Shoot	0.523
35	Arm	0.496

The probability ranking of features refers to the importance of those anatomical features in a particular letter. It is a relative calculation considering a single letter. The value expresses the need for the feature in a letterform. Such as the first feature 'Dot or Bindu' is most important and without it, the letterforms completely change its identity. Thus, the feature is highly recommended above all other features whichever letters have it. Similarly, other features possess corresponding probability value of identification that accommodates the identification possibility within a letter.

4.14.2. Calculation of the Wrong Percentage of Data

The objective of this study also determined the intriguing features of the letter that makes the individual letter unique and distinct. The wrong feedbacks of readers indicate the confused letter with the original exposed letter. The overall percentages

of wrong data conclude the rank of confused letters. These values open the scope of discussion on how and why letters get confused by the readers. The ranking of the confused letters is given in Table 4.11.

Table 4.11: Right & Wrong Data of Responses

Sn	Letter No	Bengali Letter	Right Response	Wrong Response	Total Response	% Wrong
1	15	ঙ	316	974	1290	75.504%
2	46	ৰ	487	803	1290	62.248%
3	37	র	606	684	1290	53.023%
4	47	ৱ	612	678	1290	52.558%
5	27	থ	624	666	1290	51.628%
6	34	ভ	705	585	1290	45.349%
7	30	ন	707	583	1290	45.194%
8	43	ড়	761	529	1290	41.008%
9	24	ঢ	778	512	1290	39.690%
10	44	ঢ়	788	502	1290	38.915%
11	45	য়	798	492	1290	38.140%
12	39	শ	845	445	1290	34.496%
13	26	ত	944	346	1290	26.822%
14	17	ছ	952	338	1290	26.202%
15	12	খ	975	315	1290	24.419%
16	25	ণ	1012	278	1290	21.550%
17	23	ড	1019	271	1290	21.008%
18	16	চ	1024	266	1290	20.620%
19	36	য	1049	241	1290	18.682%
20	19	ঝ	1059	231	1290	17.907%
21	6	ঋ	1075	215	1290	16.667%
22	21	ট	1085	205	1290	15.891%
23	35	ম	1099	191	1290	14.806%
24	29	ধ	1108	182	1290	14.109%
25	7	এ	1113	177	1290	13.721%
26	42	হ	1119	171	1290	13.256%
27	9	ও	1120	170	1290	13.178%
28	5	ঊ	1134	156	1290	12.093%
29	20	ঞ	1135	155	1290	12.016%
30	18	জ	1141	149	1290	11.550%

31	33	ব	1153	137	1290	10.620%
32	13	গ	1159	131	1290	10.155%
33	28	দ	1170	120	1290	9.302%
34	31	প	1177	113	1290	8.760%
35	4	উ	1183	107	1290	8.295%
36	40	ষ	1196	94	1290	7.287%
37	2	ই	1225	65	1290	5.039%
38	14	ঘ	1225	65	1290	5.039%
39	22	ঠ	1228	62	1290	4.806%
40	1	অ	1230	60	1290	4.651%
41	32	ফ	1230	60	1290	4.651%
42	41	স	1235	55	1290	4.264%
43	8	ঐ	1236	54	1290	4.186%
44	3	ঈ	1238	52	1290	4.031%
45	38	ল	1240	50	1290	3.876%
46	10	ঔ	1241	49	1290	3.798%
47	11	ক	1269	21	1290	1.628%
		Total	47825	12805	60630	21.120%

The detail data of individual exposed letters that are confused with the other letters are given in Appendix XI. The data are divided into three clusters based on the percentage of wrong response. They are 1) more than 50% wrong response, 2) 20% to 50% of wrong responses and 3) below 20% wrong responses. The clusters are an abstract idea of complexity of letterforms. The first cluster consists of five letters as in Table 4.11. Among them, three letters belong to the same group, and their discriminating features are marginal. The other two consist of entirely different letterforms that share very few common feature resemblances. The second cluster consists of the thirteen letters next to the first cluster (follows in Table 4.11). The shape of the letters in this cluster is vastly different. Though, similarity among few letters within the cluster is noticeable. However, direct conclusion cannot be drawn with such variety. The letters having discriminating features that do not resemble the other letter features in this group. Therefore, the role of letter feature in identification process is crucial by which the individual identification of the letters is possible. The third cluster is less than twenty percent wrong identification. The reason possibly is

the combination of stroke features that are unique for each letter. Some inferences from the Table 4.11 are following:

Cluster One:

The cluster consists of letters 'Uyno/ ঙ', 'Wa-Ba/ ৰ', 'Bengali Ra/ ৰ', 'Assamese Ra/ ৰ' and 'Tha/ থ' (first five letter, S.No.: 1 to 5 in Table 4.11).

- The first and most confused letter 'Uyno' is the unique letter in this cluster. It consists of unique features like 'Loop' and common feature like 'Bowl'. The confusion may happen with this letter due to inconsistency in the single feature or may be due to commonalities with other letters.
- Next three letters 'Wa', 'Ra' and 'Assamese Ra' belong to the same group having 'Delta' feature in common. Here, distinctive features of these letters may not be differentiable enough to recognise individually.
- The last letter 'Tha' is again the single letter that shares very less feature with the rest of the letters. The 'Wedge' and 'Vertical Stem' are only in common with the previously discussed 'Delta' group.

Cluster Two:

The cluster consists of thirteen letter (S.No.: 6 to 18) as in Table 4.11.

- The cluster consists of most confused letters according to Table 4.11. The chance of contradictions may be frequent since all letters are having enough percentage of wrong responses.
- Letters like 'Bha/ ভ', 'Da-Ra/ ড়', 'Ta/ ত' and 'Da/ ড' have common features. It is apparent that these letters will get confused with others or among themselves.

- Similarly, letters 'Dha-Ra/ ড', 'Dha-Ra/ ঢ়', and 'Cha/ চ' have many features in common. 'Matra', 'Stem' and 'Arm' are the few features that are shared by these letters.

- 'Na/ ন' and 'Nna/ ণ' are the two letters that share all features except 'Matra'.

- Letters 'Sha/ শ' and 'Kha/ খ' are two distinct letters that have no resemblance to others letters. There is, even, no apparent similarity of forms, but the wrong response is substantial. Further, justification is needed to understand the confusion.

Cluster Three:

The cluster consists of letters from S.No.: 19 to 47 in Table 4.11. The cluster is a collection of the twenty-nine individual letters. Though it's the largest collection of letters, there may be a very less strong case of letter confusion.

- The three letters 'Jha/ জ', 'Rhye/ ঋ' (S.No.: 20 & 21) and 'Dhya/ ধ' (S.No.: 24) have common features and neighbourhood letters belongs to the first cluster. Hence, the features of these letters may be distinct enough for uniqueness.

- The other letter 'Ka/ ক' belongs to this cluster also ranks the lowest confusion. Thus the feature that is not common to others is dominant and creates a unique combination. As a whole, the letter also becomes easily distinctive enough. The same case is with the letter 'Pha/ ফ' (S.No.: 21). The confusion occurs with the other neighbour letters but not with it due to the presence of the same feature as in letter 'Ka/ ক'.

- The letters 'A/ এ', 'Jha/ য' and 'Rhye/ ঋ', all have common feature 'Wedge' and 'VStem'. Though, the letter 'A' has a higher recognition rate than the rest

of the two. The 'Jha' and 'Rhye' have common feature 'Delta' that makes letter confusion rate higher than the letter 'A'.

The other letters are also having confusion but not accountable for detail discussion. But, the letters may have individual personalities and distinctiveness that will be discussed in the next section.

4.14.3. Discussion

The important letter features are shown in Table 4.10 in ascending order. The ranking is representing feature recognition probability to recognise a letter. It means if a letter possesses a particular feature, it will be recognisable according to chance of (higher/lower) ranking to recognise the particular letter. The 'Dot' feature is most important for identification of letters 'Ra/ র' and others (Row 3, 8, 10, 11 in Table 3). Also, the probability ranking of 'Dot' is highest among all as in Table 4.10. The letters 'Ra/ র', 'Da-Ra/ ড়' and others completely depend on the recognition of the feature since without it the letters will be 'Ba/ ব', 'Da/ ড' and similarly others. Therefore, it is one of the crucial feature that is essential in letter recognition process.

Letters with 'Delta' feature can easily be separated from other letters due to its unique triangular structure. Letter 'Ba/ ব', 'Assamese Ra/ ৰ', 'Bengali Ra/ র', 'Wa-Ba/ ৱ', 'Jha/ ঝ' and 'Rhye/ ঋ' have 'Delta' feature. Altogether, they create a unique group of 'Delta' letters (Fig. 4.19). The feature narrows down the letter identification process that confines letter recognition within the group. The letters "Assamese Ra/ ৰ', 'Bengali Ra/ র' and 'Wa-Ba/ ৱ' (Row 2, 3 & 4 in Table 4.10, marked as 1A in Fig. 4.19) have the common feature 'Delta'. They are easily separated by the 'Delta' feature from other letters but confused among themselves. Here, the minor discriminating features the 'Crossbar' of 'Assamese Ra/ ৰ', the 'Dot' of 'Bengali Ra/ র' and the extra stroke of 'Wa-Ba/ ৱ' are crucial for letter recognition which separate

them from ‘Ba/ ব’ within the group. The perceptions of these features are crucial and make the letters recognizable.

Fig. 4.19: Letters in 'Delta' feature group (Group 1)

Now, the concern with Delta group marked as ‘1A’ possesses confusion with letters marked as ‘1B’ in Fig. 4.19. They are marginally confused (no confusion in case of letter ‘Ka’) within the own group. The discriminative letter features like Arm of ‘Ka/ ক’, Extra Wedge of ‘Jha/ ঝ’, Curl of ‘Dhya/ ধ’ and ‘Rhye/ ঋ’ are significant in terms of identification marks due to their exclusiveness with Delta feature. The features in group 1A are also significant and they are crucial in identification task as in Table 4.10 (See Table 4.10, row 1, 3, 26, 28 & 35). These features combine with the Delta to form a unique structure. The letters in group 1A have three distinct features that are marginally different among them. Whereas in group 1B, discriminating features are significantly different among themselves. But combination of Delta and those discriminating features are exclusive for all letters in groups 1A as well as in group 1B. The role of feature is described below with letter ‘Ra/ ৰ’ (as in Fig. 4.19).

First, the letter is perceived by the eye and creates an image on the retina (as in Fig. 4.20). According to DRC model, human brain tries to match letter features with already known letters that we previously knew. At this point in time, recognised ‘Dot’ feature sorts down few letters from vast collection of known letters and creates the array of possibilities. Further, the second neural process activates the search for the match with ‘Delta’ group. The third neural process tries to match the ‘Dot’ and ‘Delta’ feature together that results in the identification of letter ‘Ra’. The neural network model works collectively to identify letters by proceeding feature comparison

and matching the pattern with letter (Beier, 2009; Nedeljković, Puškarević, Banjanin, & Pinćjer, 2013). The correct match with known letters with perceived letter features leads to identification of letter with completion of letter processing (McClelland & Rumelhart, 1981). Though, it does not guarantee correct identification of letters. The case can be explained by letter 'Bha/ ভ' and 'Da/ ভ' (Row 6 & 17 in Table 4.11) or 'Dha' and 'Cha' (Row 9 & 18 in Table 4.11).

The letters in Fig. 4.21 'Bha/ ভ & Da/ ভ' and 'Dha/ ঢ & Cha/ চ' are confused with each other due to feature confusion. The initial with an aperture of 'Bha/ ভ' is confused with the vertical stem of 'Da/ ড' and vice versa. In the second row of the 'T' junction of 'Da/ ড' is recognised as the initial of the 'Bha/ ভ' which leads to final confusion between the letters. Similarly, the terminal of 'Dha/ ঢ' perceived as continuous, touched the vertical stem that ends up identifying it as 'Cha/ চ'. Thus, perception of letter features is crucial in the identification process. Successful identification needs right feature recognition that depends on identification of anatomical features. Alternatively, perception of letterform is crucial for correct recognition of anatomical feature. Therefore, combination of features makes letter unique in the recognition process.

Fig. 4.20: Letter identification process of letter 'Ra'

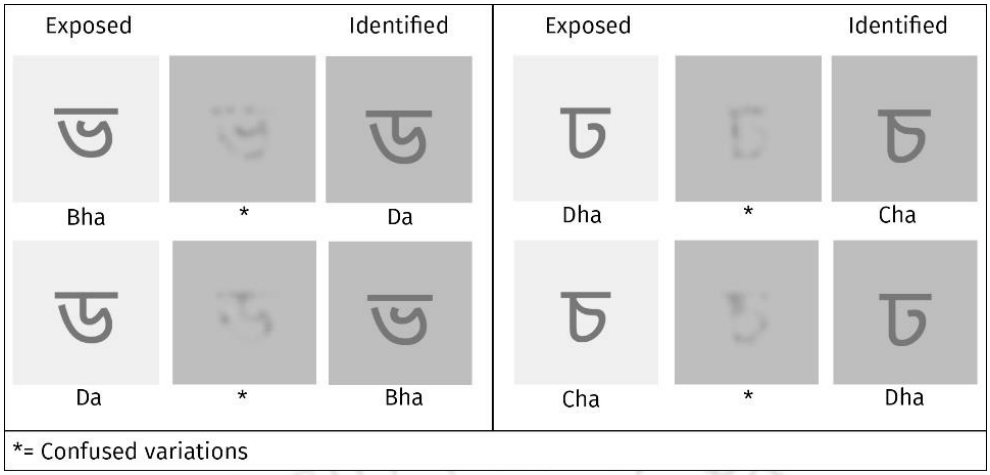


Fig. 4.21: The confused letters and variations

4.15. Conclusion

We know from eye-tracking study that anatomical feature plays a role in letter identification. The process of letter identification involves many aspects of design of letters and viewing conditions. The perception of letters is very much essential and controls the letter identification process (McClelland & Johnston, 1977; McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982; Nedeljković, Puškarević, Banjanin, & Pinćjer, 2013). Whereas, letter features facilitates the letter identification process by controlling various condition of viewing (Pelli, Burns, Farell, & Moore-Page, 2006). Previously, Pelli et al. (2006) show that identification and detection thresholds are independent of letter complexity. They assume that the feature detection depends only on the stimulus (input feature) regardless of task (recognition or identification) (Pelli, Burns, Farell, & Moore-Page, 2006). Here, we are deducting the role of letter feature that facilitates letter recognition for identification task. The study shows the anatomical features of Bengali that is essential in the recognition process for letter identification. The process follows the Gestalt law of good continuation (Pelli, et al., 2006) where combination of features creates good continuity (according to our study). Fig. 4.20 explains the process of

multiple neural activations that supports the Gestalt law of grouping in letter recognition.

The recognition of features depends on the perception of anatomical structure of letters. Perception is dependent on the designing of the letterforms (Pelli, Burns, Farell, & Moore-Page, 2006). The design of letters is always subjected to legibility issues. To control legibility, we need to control the letter perceptibility that results in successful letter feature recognition.

The study concludes that letters are unique in combination with features. Every combination of features is unique discriminating characteristics of the corresponding letter. The chance of letter identification is dependent on this combination of anatomical features that belong to a particular letter. If a feature is correctly recognised, the letter will be identified successfully (result from short exposure test). All successful recognition of the anatomical features can definitely lead to successful identification of the letter. Thus, it can be concluded that 'there is a significant effect of letter anatomy, i.e. critical letter features for letter identification in case of Bengali letterforms'. Hence, visibility of letters can be improvised by anatomical features with distinctiveness. In the next chapter, the analysis of individual letterforms will be performed to propose the design guidelines of Bengali letters.

Chapter Five

Framework for Legibility

Introduction

In the previous chapters, the short exposure test revealed the features that were responsible for the letter identification task. In this chapter, we will discuss the legibility issues of the Bengali letterforms in co-relation to the letter identification task. The chapter identifies the letter features that are important in Bengali typeface not only for reading but also for design purposes. The analysis is done here in two-phase –

1. Individual letter analysis (ILA)
2. Categorical letter analysis (CLA)

Previously, we already have three empirical studies that provide us with the wide range of statistical data which are listed below –

- The eye-tracking data and the inference of the fixation.
- The important anatomical features of letters with rank.
- The table of data in ascending order of wrong input.

5.1. Individual letter analysis

In the section, the detailed analysis of individual letterforms was done to understand the role of anatomical process in letter identification. The results of the study have led us to propose design guidelines for individual letterforms. To draw the conclusion on letter legibility and design aspect, data from previous studies (from Chapter 4) has been considered to conduct the individual letter analysis.

The study is a critical analysis of individual letter with confused letters that occurred during the short exposure test (in Chapter 4). Exposed masked letters (wrong recognized letters) are critically examined with the original exposed letter to understand the identification process and design issues with the letterforms. In Fig. 5.1, the left blurred image represents the exposed masked letter and denoted as (vx) where 'x' indicates the variation numbers. The middle image in Fig. 5.1 is the identified letters by participants. It is denoted as 'ly' (lowercase L & y) where 'y' indicates the letter value such as for 'A' & 'Ka', they are 1 & 11 correspondingly. The last or right image in Fig. 5.1 is the original image of letter and denoted as 'Lz' ('z' represents letter number) with light background compared to 'ly'. The variation of 'Lz' was exposed as 'vx' that was recognised as 'ly'. Here, in the study, all 'ly' are the confused letters and 'Lz' is the original letter that is confused with 'ly'. The analysis was performed accounting the wrong variations ('vx') with confused and original letters. These image notations were used for analysis of each letter with varying denoted number.

Fig. 5.1: Sample image for critical analysis

Letter 15 (Uyno/ ঙ)

The first and most confused letter is 'Uyno/ ঙ'. The common letter part of the letter is the 'Bowl' (Fig. 5.2). The letter is confused with letters like 'Harsh-U/ ঊ', and 'Dda/ ড'. This common feature triggers the letter selection process by rejecting the others. Later the corrected identification is perceived by the distinguishing parameter among the selected letters (in the same group, as in Fig. 5.2). The letter recognition process, in this case, occurs by eliminating all discriminatory features but accepting the unique one that is identified by the reader correctly. Therefore, it can be said that:

- The design of loop and counter is necessary for recognition.
- The design of the upper section is essential since it can be confused with Letter 'Harsha-U/ ঊ' and 'Dda/ ড' as in Fig. 5.2.

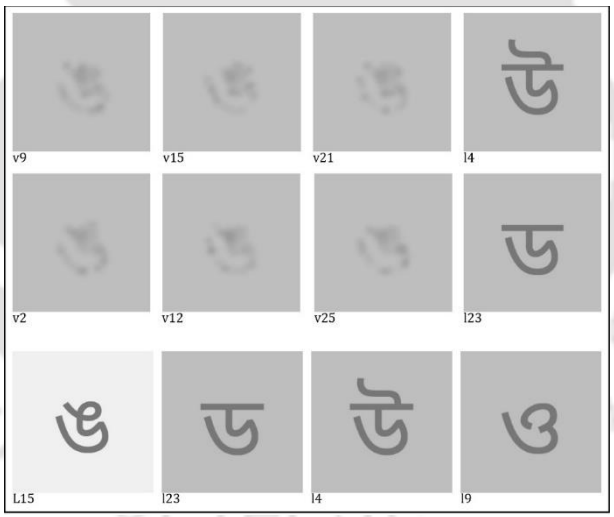


Fig. 5.2: Letter group 'Uyo'

Letter 46 (Assamese Ra/ ৰ)

The letter is only used for writing Assamese language. The presence of feature 'crossbar' is uncertain (Fig. 5.3). The word many times recognised as 'Ba/ ব' due to

the absence of crossbar. The letter closely resemblances to 'Ba/ ব'. Few characteristics of the letter –

- The familiarity with the letterform
- The influence of basic structure (basic letterform structure is 'Ba/ ব')

Again, the incompleteness or the inappropriate counter between Matra and Delta can resemble to letter 'Dhya/ ধ' (as in Fig. 5.3). When Matra is not defined, the identification process tries to complete the gap by other means and that leads to the predictive letter feature Arm of letter 'Dhya/ ধ'. The readers perceive fabricated feature that anticipated in identification process to complete the letterform. Such biases result in the identification of similar letter that resembles it.

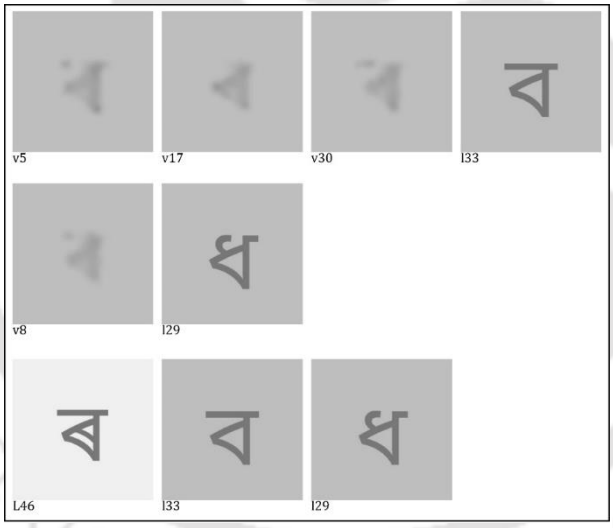


Fig. 5.3: Letter 'Assamese Ra' and Bengali letters 'Dha' & 'Ba'

Letter 37 (Bengali Ra/ র)

Here, the visibility of Dot or Nukta is important since it is the only feature that separates from others (as in Fig. 5.4, third row). Like previous letter, readers predicted the letter as 'Ba/ ব' or 'Dhya/ ধ' without the 'Dot' feature, or predict it as 'Yo/ য়' due to crowding around Matra and Delta.

- The Nukta/ Dot is an important feature for identification task.

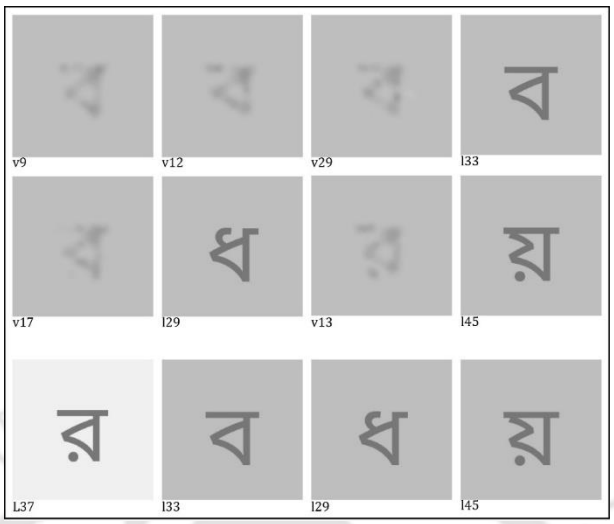


Fig. 5.4: Letter 'Bengali Ra' and others

Letter 47 (Wo/ ৱ)

The single (isolated) stroke is a critical feature (as in Fig. 5.5). The identification is dependent on the visibility of this feature. The poor design leads to lower visibility that confirms readers to identify it as other letters.

- The single stroke needs to be well defined, i.e. with enough length and counter space. It can resemble with Dot that leads to predicts it as Bengali 'Ra/ ৱ'.

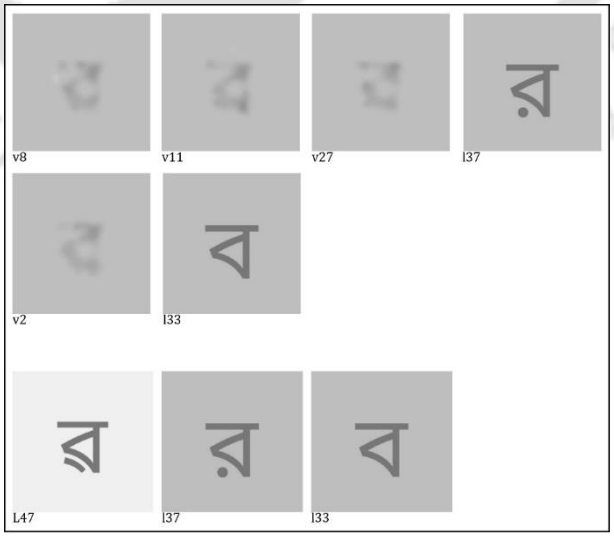


Fig. 5.5: Assamese letter 'Wo' and Bengali letters 'Ra' & 'Ba'

Letter 27 (Tha/ থ)

The letter is very similar to letter 'Khya/ খ' (as in Fig. 5.6). Only the initial letter-part, the 'Lobe', is different and rest of the parts are similar. Due to crowding, the letter is confused with 'Mudhyana-Sha/ ষ' (the third letter in the Fig. 5.6), 'Jha/ ঝ' and 'Dhya/ ধ' respectively around the Lobe and VStem. Therefore, the counter is crucial and needs proper distance between Bowl and VStem.

- There should be enough counter space between Lobe and VStem that helps to separate the letter from 'Mudhanya-Sha/ ষ' and 'Dhya/ ধ'.

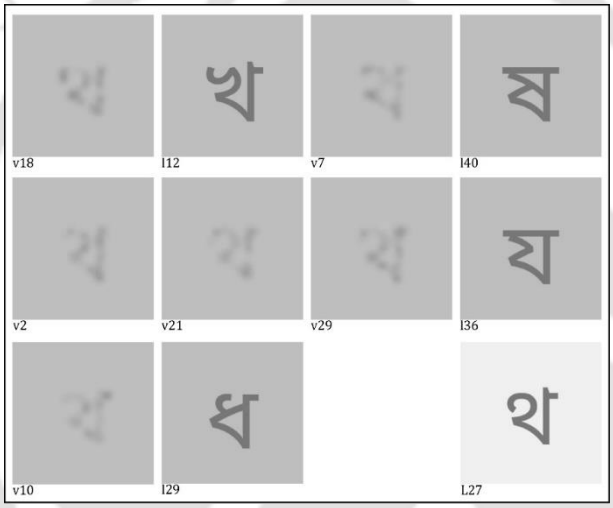


Fig. 5.6: Letter 'Tha' and similar letters

Letter 34 (Bha/ ভ)

Here, the contrast is a very dominant bias. The link between 'Initial' of the letter and Matra is a crucial factor of recognition. The general tendency of the reader is to confuse it with 'Dda/ ড' due to an enhanced feature at 'Initial' (as in Fig. 5.7). To stop connecting 'Initial' and 'Matra', a clear distinction is required between them. In traditional design of this letterform, there is 'Bud' feature that probably helps to stop the connection for wrong identification.

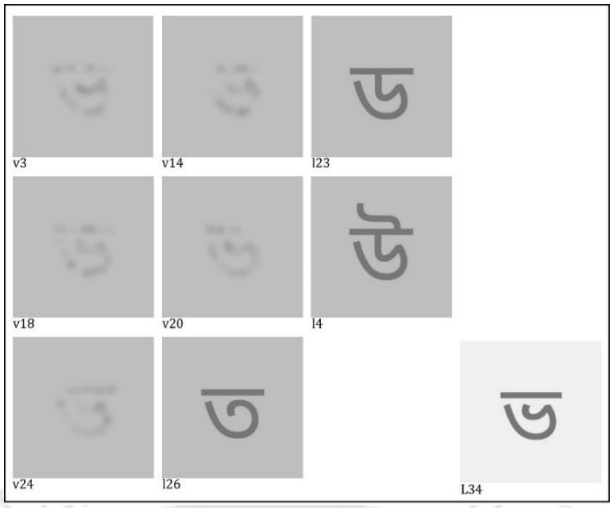


Fig. 5.7: Letter 'Bha' and similar letters

Letter 30 (Na/ ন)

Here, participants tend to compare the letterform with the nearest match considering the perceived form (Fig. 5.8). The crucial part is the Arm and the Counter between Arm & Matra.

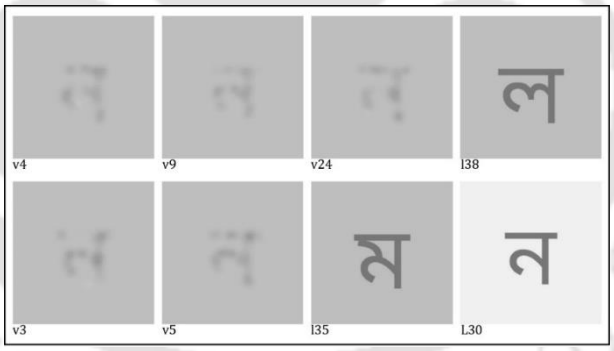


Fig. 5.8: Letter 'Na' and confused with letter 'Na' & 'Ma'

Letter 43 (Dda-Ra/ ড়)

Human mind always tries to match best fit when comparing any object. It is same with 'Dda-Ra/ ড়'. The absence of Dot cannot force the participant to identify the letter as 'Dda-Ra/ ড়', instead it is identified as 'Dda/ ড়' only (Fig. 5.9).

- The Dot is an important feature for identification.

Fig. 5.9: Letter 'Da-Ra' with confused letters ‘Da’ & ‘Dirgha-U’

Letter 24 (Dha/ ঢ)

The objective of the readers is to complete a stroke from beginning to possible end. It is perceptible in case of ‘Dha/ ঢ’. There is a possibility to think that the termination of stroke (Terminal of Dha) is at the very end on VStem. Such enhancement of ‘Terminal’ leads to false identification of ‘Dha/ ঢ’ as ‘Cha/ চ’ (as in Fig. 5.10). Such extension of feature has been countered with ‘Bha/ ভ’ that clarifies that there is a need of termination mark at the beginning or end of a stroke.

- A threshold gap or termination mark is required between VStem and Terminal.

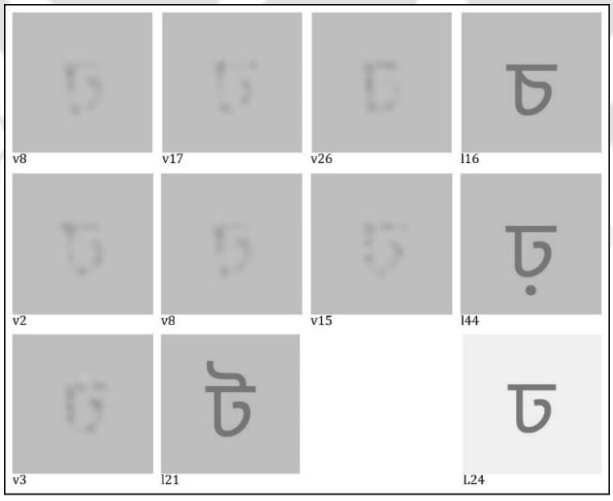


Fig. 5.10: Letter ‘Dha’ mostly confused with Letter 'Cha'

Letter 44 (Dha-Ra/ ঢ়)

The identification of this letter is dependent on the Dot feature. If it is visible enough, the letter is never confused with other letters. If it is not visible enough, it is confused with 'Dha/ ঢ' and 'Cha/ চ' (as in Fig. 5.11). The probable reason for the confusion is discussed previously.

- The Dot is an important feature of recognition.

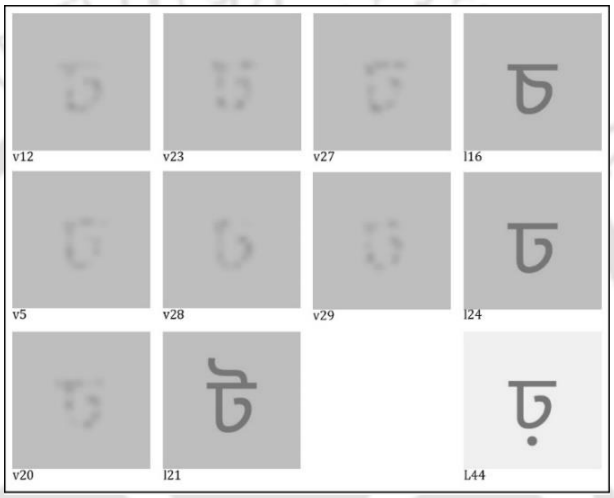


Fig. 5.11: Letter 'Dha-Ra' with confused letters 'Cha', 'Dha' & 'Tta'

Letter 45 (Ja-Ra/ য়)

The Dot feature is essential for correct identification of the letter. Without Dot feature, there is a possibility of wrong identification with 'Ja/ য' and 'Gha/ ঘ'. The initial stroke - 'Arm' of letter 'Gha' (third letter in second row) is an important feature to distinguish between them (Fig. 5.12).

- The Dot is an important feature of recognition.

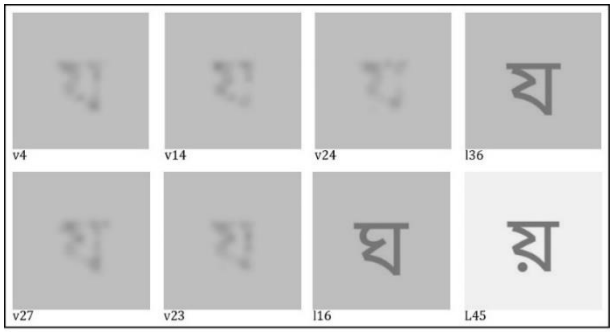


Fig. 5.12: Letter 'Ja-Ra' with the confused letters 'Ja' and "Ghya'

Letter 39 (Sha/ শ)

The letter is mostly confused with 'Mudhyan-Na/ ণ' and 'Pa/ প'. The spatial distribution of letter strokes of these three letters is similar. The special information creates the confusion among them that leads the readers to wrong identification. Additionally, all three letters have VStem at the right side and a shooting stroke or Arm from the top of it to approaching left side. This common characteristic reduces the chance of recognition correctly.

- The design of the double 'Knot' is vital since it helps to discriminate the letter from other letters like 'Pa/ প'.

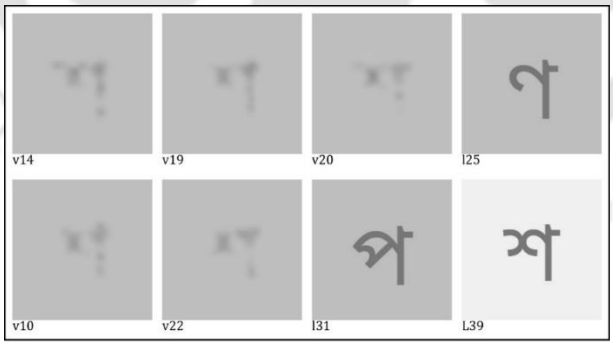


Fig. 5.13: Letter 'Sha' and other similar confused letters 'Pa' and 'Nna'

Letter 26 (Ta/ ত)

The letter is confused with the letter 'Dda/ ড' and 'Bha/ ভ'. The space or counter between Matra and main body is the confusion zone due to crowding. If the contrast

enhances the feature properties, it is recognized as ‘Dda/ ড’ and vice versa for the ‘Bha/ ভ’. The clear separation between those two letter parts (Matra and Main letter body) is required.

- The gap between Matra and initial stroke of the letter is crucial for the recognition.

Fig. 5.14: Letter 'Ta' confused with 'Bha' and 'Da'

Letter 17 (Chya/ ছ)

The critical structure of this letterform creates extensive confusion with many letters (Fig. 5.15). The ‘Leg’ is confused with ‘Ha/ হ’. The close counter confused with ‘Dha/ ঙ’. The complex structure induces perception of many letters due to perceived intensity of contrast of exposed letters.

- There is a resemblance between letter ‘Chya/ ছ’ and ‘Ha/ হ’. Both have ‘Leg’ feature in common.

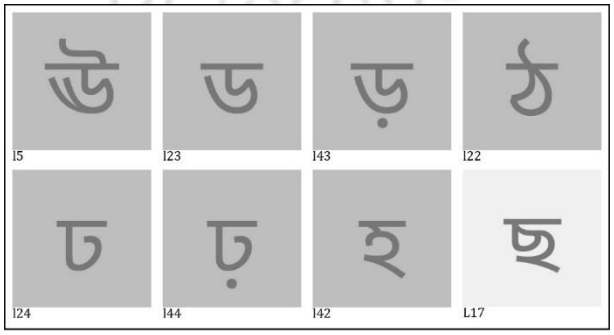


Fig. 5.15: Letter 'Chya' and range of confused letters

Letter 12 (Kha/ খ)

The contrast sometimes diminishes the feature by that letter loses its identity. This can be seen in the Bud and Arm of 'Kha/ খ' (Fig. 5.16). The Bud and Arm together appear as a Matra and the letter is identified as 'Ba/ ব'. Another kind of mismatch with this letter is 'Rhye/ ঋ'. Due to density and crowding around the Arm and joinery detail, the letter recognised as 'Rhye/ ঋ' by dismissing the VStem in the middle. The double 'Wedge' character of the letter went missing due to high density in the middle.

- The 'Arm' of Rhye is similar to Arm of 'Kha/ খ'.

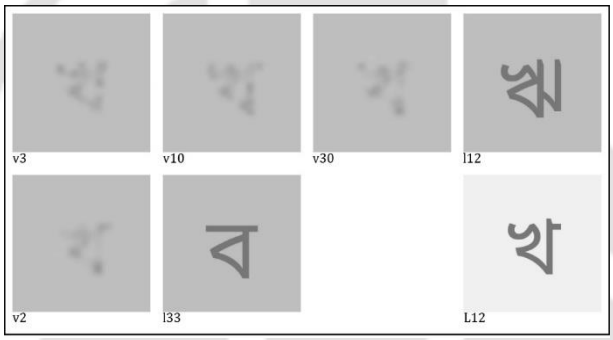


Fig. 5.16: Letter 'Khya' with confused letters 'Rhye' & 'Ba'

Letter 25 (Mudhyan-Na/ Nna/ ণ)

All three letters in Fig. 5.17 (except 'Na/ ন') have structural similarities such as 'VStem' and 'Arm' that led to the confusion during identification task. Here, discriminatory parts are crucial for correct recognition.

- The design elements are similar in 'Ga/ গ' and 'Pa/ প'. Emphasis is essential on distinctive parts. The 'Na/ ন' is also similar to 'Nna/ ণ' without Matra.

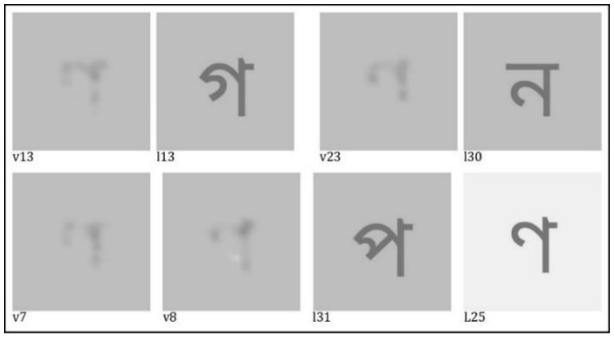


Fig. 5.17: Letter 'Mudhyan-Na' or 'Nna'

Letter 23 (Dda/ ড)

Here, the role of contrast is very dominant especially in the (T) junction area (Fig. 5.18). The enhancement or diminishment of the (T) junction determines the identity of the letter whether it is 'Bha/ ভ' or 'Dda/ ড'. If the letter is identified as 'Dda/ ড', then the probability of confusion arises with 'Dda-Ra/ ড়' and 'Harsa-U/ ঊ' depending on the contrast of crowding on the letter.

- The (T) junction of the letter is crucial for the recognition.

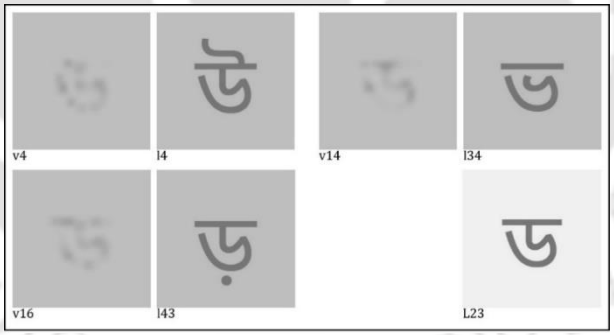


Fig. 5.18: Letter 'Dda' with confused letters 'Bha' & 'Da-Ra'

Letter 16 (Cha/ চ)

The letter 16 (Cha/ চ) is only confused with the letter 24 ('Dha/ ঢ'). The connecting line (Horizontal as in Fig. 5.19) from Arm to vertical stem is crucial for correct identification.

- The stroke HStem that joins ‘Arm’ and ‘VStem’ is an important feature.

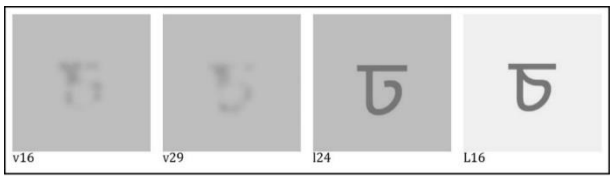


Fig. 5.19: Latter 'Cha' with only confused letter 'Dha'

Letter 36 (Ja/ য)

The correct identification of ‘Ja/ য’ depends on the curvature of initial stroke (Fig. 5.20). The initial stroke of ‘Ja/ য’, ‘Ghya/ ঘ’ and ‘Tha/ থ’ almost appears similar irrespective of curvature being different.

- The curvature of initial stroke is key to differentiation of three letters.

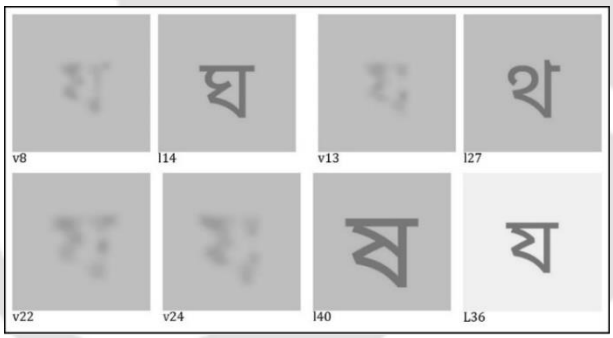


Fig. 5.20: Letter 'Ja' and the other confused letters

Letter 19 (Jha/ ঝ)

It is possible that the ‘Wedge’ is the primary reason for confusion with other letters. The stroke density of all three letters is high and ‘Wedge’ is placed at the right to every letter (as in Fig. 5.21). High density, crowding and contrast together create illusion between Bowl and Delta to confirm its actual identity.

Fig. 5.21: Letter 'Jha' with confused letters ‘Rhye’ & ‘A’

Letter 6 (Rhye/ ঋ)

The confusion in the letter is due to spatial distribution of strokes almost like letter ‘Jha/ ঝ’ (Fig. 5.22).

- The ‘Arm’ and ‘Shoot’ are key features to differentiate them.

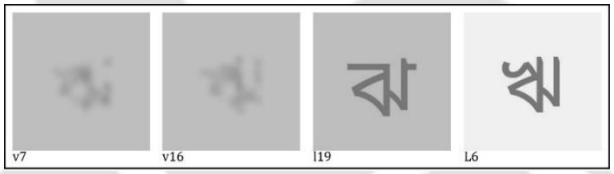


Fig. 5.22: Letter 'Rhye' with confused letter ‘Jha’

Letter 21 (Tta/ ট)

The upper tail creates confusion with letters ‘E/ ই’, ‘Oi/ ঐ’ and ‘Harsha-U/ ঊ’ (Fig. 5.23) due to crowding and contrast.

- The upper tail is a feature of confusion.

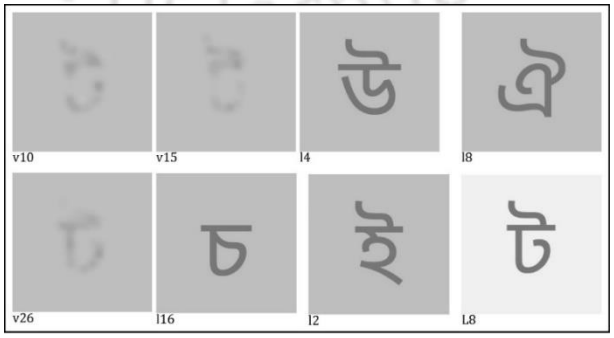


Fig. 5.23: Letter 'Tta' with confused letters

Letter 35 (Ma/ ম)

The bottom left of the letter is a crucial part for identification. It can be an open curvature or Loop or Knot (Fig. 5.24).

- The letter needs specific design consideration in bottom left junction.

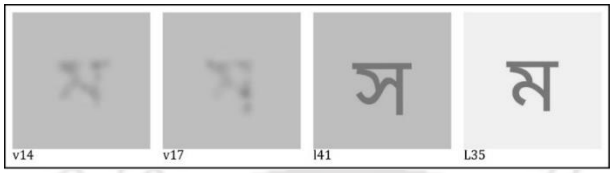


Fig. 5.24: Letter 'Ma' with confused letter ‘Sa’

Letter 29 (Dhya/ ধ)

The letters ‘Dhya/ ধ’ and ‘Gha/ ঘ’ almost have same structure except for the long Matra and Delta Junction. The stroke path needs to be different from ‘Dhya/ ধ’ and ‘Gha/ ঘ’.

- The ‘Arm’ is the significant feature of identification.

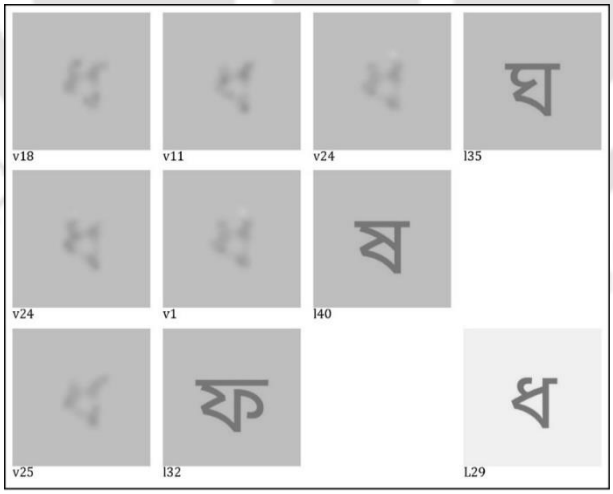


Fig. 5.25: Letter 'Dhya' that mostly confused with 'Ghya' & 'Ssa'

Letter 7 (Aya/ এ)

There is no as such confusion with 'Aya/ এ' (Fig. 5.26). The crowding leads to enhancement of feature that creates confusion with 'Oye/ ঐ'.

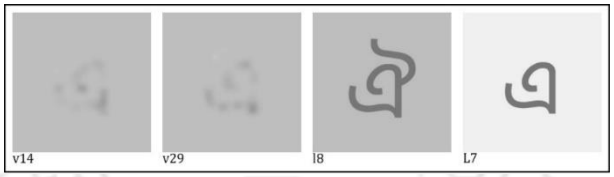


Fig. 5.26: Letter 'Aya' with confused letter 'Oye'

Letter 42 (Ha/ হ)

There is no as such confusion with 'Ha/ হ' (Fig. 5.27). The crowding leads to enhancement of feature that creates confusion with 'E'.

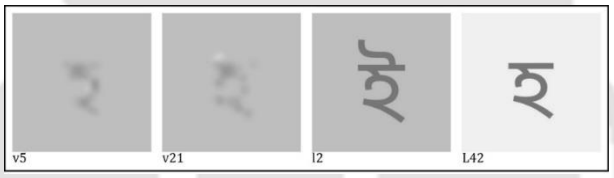


Fig. 5.27: Letter 'Ha' with confused letter 'E'

Letter 9 (O/ ও)

The letter 9 (O/ ও) is significantly confused with letter 10 (Oi/ ঔ) and marginally confused with 'Ta/ ত' and 'Aya/ এ' (Fig. 5.28). The crowding leads to enhancement of feature that creates confusion with 'Oi/ ঔ'. The Lobe of 'Oi/ ঔ' sometimes can appear as Matra which can create confusion with 'Ta/ ত'.

- The 'Knot', junction of 'Lobe' and 'Bowl', is an important feature for identification.

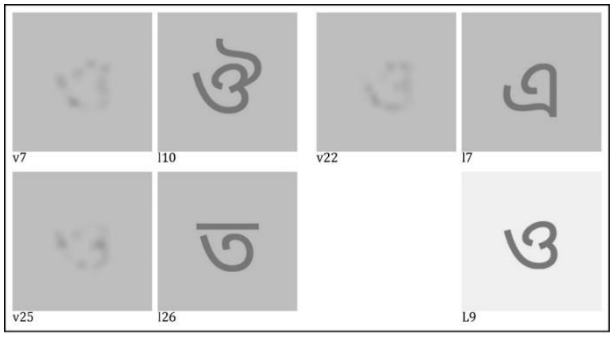


Fig. 5.28: Letter 'O' with other confused letters

Letter 5 (Dirgha-U/ ঊ)

The extra 'Tail' is the only discrimination feature for identification (Fig. 5.29).

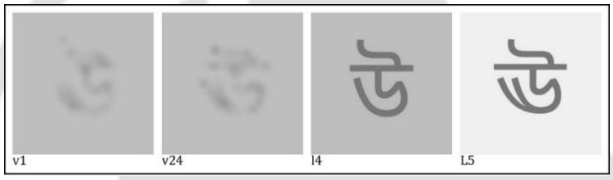


Fig. 5.29: Letter 'Dirghu-U' with confused letter 'Harshu-U'

Letter 20 (Eyna/ ঞ)

Here again, the letter is only confused with the letter 8 (Oye/ ঐ) (Fig. 5.30). The small Lobes features back of the letter is confused with Tail of letter 8 (Oye/ ঐ) due to crowding and contrast effect.

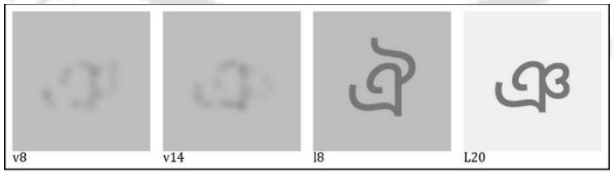


Fig. 5.30: Letter 'Eyna' with confused letter 'Oye'

Letter 18 (Ja/ জ)

The illusive structure majorly confuses with the letter 20 (Eyna/ ঞ) due to close Nose and Shoot (Fig. 5.31). Crowding is the major reason for confusion and sufficient counter space is required between Nose and Leg.

Fig. 5.31: Letter 'Ja', complex letter and confused with 'Eyna', 'Da' & 'A'

Letter 33 (Ba/ ব)

The structure of 'Ba/ ব' is a basic structure of Delta group's letter and combination of Delta with Matra only (Fig. 5.32). The letter is confused with 'Ssa/ ষ' and 'Ra/ ৰ' due to the crowding around the junction of Delta and Matra.

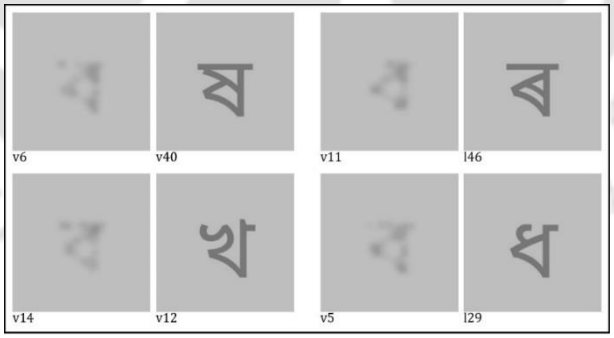


Fig. 5.32: Letter 'Ba' confused with other letters

Letter 13 (Ga/ গ)

The letter is only confused with the letter 31 (Pa/ প) due to similar spatial distribution of letter-strokes (Fig. 5.33).

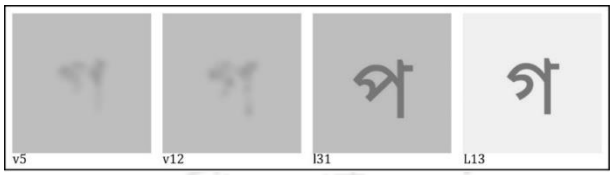


Fig. 5.33: Letter 'Ga', confused with 'Pa'

Letter 28 (Da/ দ)

The letter is not as such confused with any letter. Only a few confusions are observed with 'Dirgha-E/ ঈ' and 'Sa/ স' due to contrast and feature diminishment (Fig. 5.34). Otherwise, the letter is very unique in combination with anatomical features.

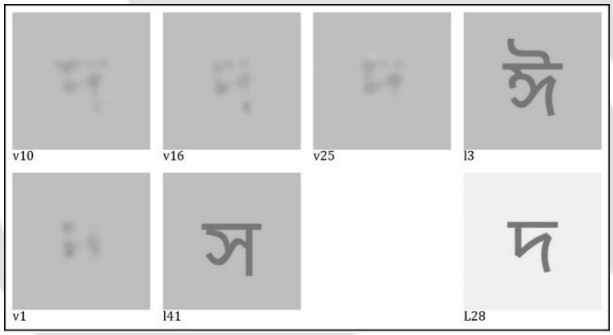


Fig. 5.34: Letter 'Da'

Letter 31 (Pa/ প)

The letter was marginally confused with 'Ga/ গ' and 'Sa/ স' (Fig. 5.35).

- The diagonal 'Crossbar' Lobe to VStem near joinery is an important feature for identification purpose.

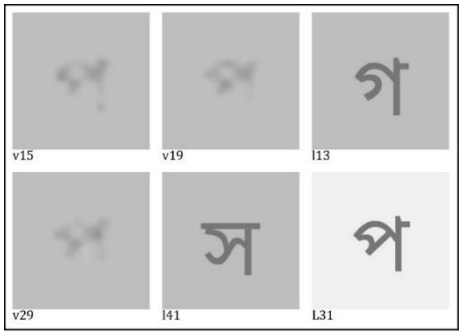


Fig. 5.35: Letter 'Pa' with confused letters ‘Ga’ & ‘Sa’

Letter 4 (Harsha-U/ উ)

The letter is negligibly confused with ‘Dirgha-U/ ঈ’ due to crowding or over contrast (Fig. 5.36).

Fig. 5.36: Letter 'Harsha-U' with confused letter ‘Dirgha-U’

Letter 40 (Ssa/ ষ)

The ‘Crossbar’ is the crucial feature for identification of ‘Ssa/ ষ’ (Fig. 5.37). The letter is marginally confused with ‘Ma/ ম’ and negligibly with ‘Sa/ স’ and ‘Kha/ খ’.

- The Crossbar and Wedge are important features for identification.

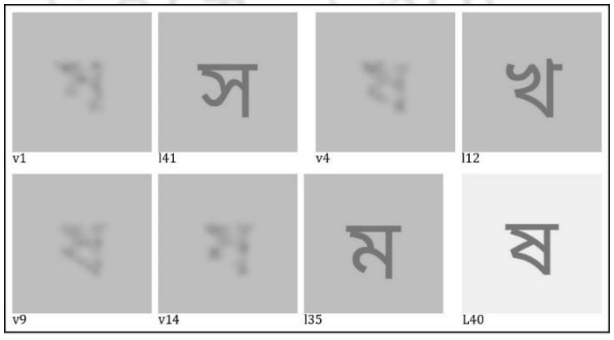


Fig. 5.37: Letter 'Ssa' with other confused letters

Letter 2 (E/ ই)

The letter is negligibly confused with 'Oye/ ঔ' and 'Ha/ হ' (Fig. 5.38).

- The 'Leg' and upper 'Tail' are the key features for identification.

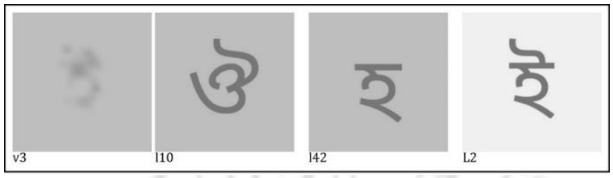


Fig. 5.38: Letter 'E', confused with 'Oyu' and 'Ha'

Letter 14 (Ghya/ ঘ)

The letter is negligibly confused 'Ja/ য' (Fig. 5.39).

- The curvature of initial stroke (below Matra) is the important feature to discriminate 'Ghya'.

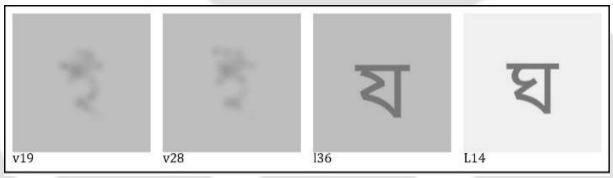


Fig. 5.39: Letter 'Ghya' with confused letter 'Ja'

Letter 22 (Ttha/ ঠ)

The letter is slightly confused with 'E/ ই', 'Oye/ ঐ' and 'Dha/ ধ' (Fig. 5.40). The structural formation of the letter is significantly unique that makes it almost always identifiable.

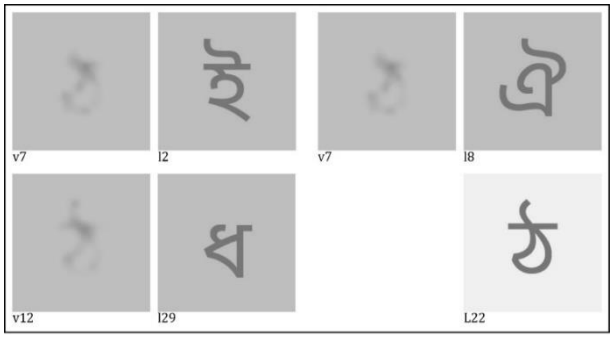


Fig. 5.40: Letter 'Ttha' with other confused letters

Letter 1 (A/ অ)

The letter 'A' is hardly confused with any letter except 'Eyn/ ঍' (Fig. 5.41).

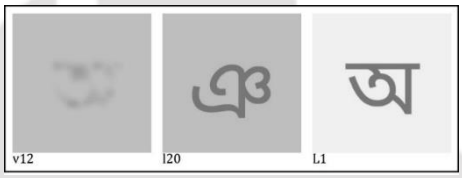


Fig. 5.41: Letter 'A' with confused letters 'Eyn'

Letter 32 (Pha/ ফ)

The letter is marginally confused with 'Ka/ ক' and negligibly with 'Ja/ য' (Fig. 5.42).

- The angle of initial stroke (below Matra) is a key feature for identification.

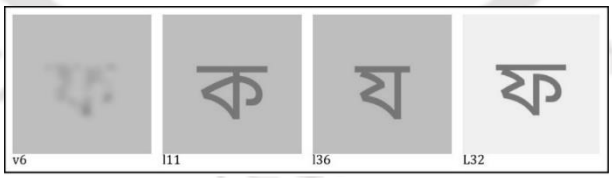


Fig. 5.42: Letter 'Pha' with other confused letters

Letter 3 (Dirgha-E/ ঈ)

The letter is negligibly confused with 'Sa/ স' (Fig. 5.43) and has a unique structural formation.

- The Tail and Leg are important features for identification.

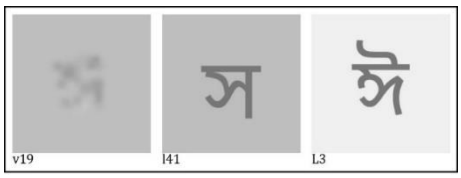


Fig. 5.43: Letter 'Dirgha-E' with confused letter ‘Sa’

Letter 10 (Oyu/ ঔ)

The letter is negligibly confused with ‘Sa/ স’ (Fig. 5.44).

- The Knot is the key feature for identification.

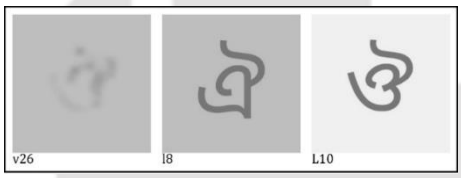


Fig. 5.44: Letter 'Oyu' with confused letters ‘Oye’

Letter 41 (Sa/ স), 8 (Oye/ ঐ), 38 (La/ ল) and 11 (Ka/ ক)

These letters do not account for any confusion with any other letters.

Fig. 5.45: Group of letters with negligible confusion with others

The above analysis has been performed considering the design characteristics of letterforms. The requirement of anatomical features targeted features and omitted features during letter identification have been discussed. Issues related to letter anatomy and their complexities have been identified in the analysis. However, the letter recognition and identification strategies and processes are not discussed here

since it is neither objective of the study nor scope of this thesis. To understand the recognition issues with key anatomical features and letter information processing, further in-depth study is required.

5.2. Grouped based letter analysis

In above section, individual letters were analysed in detail. Here, a grouped based analysis has been done to access the above information of single letters. It is done through collective information of common confusion with a group of letters. The analysis has been done after going through the results of individual letter analysis. Letters with similar issues with anatomical features or space or position related issues have been considered in the analysis. It was done by comparing letters as shown in Table 5.1:

Table 5.1: Categorical letter analysis of Bengali

Cluster	Commonly confused letters	Issues in anatomy
Letter 37, 46, 47 র ৰ ৱ	Letter 29, 33 ধ ব	Visibility of distinctive features – Arm and Matra.
Letter 34, 24 ঢ ভ	Letter 16, 23 চ ড	A threshold gap or termination mark is required.
Letter 37, 43, 44, 45 র ড় ঢ় য়	Letter 23, 24, 33, 36 ড চ ব য	Dot is a key feature.

Letter 16, 24 	Letter 16, 24 	Alternative forms. • Termination for letter 24 (Dha). • Threshold aperture for letter 16 (Cha).
Letter 6, 19 	Letter 6, 19 	Similar structural formation – Delta & double Wedge.
Letter 13, 25, 31 	Letter 13, 25, 31 	Similar structural formation – VStem, Arm and Short Matra.

The clusters of Bengali letters arrive through the issues found in anatomical formation. It has been noticed that Bengali script is sinuous and repetitive at basic structural level. The confusion is more with such group of letters. Distinctive features become more important with such letters since they become crucial to differentiate and contribute in the recognition process.

5.3. Design Approach for single letters

The results of previous studies, individual and cluster letter analysis, were examined further to determine the role of letter feature in design process. The study was undertaken considering the short exposure test and confusion with exposed (original) and confused (masked) letters. The comparison was done across different letterforms and within a group of letter of common structure. In case of common structure group, the distinctive feature was considered as key features to differentiate them. The comparison has been done to identify specific anatomical features of letters. In the following Table 5.2, the critical analyses of features that are easy to perceive are given:

Table 5.2: Recognition and design aspects of Bengali letters

Sn	Letter	Anatomical Feature	Design Feature (critical for identification)	Design Feature (easy for identification)
1	ঙ	Loop	Counter of Loop	Bowl
2	ৰ	Crossbar	Familiarity with the letterform	Delta
3	র	Dot	Familiarity with the letterform, Counter between Delta & Matra	Delta
4	ৱ	Individual Stroke	Counter of Delta and the Gap between Delta and stroke	Delta, Position of Stroke
5	থ	Lobe	the counter between lobe and Vstem	Wedge
6	ভ	Initial & Arm	Counter between Initial and Matra	Bowl
7	ন	Arm	Counter between Arm and Matra	Arm
8	ড়	Dot	Clarity of Dot	Bowl
9	ঢ	Terminal	Counter between Arm & Vstem	VStem, Arm
10	ঢ়	Dot	Dot and surround counter	VStem, Arm & Dot
11	য়	Dot, Initial Stroke	Initial stroke and counter (Stroke path)	Wedge
12	শ	Double Knot	Junction of Knot	Arm, Vstem and joinery
13	ত	Initial	Counter between Initial and Matra	Bowl
14	ছ	counter, shoot & leg	the arrangement of shoot and leg	Counter
15	খ	Initial	the counter between Shoot and VStem	Wedge
16	ণ	Initial	Arm with counter	Arm, Vstem and joinery
17	ড	Matra, Short Stem	The 'T' joinery, Nose	Bowl
18	চ	Counter	The joinery between Arm & Vstem	Vstem, Arm
19	য	Initial stroke, Counter	Counter of Initial stroke, stroke path	Wedge
20	ঝ	Delta, Matra & Double VStem	Counter of Delta, between Matra & Delta, Matra	Double Wedge
21	ঋ	The Arm and Shoot	Design of joinery of shoot and Delta	Double Wedge
22	ট	Vstem, terminal	the counter Arm & Vstem	Vstem, Arm & Upper Tail

23	ম	Counter & Arm	Close counter & Finial (Stroke Path)	Vstem and joinery at middle of Vstem
24	ধ	Arm, Delta	Design of Arm & Counter of Delta	Delta
25	এ	Vstem, Lower Tail	Counter	Vstem with Lower Counter
26	হ	Matra	The counter between lobe and Matra	Lobe & Leg
27	ও	Initial & Joinery	Design of Bowl with joinery	Bowl
28	ঊ	Extra side tail	counter between the bowl and side tail	Bowl
29	ঞ	Symmetrically connected lobe	Counter of SCL & between joinery	Vstem & Lower Tail
30	জ	Arm, Shoot	Close design of the Nose and Shoot	Bowl, Leg
31	ব	Delta, Matra	Counter of Matra and Delta	Delta
32	গ	shoot, Lobe	the counter of Lobe and shoot	Vstem, Lobe
33	দ	Diagonal, Nose	Design of counter between diagonal and Matra	Leg
34	প	lobe, Diagonal	Design of Lobe and diagonal, counter	Vstem, Shoot
35	উ	Terminal of Bowl	Terminal	Bowl, Upper Tail
36	ষ	Initial, crossbar, diagonal of Wedge	Initial of Matra and letter body	Wedge
37	ই	Upper Tail	Junction of Lobe and Leg	Initial of Lobe and Tail
38	ঘ	Initial	Counter of Initial (Stroke path)	Wedge
39	ঠ	Upper tail, close counter	Shape of close counter	Tail
40	অ	Bowl	Counter of Bowl and Vstem	Combination of Bowl and Wedge
41	ফ	Upper diagonal of Delta	the counter of initial of Vstem	Arm, Vstem
42	স			Vstem, Shoot
43	ঐ			Vstem, Lower Tail, Upper tail
44	ঈ	Diagonal, Initial Arm	Stroke Path of Diagonal and Initial Arm	Leg, Tail. Diagonal
45	ল			Arm & Lobe, Vstem
46	ঔ	Upper Tail, Bowl	the counter of bowl	Bowl, Tail
47	ক			Delta, Arm

The above Table 5.2 has been prepared considering the individual and cluster letter analysis with results from short exposure test. Most of the letters have certain features that help letters to perceive easily. The probability value of each anatomical feature from the previous chapter actually explains the effortless identification of letter anatomy. The Table 5.2 is also the result of probability data with respect to their feature confusion. Most of the letters have a few features that are efficiently perceived which makes letter easy for identification. Also, they have few intricate features that create confusion with other letters.

Apart from them, there are few letters such as letter 42 'Sa/ স', 43 'Oye/ ঐ', 45 'La/ ল' and 47 'Ka/ ক', they do not have any complex or intricate anatomical features. Now, the probability value or rank of anatomical features of these letters is higher and their combinations are higher with unique structural formation. An example of letter is 'La/ ল', which has two consecutive Arm connected by a Knot. The structural formation of this letter is unique and the rank of Knot itself is fifth with value 0.826 (Table 4.10, p.137, row 5) which make the letter easy for identification. Letter 'Ka/ ক' has combination of Delta and Arm which is again unique. Thus, unique structural letters are easily identified.

5.4. The Design Guideline

The previous studies have been done to determine the distinctiveness and similarity in anatomical feature. The anatomical features facilitate the letter identification process with intricacy at structural formation. Similar anatomical features appearing in multiple letters need precise attention to identify, also their design should segregate them easily. The distinctive design of the anatomical features can minimize letter confusion at perceived level. If the letters have minimum confused anatomical structure, perceived letterforms will be easy to recognise. The easy and comfortable perception of letters is the legibility of letters (according to the definition of legibility by Beier, 2009; Lund, 1999; Gaultney, 2000). We already know the anatomical

features of Bengali letters (as in Table 4.10, p.137). The crucial features that distinguished identity of letters are explained in Table 5.2. Apart from this information, Bengali letterforms have few structural characteristics in their formation. They are –

1. Common letter feature –

As discussed, Bengali letterforms have repetitive structure at basic level (see Section 5.2). They were categorised in Section 3.5 considering different aspects of anatomical formation. Few examples are given in the following Table 5.3 –

Table 5.3: Common letter feature

Features as in Table 4.10	Letters	Characteristics
2, 3, 4	ৰ র ৱ	Delta with minor variations
5, 11, 15, 19, 31, 36, 38	থ য় খ য ব ষ ঘ	Wedge, VStem
6, 8, 13, 17, 27	ভ ড় ত ড ও	Bowl
7, 16	ন ণ	Arm, VStem
9, 10, 18, 22	ঢ ঢ় চ ট	VStem, Arm, Terminal
20, 21, 24	ঝ ঋ ধ	Delta, Wedge, Extra VStem
32, 34	গ প	VStem, Arm

2. Representation of ascending and descending features –

Bengali letters do not have ascenders or descenders. They have few features that expand up to down below like 'upper tail' or 'leg'. These limits define the standard body height of letterforms (as in Fig. 5.46).

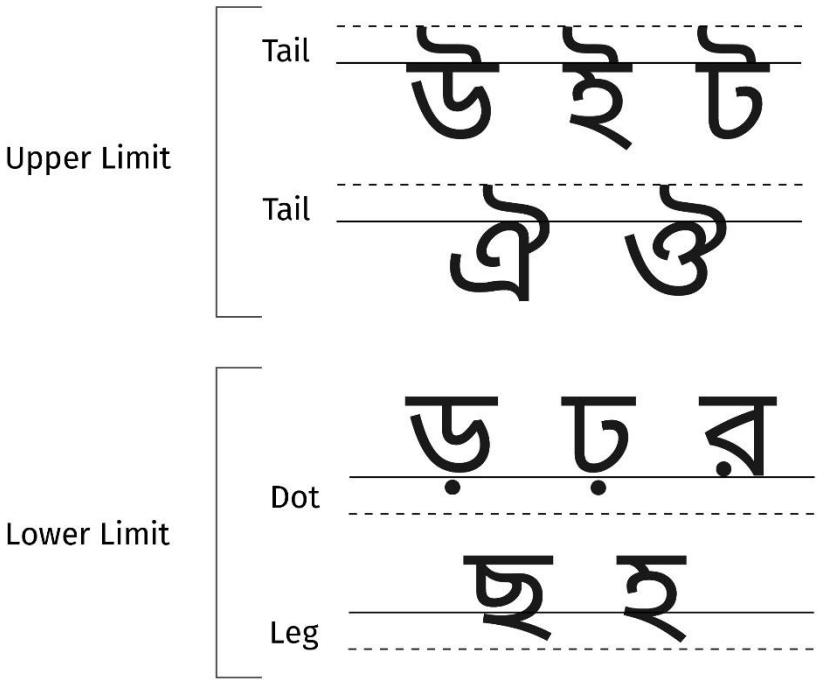


Fig. 5.46: Body height of letters

3. Representation of Matra and without Matra letters

There are six vowels and nine consonant letters in Bengali that do not have Matra. Rest of the letters have Matra in Bengali.

Fig. 5.47: Letters with and without Matra

Now, considering the script characteristics and previously analysed letters (individually and as cluster), following Table 5.4 is prepared to understand the holistic characteristics of the script. The letterform characteristics are derived from the letters confused by the participants in Section 5.1 with a correlation to letters that are provided in the above Table 5.4.

Table 5.4: Script Characteristics

Characteristics	Letters	Features (Number denotes row in Table 4.10)
I. Complex Letters		
Junction and counter (among strokes) of two letter strokes.	জ ছ ঙ	5-Knot, 6-Joinery of Curl & Leg, 8-Extra Tail, 11-Bowl, 21-Double Knot, 22-Joinery of Tail & Bowl, 31-Nose, 34-Joinery of Arm & Shoot
	ঙ - Most confused letter (see) ছ - Confused with many letters জ - Confusion pattern like ঙ	
II. Wedge Characteristic		
The relative angle of a stroke.	ব য জ	6- Joinery of Curl & Leg, 9-Joinery of Delta & Matra, 13-Joinery of Lobe & Leg, 16-Joinery of '>' & Wedge, 23-Junction of '<', 26-Curl, 33-Junction of VStem & Nose
	ব - Confused with many letters, Wedge য - Confused with many letters, Wedge, Initial, '>' জ - The stroke shoot and Leg Common Features: Wedge - অ, ঝ, অ, ঋ, ফ, ষ, য Critical Features: Shoot & Leg Junction - জ	
III. Bowl Characteristic		
Different characteristics of Bowl.	ভ ড় ত ড ও	11-Bowl
	ভ - Confused with ড, ত	
IV. Shape of Counter		
Appearance of Close Counter.	ব ঘ চ য	2-Delta, 4-Loop
	Counter shapes	

V. Aperture		
Different characteristics of Aperture.	ত ভ খ	11-Bowl, 35-Arm
	ত - Confused with ভ Common Features: Initial/ Finial - ত, আ, অ, খ, য, থ Short Matra - খ	
VI. Double Wedge		
Design of Extra/double Wedge.	ঝ ঋ	3-VStem
	Critical Feature: Delta & Shoot Junction	
VII. Thin Letters		
Design of (curve to VStem) joinery with short Matra.	প গ ণ	32-Junction of HStem & Arm
VIII. Dot Feature		
The appearance (position and counter) of the Dot feature.	য় ড় ঢ় র	1-Dot/ Bindu
	Critical Feature: Dot - ঢ়, ড়	
IX. Tail Feature		
The appearance of the upper tails with appropriate length.	উ ই ট ঐ ঔ	12-Upper Tail
	Common Feature: Matra & Tail Junction - ট, ঠ	
X. VStem Position		
Position of the Vertical Stem - to control the horizontal proportion of the letters	অ ক চ	28-Wedge
	V Stem (Right Side): অ আ ঋ এ খ গ ঘ ঝ ণ থ ধ ন প ব ম য র ল শ ষ স য় ৰ ৱ V Stem (Left Side): চ ছ ট ঢ ঢ় V Stem (In-between): ঐ ক ঞ ফ	

Based on the information above, a design guideline is prepared. It can be useful for designers to retain the structural balance with legible form of letters. The guidelines are suggestions to be considered during design process. It can be useful to avoid structural flaws during design that causes illegibility. The design process of letterforms is not bounded by any rules to follow. It is designers' instinct that drives the process of typeface design. The guidelines are only for aiding them to make their typeface legible across different mediums. The guideline is proposed in following Table 5.5.

Table 5.5: Design Guidelines

Design	Letters
Junction and counter (between strokes) of two curves.	জ ছ ঙ
The relative angle of a stroke (curve or straight line) with appropriate counter space.	ব য জ
Different characteristics of Bowl.	ভ ড় ত ড ও
Appearance of close counter.	ব ঘ চ য
Aperture/ gap between two near curves or terminal.	ত ভ খ
Design of Extra/double Wedge (other discriminating features are crucial).	ঝ ঋ
Design of (curve to VStem) joinery with short Matra.	প গ ণ
The appearance (position and counter) of the Dot feature.	য় ড় ঢ় র
The appearance of the upper tails with appropriate length.	ঊ ই ট ঐ ঔ
Position of the Vertical Stem - to control the horizontal proportion of the letters.	অ ক চ

The design process of letters involves idea, strategy, approaches and design specifications. One of the first steps in the design process is designing of few first letters. The first set of letters helps to determine the design vocabulary of the typeface. The harmony and balance among letterforms can be maintained further to design the rest of the letterforms. There is no such guideline for designing letters in Bengali that can maintain the harmony and balance in design. The common characteristics of letters have been already proposed in Table 5.4. A new Table 5.6 has been prepared to identify the letter with basic anatomical features.

Table 5.6: Letters for Design first

Anatomical features in Table 4.10 (p.137)	Letters	Characteristics	Letter(s) with basic anatomical features
2, 3, 4	ৰ ৱ ৱ	Delta with minor variations	ব
5, 11, 15, 19, 31, 36, 38	থ য় খ য ব ষ ঘ	Wedge, VStem	য খ
6, 8, 13, 17, 27	ভ ড় ত ড ও	Bowl	ভ ড
7, 16	ন ণ	Arm, VStem	ণ
9, 10, 18, 22	ঢ ঢ় চ ট	VStem, Arm, Terminal	ঢ ঢ় চ

20, 21, 24	ঝ ঋ ধ	Delta, Wedge, Extra VStem	ব
32, 34	গ প	VStem, Arm	গ
11	ত অ	Bowl	অ

The letters that have fundamental structure is introduced in Table 5.6 (fourth/ last column). The grid system of the script comprises multi-tier that has to fit within body height (Ross, 2009). Thus, it is necessary to consider those letters during initial phase of design to create the visual balance within a typeface. The final set of letters is proposed in Table 5.7.

Table 5.7: Proposed Letters to Design

Letters	Strategy for Design
অ ড খ গ ব য ঢ চ	They are the basic letterform of common group letters with standard body height of letterforms.
ঊ ট ই	The ascender or tail can be defined by these letters.
ঢ় ড় ই	The descending height of the letter body can be defined by them.

5.5. Conclusion

The chapter made a detailed analysis of Bengali letterforms. The crucial anatomical features that have issues with identification were discussed in details from anatomical perceptive. Anatomy is the backbone of letterforms. If letters have problems with their anatomy, it can be rectified at various stages of typeface design. Here, the analysis was done with respect to the designing of letterforms.

The study was intended to provide assistance in the design process to achieve legibility in letterforms. Critical anatomical issues were identified to understand with the letter identification issue. The solution to letter identification issue can reduce the illegibility problem to certain extent. There can be other aspects of illegibility which is not part of this thesis, only anatomical issues were considered for the study. The

analysis concludes by proposing a set of key anatomy of letterforms that can be considered during design of letterforms to improve legibility. In the next chapter, the conclusion of this thesis has been drawn with significance, findings, contributions and limitations of this research.

Chapter Six

Conclusion

A script consists of letters, numbers and punctuation marks. A 'typeface' is the design of those letters, numbers and punctuation marks. A typeface can represent many scripts that share common design. Bengali is a Non-Latin script used by the Bengali population in the eastern part of India and Bangladesh.

The initial objective of the research was to determine the anatomy of Bengali script. During the study, it was found that there is a lacuna in methodology to define Indic or Bengali typeface anatomy. Its discussion is rare in any existing literature. It is only in the last two decades, non-Latin including Indic typefaces are getting attention from the research community. This, in turn, has enabled to look into the existing process of defining the anatomy of typefaces from a comparative point of view. Anatomical studies that identify the nomenclature of letter-parts do not follow any standard methodology. In many cases, the anatomical knowledge of non-Latin typeface is borrowed from the Latin typeface, which might be inappropriate. Also, it is unjustified to compare the anatomy of Latin with Bengali as there are no diacritics in Latin or lowercase letters in Bengali. The letters of a word usually do not touch one another by a common stroke in case of Latin script. But, it touches each other at Headline or Shiro-rekha in word formation in Bengali. Therefore, it is not justified to define anatomy with Latin nomenclature.

One of the purposes of typeface is to achieve 'legibility'. The term legibility refers to the design quality of letterform that is understandable without any hesitation. It is also the reason for making typefaces unique and promoting its exclusiveness. This design philosophy of typeface indicates the purpose of creating

typefaces. Legibility is a term that is defined by many designers and researchers in various contexts while discussing design process. Some definitions have common objectives and some have a different statement altogether. The context of legibility refers to the various designations of reading such as – 1. Legibility of letters, 2. Legibility of words and 3. Legibility of continuous text (Tinker, 1944, 1963; Lund, 1999; Beier, 2009). The literature reveals that reading of continuous text is the collective influence of context on lexical processing. In such a position, the letter legibility is important in the context of word recognition. Distance reading such as signboards, road signage and graphic-textual communication is the context where visual letter recognition is primarily considered. In such cases, the legibility of letters is crucial since the meaning-making of the word structure relies on the letters of the word. According to Sofie Beier (2009), the legibility is described as the clarity of letters while influenced by typeface familiarity (Beier, 2009).

The legibility parameters that are found in the literature are x-height, Letter height, Stroke weight & width, Stroke contrast, Stroke density, Terminals and Gridlines. These parameters are potential constructs to measure legibility. But few of them are proven to be a true predictor of the legibility. The process of designing a typeface does not involve any legibility measurement criteria. Most of the understanding and information are derived from visuals and practices in the field where designers and researchers work together.

To understand the legibility issues with Bengali script, first the understanding of the 'script grammar' is essential. The anatomy of the letterforms, vowels, consonants, conjuncts, diacritics and the word formation are the key to this knowledge domain. There is a rich literature on the script composition grammar that discusses the structure of languages. The diacritics position, ligature formation, formation of conjunct, role of vowels and consonants in conjunct and their position during formation are sharply defined in literature. However, not much literature is available on the anatomy of letterforms which is the foundation of type design.

Considering anatomy as a major aspect of type design, this research was commenced to contribute in the domain of type design. The first chapter discusses Bengali script, evolution of the script, and writing style. Apart from the overviewing of Bengali script, a broad understanding of typeface, typeface anatomy, design process of typeface with motivation and research gap, research assumption and the methodological framework have been proposed here.

In chapter two, the literature on typeface anatomy and legibility are briefly discussed. The aim of the research is to prepare a guideline for designers to address the legibility issues. Anatomy and legibility are co-related. Anatomy defines the structure of letters that have to be perceivable. If the letters are understandable, then they are legible also by definition of legibility. In this chapter, a brief discussion on lacuna in research has been discussed with the research problem. According to problem formulation, the study was organized in three different phases. They are –

- Systematic formulation of typeface anatomy of Bengali
- Legibility measurement and identification of important letter-features
- Proposing support for type designers

The literature review was done in two stages. In the first section, the anatomical study of the Latin and non-Latin typefaces with specific focus on the Bengali have been discussed. The anatomy of Bengali script has been mostly borrowed from the Latin. Use of anatomy in Latin anatomy in context of Bengali may not be an appropriate proposition considering the script grammar. The origins of Latin and Bengali scripts are different. The indigenous characteristics of Bengali script are not similar to Latin. The structural formation and complexity of these two scripts are distinct. Anatomy and legibility of Bengali typefaces, therefore, need to be studied separately. Therefore, the possibilities in research include creation of anatomy of Bengali script, identifying the role of anatomy in typeface legibility, measuring

legibility and to establish the important anatomical features for letter identification. We also conclude that the letter perception without any visual hesitation is a process of measuring the legibility. Therefore, the visibility of the visual feature is crucial for letter identification. These features further can contribute to the design process of the letters that may aim to increase the visibility of the form. Considering the scope of the research, the study is limited to defining the anatomy of Bengali letterforms and important letter feature for letter identification task.

In literature, there is no standard method to define the anatomy of the letterforms for Bengali. There were few attempts to define anatomy by researchers and they lack systematic approaches in the process. Further, there are no previous studies that indicate the important letter feature for the identification purpose in Bengali. Considering the gap in research, it is aimed to determine the anatomy of Bengali letters and provide a guideline for the designer. The Design Research Method (DRM): Type 2 has been adopted for the study.

Chapter three consists of anatomical study of Bengali letterforms. A systematic method of defining anatomy was formulated to analyse the Bengali letterforms. A semiotic method was employed in combination of syntactic and semantic methods. At syntactic analysis, the letters are dismantled retaining the single stroke unit. Later, they are grouped according to common characteristics with an appropriate name in the semantic study. The semantic study comprises two stages of analysis - syntagmatic and paradigmatic analysis. The syntagmatic analysis is used to determine the letter anatomy with nomenclature. Paradigmatic analysis is used to validate the anatomy by revisiting the results across different typeface. The method is repeated measurement technique with multiple typefaces. The study is further extended to the categorization of letters in prescriptive study.

In chapter four, the role of anatomical features is established that contributed to letter identification process. The chapter is divided into two parts, in part A the

role of anatomical features is determined in Bengali letter recognition. The crucial anatomical features for letter recognition are identified in part B. In part A, an eye-tracking study was conducted to identify the role of visual features in letter recognition. The study found out that both common and specific letter features are responsible for letter recognition. The combination of both features leads to the uniqueness of each letter.

Part B of chapter four is about the identification of the anatomical features with respect to the Bengali script. A short-exposure test with masked letters was commenced to reveal the important features. Masked letters are made of bubbles or holes as a window of exposed anatomical features. The data analysis determines fifty-one distinct features that are important for letter recognition. The experiment also revealed that letter features are crucial for letter recognition. Also, the combination of letter features makes letterforms unique in structure. The combination of features, therefore, plays a significant role in Bengali letter identification.

In chapter five, a design guideline has been proposed. The guideline was concluded by the previous eye-tracking data and short-exposure data. The data of individual letters from short-exposure test has been analysed qualitatively. The analysis provides a guideline for individual letters. Also, data of a group of letters as a cluster was analysed to propose a general guideline for Bengali script. During the analysis, it was noticed that the repetitive special distribution of letter stokes is a major issue of letter confusion. Individual anatomical features for each letter were identified to study the identification issues. The study also proposes that a group of letters that can be designed initially, to begin with the design process of Bengali letterforms. If the structural complexities are initially sorted out with basic letterforms, the less legibility issues can be faced at later stages.

The research was started by identifying the legibility issues around the Bengali typefaces. The problems had emerged from the quality of the fonts that are used in

daily basis in digital platform. The inquiry began from there and the literature led to the direction of letter anatomy study. It is one of the causes of legibility issues that have been considered for this study. The fundamental knowledge of letter anatomy was the main lacuna that has been addressed in this research. Considering that lacuna multiple anatomical aspects with letters were identified. A guideline has also been proposed that could be considered during design. The guidelines will be useful for the type designers during designing of letterforms for future use.

6.1. Significance of the research

The research is in the domain of Typeface Design. The research has been done to understand the anatomical knowledge and its use in letterform legibility. In other words, the knowledge of anatomy has been transferred to solve the legibility issue keeping in mind the reachability of the design domain. The research has been done in following stages –

- Problem formulation in the domain of type design
- Understanding of Bengali typeface anatomy
- Developing the anatomy of Bengali
- Formulating the process of anatomical knowledge in legibility
- Evaluating the method of anatomical representation in legibility

The Latin typeface has been enriched by researchers across the world and it is considered to be one of the primary languages in global communication. Chinese is one of the leading language and script after Latin. Bengali, on the other hand, is also considerably larger and holds the seventh position globally in terms of spoken language. Therefore, the use of the script is increasing with the need for new fonts for

print for digital purposes. The quality of font production is a major concern now. The thesis clearly discusses the research gap in the domain of type design.

At present, there is hardly any legibility research on Bengali typeface. The quality of the fonts is merely a consideration when font production in Bengali is more challenging. With the beginning of the UNICODE and OpenType fonts, many technical challenges and keyboard layout have been solved. Now, it is the appropriate time to consider the legibility and the design of letterforms earnestly.

6.2. Findings of the research

The research has been done to understand the anatomical feature and letter legibility issues. The key findings of the research are as follows –

- In the anatomical study, it offers twenty distinct anatomical parts of letters with nomenclature.
- The major contribution of the research is the identification of important visual feature. Fifty-nine (59) different anatomical features have been identified in the context of Bengali typeface that is important for letter identification. Among them, 34 features are significant in the process of letter recognition.
- The study concludes that the combination of the anatomical features is explicit in process of letter recognition. The distinctive design of the anatomical or visual features minimizes the letter confusion by maximizing the visibility of the letters.
- The study suggests few letters that can be designed initially to maintain a design grammar of the typeface.

6.3. Contribution of the Study

The major contribution of the research is following –

- There was hardly any methodology available for defining the typeface anatomy in Bengali. The study, in contrast, offers a systematic method to define the typeface anatomy using a semiotic method.
- The study proposes a set of anatomical letter-parts that may be useful for the OCR systems for the purpose of the detection of the letters.
- The study, in the end, proposes a set of design features that are vital for letter identification. The design features are proposed based on the results of short exposure test.
- A design guideline has also been proposed at the end of the study. The guideline can facilitate designers to achieve legibility in designing Bengali typeface.
- The study contributes to the area of visual word recognition where letter structure is essential in reading such as signage, billboards and hoardings. Reading of letters is very crucial in these cases since word communication is of primary concern of these mediums.

6.4. Limitation

There are few limitations of the study –

- The study has been done only with the digital typeface that is mostly used for reading purposes. The handwritten letterforms and calligraphic typefaces are not considered during the study.

- The anatomical analysis is limited to the basic letterforms i.e. Vowels and consonants which have twenty letter features. Conjuncts are not considered in the study.

- The readability study is executed considering on-screen reading. Print-based reading study is not performed here.

- The eye-tracking study has been done retaining the familiarity factor in the process of letter identification without control of the study.

6.5. Future Scope

The future scope of the present research includes the following-

- The anatomical analysis is limited to the basic letter set i.e. vowels and consonants. The conjuncts can be considered further in the detailed analysis.

- The 'stroke-joinery' relationship model can be tested in future.

- The anatomical features can be used in OCR system for detection of letters.

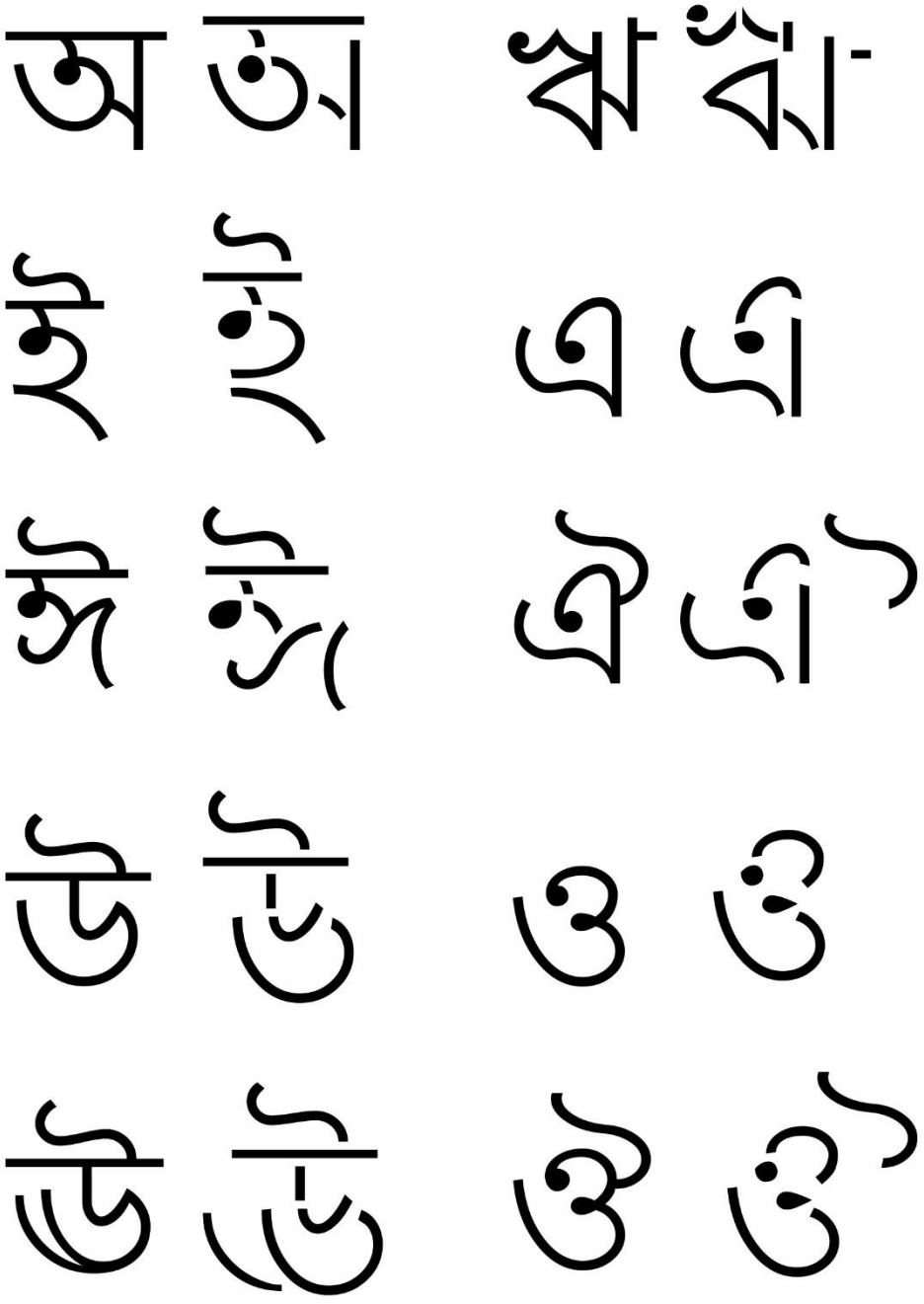
- The visual features have contributed to the letter processing that we have established in the study. But how they are doing or contributing to the recognition process needs to be investigated separately.

- The next possibility of the short exposure is to evaluate the letters with the diacritic or vowel-signs. The identification task may be different with the diacritic features. The diacritic or vowel mark signs (in case of Bengali) are positioned in all four different sides of letters. Therefore, contribution of the orthographic features is inevitable. Evaluation of such letters with feature holds significant scope in future research.

- The letter legibility in the context of word is one possible way to measure legibility. It is a fact that Bengali words are connected by the horizontal line known as Matra. They are hanging from the top line (Matra line) but not sitting on the baseline like Latin. The word formation structure is different from Latin. There is a huge scope for understanding the reading format of the word in terms of letter legibility.

Appendix I

Disintegration of letter-parts, Vowels –



Disintegration of letter-parts, Consonants –

ক	◌ি	ঝ	◌া
খ	◌া	ঞ	◌ি◌া
গ	গ◌া	ট	◌ি
ঘ	ঘ◌া	ঠ	◌ি
ঙ	◌ঁ	ড	◌ি
চ	চ◌া	ঢ	◌ি
ছ	◌ি	ণ	ণ◌া
জ	◌ি	ত	ত
থ	থ◌া	ম	◌া


দ
য
ধ
র
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ব
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ৱ

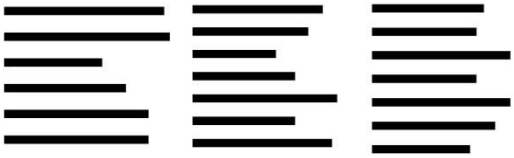
Appendix II

The result of syntactic analysis of Bengali letterforms –

Vertical Stem (VStem) : **S1**

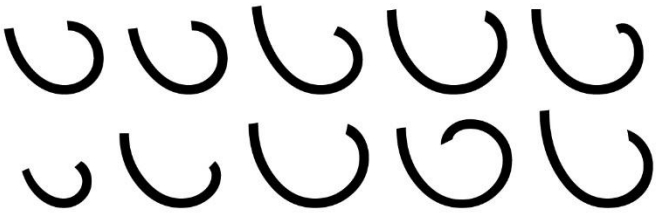
Short Vertical Stem (VStem) : **S2s**

Vertical Stem (VStem) : **S1a**



Horizontal Stem (HStem) : **S2**

Short Horizontal Stem (HStem) : **S2s**



Rounding : **S3**

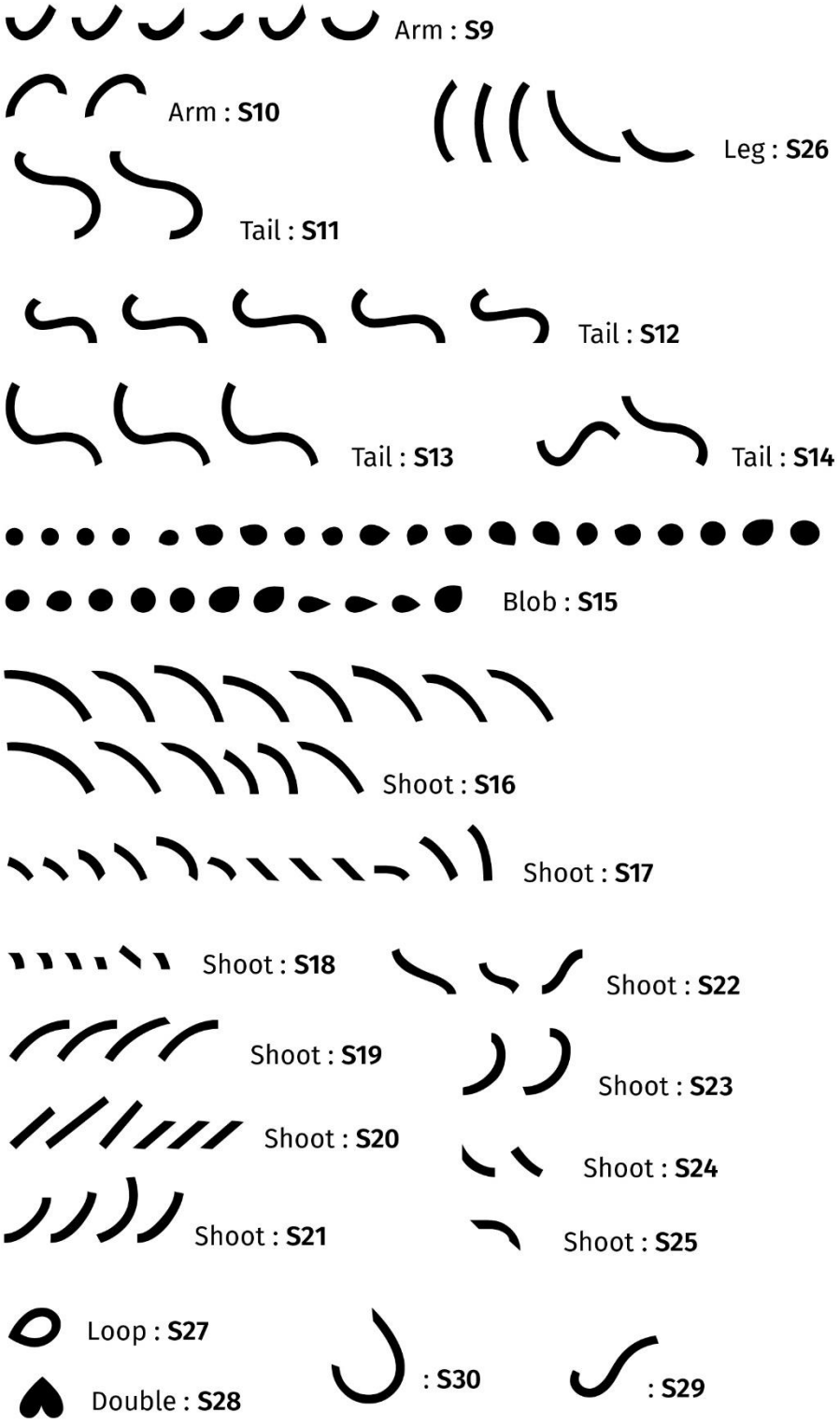
Rounding : **S4**

Rounding : **S5**

Rounding : **S6**

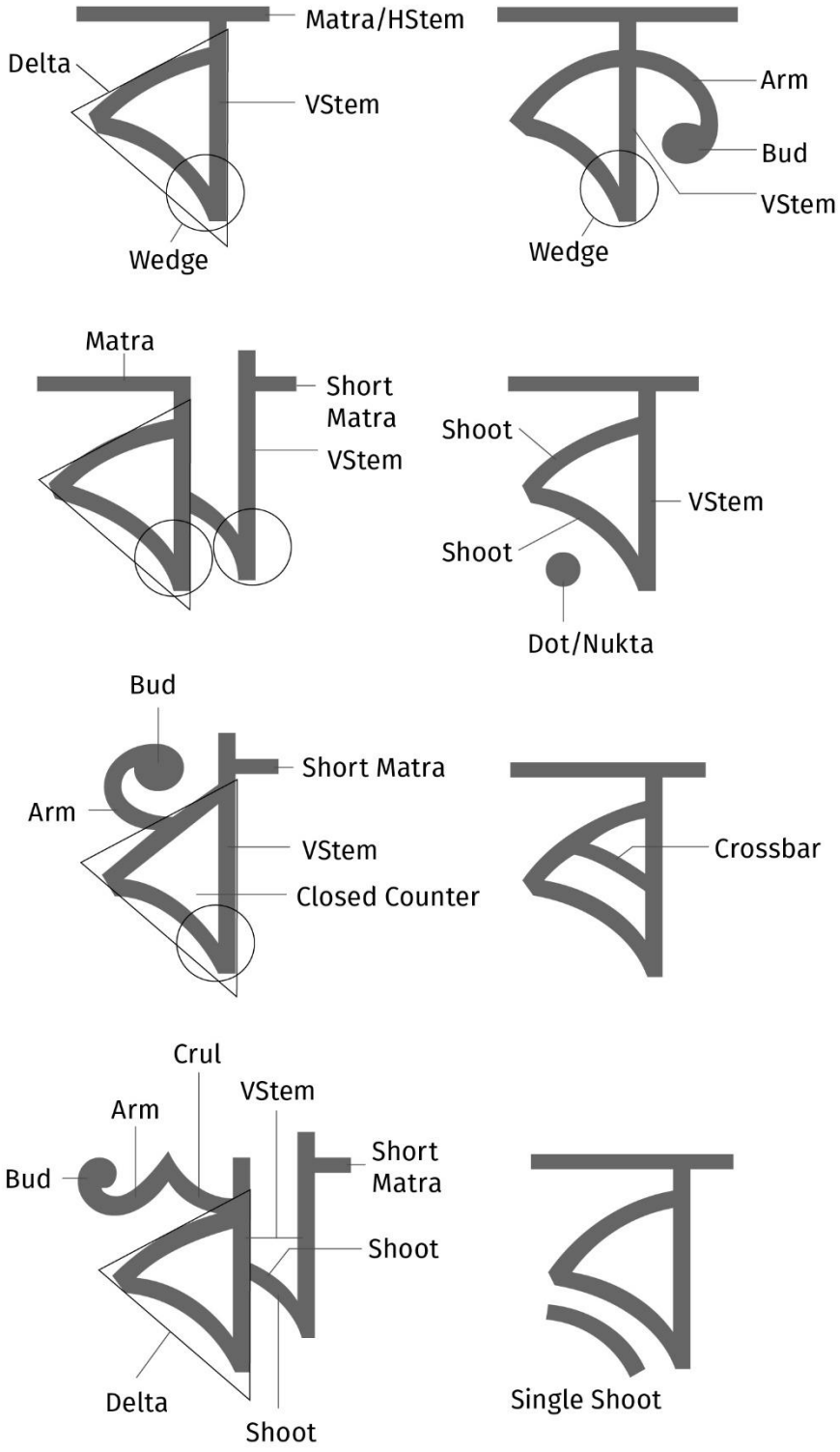
Rounding : **S7**

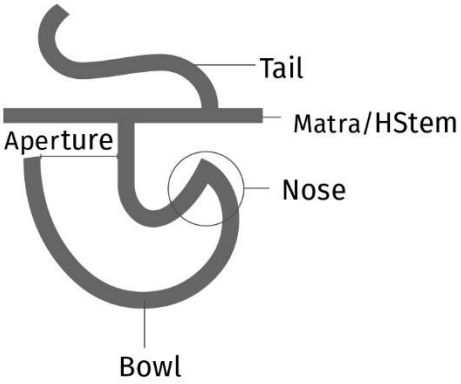
Rounding : **S8**

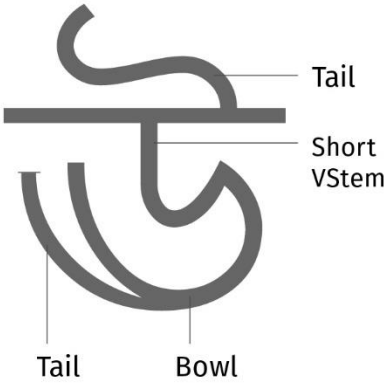


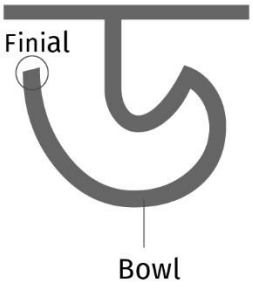
Appendix III

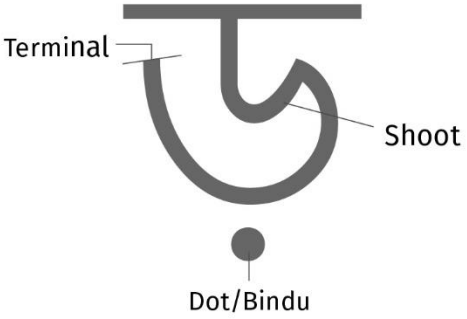
Syntagmatic analysis of Bengali letterforms –

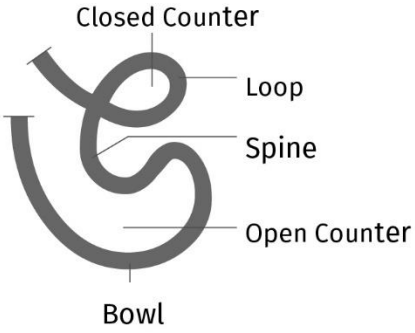


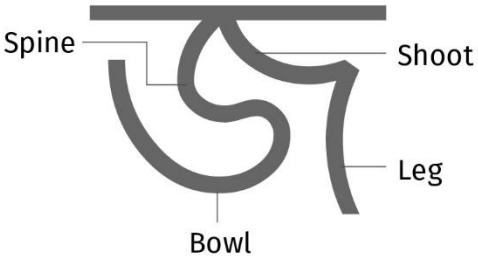


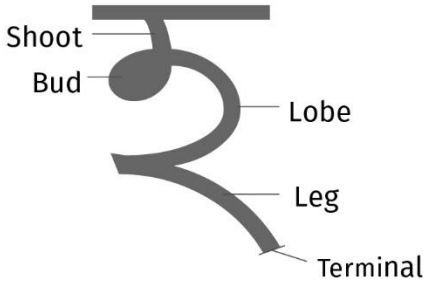


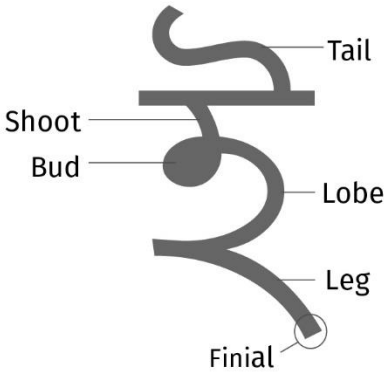


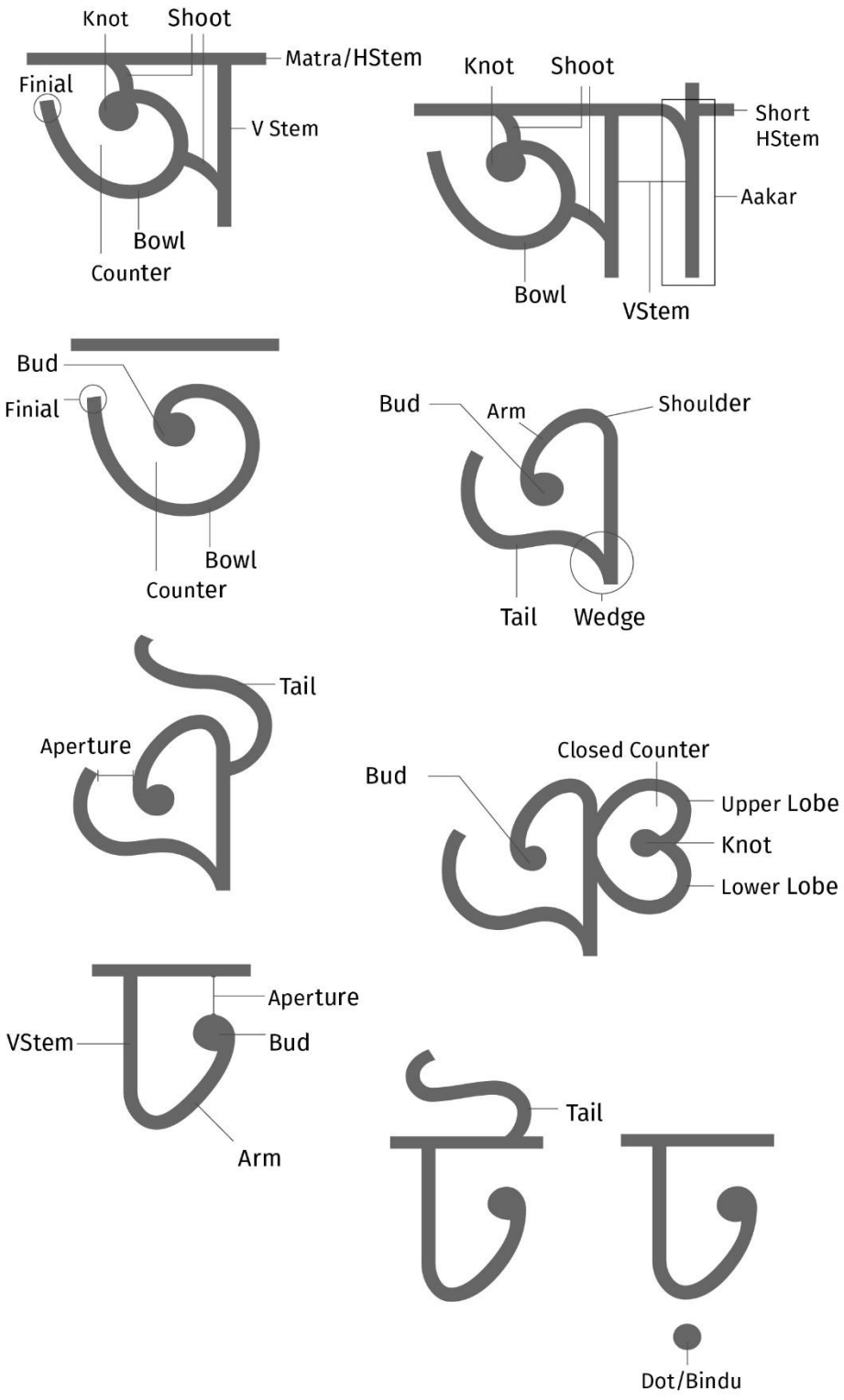


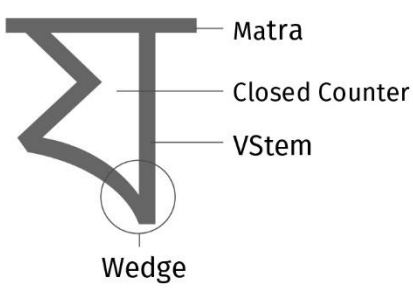


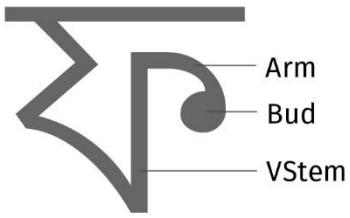


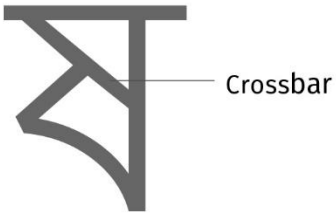


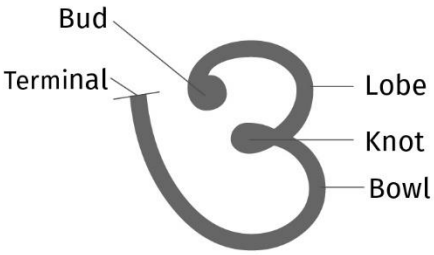


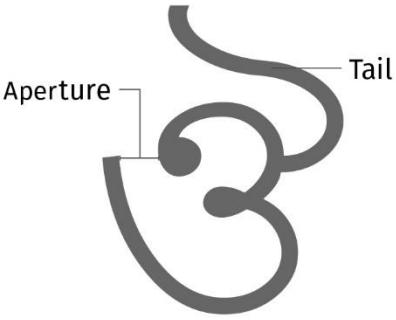


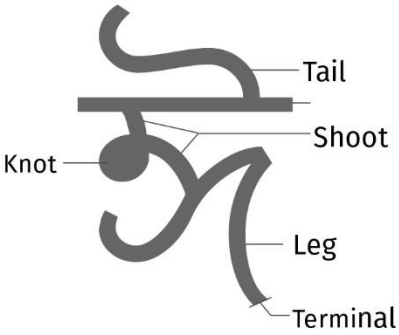








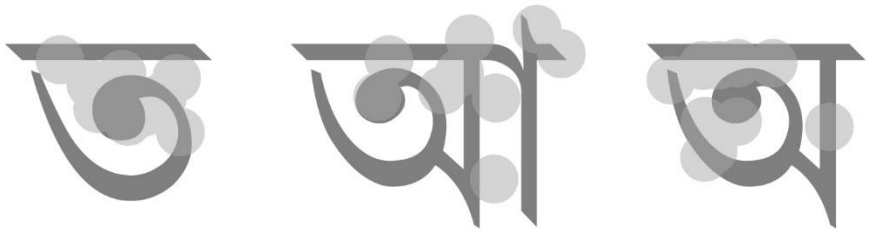




Appendix IV

The heat-map and fixation data of letters are given below:

1. Letters – ত, আ, অ



Participant	Fixation(s)	Exposed Letters - ত, আ, অ
S1	2	Counter and/ between Matra & Bowl ত
	7	The 'T' junction of আ
	8	Counter and/ between Matra & Bowl আ
	10, 11, 12	Counter and/ between Matra & Bowl অ
S2	2	Counter and/ between Matra & Bowl ত
	6	Counter and/ between Matra & Bowl আ
	7	VStem of the আ
	8	Finialof অ
	9	Initial of অ
S3	1, 2	Initial of ত
	3	Counter of Matra & Bowl & VStem আ
	4	The 'T' junction of আ
	5	Counter and/ between Matra & Bowl অ
S4	4	Bowl of ত
	5	Wedge and the 'Aakar' of আ
	7	Bowl (near Finial) of অ

S5	2	Counter and/ between Matra & Bowl ত
	4	Counter between VStems of আ
	5	Finial of the অ
	6	VStem of অ
	9	Wedge of আ
S6	2	Bowl of ত
	4	Counter and/ between Matra & Bowl ত
	5	Counter between VStems of আ
	7	Counter and/ between Matra & Bowl অ

2. Letters – ঝ, অ, খ

Participant	Fixation(s)	Exposed Letters - ঝ, অ, খ
S1	16	VStem of ঝ on Wedge)
	17	Counter and/ between Matra & Bowl অ
	18	Initial of the খ
	20	Counter between VStem of ঝ
S2	11, 12	Wedge & VStem of ঝ
	14	Finial of অ
	16	Counter and/ between Matra & Bowl অ
	18	Near to Nose of খ
	19	Initial Arm of খ

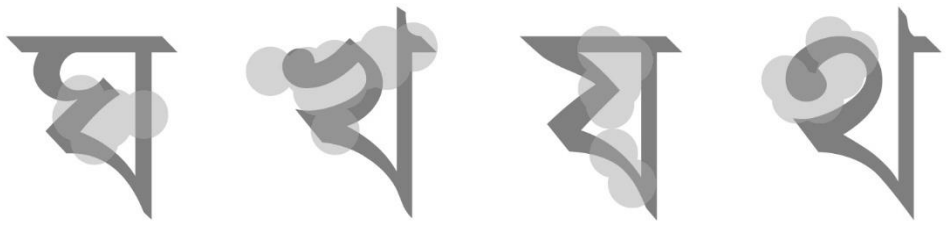
S3	9	Counter between VStem of ঝ
	12	Counter and/ between Matra & Bowl অ
	18	Nose of খ
	19	Finial of অ
S4	12	Wedge & VStem of ঝ
	13	Bowl (near Wedge) of অ
	14	Wedge of ঝ
	17	Junction of Arm & Wedge of খ
	18	VStem of অ
S5	10	Wedge of ঝ
	12	Counter near VStem & Matra of অ
	13	Junction of Arm & Wedge of খ
	14	Initial of অ
	15	Wedge of ঝ
S6	11	VStem of Wedge of ঝ
	15, 17	Counter near VStem & Matra of অ
	18	Initial Arm of খ
	19, 21	Counter and/ between Matra & Bowl অ

3. Letters – য়, ফ, ষ, য

Participant	Fixation(s)	Exposed Letters - য়, ফ, ষ, য
S1	28	On Wedge near to Dot of য়
	29	Junction of VStem & Arm of ফ
	31	Crossbar of ষ
	35	Counter near Matra of য
S2	22, 23	Junction on '>' of য়
	25	Dot of য়
	27	Wedge of ফ
	29	Arm of ফ
	33	Counter between Crossbar & Matra of ষ
	35	Wedge of য
S3	25	On Wedge near to Dot of য়
	27	Arm of ফ
	28	Matra & Counter between Crossbar of ষ
	32	Initial of ষ
	35	Counter of য
S4	28	Wedge of য়
	30	Junction on '>' of ফ
	32	Junction on '>' of ষ
	34	Crossbar of ষ
	36	'<' Junction of য

S5	17	Counter of য়
	18	Dot of য়
	20	Wedge of ফ
	21	Arm of ফ
	22	'<' Junction of ষ
	23	Crossbar of ষ
	24	'<' Junction of য
S6	25	Wedge of য়
	26	'<' Junction of ফ
	27	Arm of ফ
	30	Initial of ষ
	31	Crossbar of ষ
	33, 34	Initial of য

4. Letters – ঘ, খ, য, থ



Participant	Fixation(s)	Exposed Letters - ঘ, খ, য, থ
S1	38	Junction of Initial & '<' of ঘ
	40, 41	Near Nose & VStem খ
	42	Counter near Initial of য
	43	Initial of ঘ
	45	Initial of থ

S2	39	'<' Junction of ঘ
	43	Initial of ঘ
	44	Initial of খ
	45	Nose of খ
	47, 48	Junction of '>' of য
	53	Initial of থ
	55	Initial of য
	56	Initial of খ
S3	36	Wedge of ঘ
	38	Initial of খ
	39	Near Nose & VStem খ
	40	Initial of য
	42	Initial of য
	44	Initial of থ
S4	41	VStem of ঘ
	43	Wedge of খ
	44	Wedge of য & surround
	48	Initial of থ
S5	27	'<' Junction of ঘ
	28	Arm of খ
	29	Counter near Wedge of য
	30	Initial of থ
S6	36	Wedge of the ঘ
	40	Nose of খ
	43	Initial of খ
	48	'>' Junction of য
	54, 55	Initial of থ

5. Letters – ঢ়, ভ, ট

Participant	Fixation(s)	Exposed Letters - ঢ়, ভ, ট
S1	46	Terminal/ Finial of ঢ়
	47	Dot of ঢ়
	50	Terminal/ Final of ভ
	51	Counter of ভ
	54	Junction at Matra ট
S2	57	Terminal/ Finial of ঢ়
	58	Dot of ঢ়
	61	Counter of ভ
	66	Junction at Matra ট
S3	50	Terminal/ Finial of ঢ়
	52	Terminal/ Final of ভ
	54	Upper Tail of ট
S4	57	Arm of ঢ়
	59	Arm of ভ
	61	Terminal/ Final of ট
S5	31, 32	Terminal/ Finial of ঢ়
	35	Terminal/ Final of ভ
	37	Terminal/ Final of ট

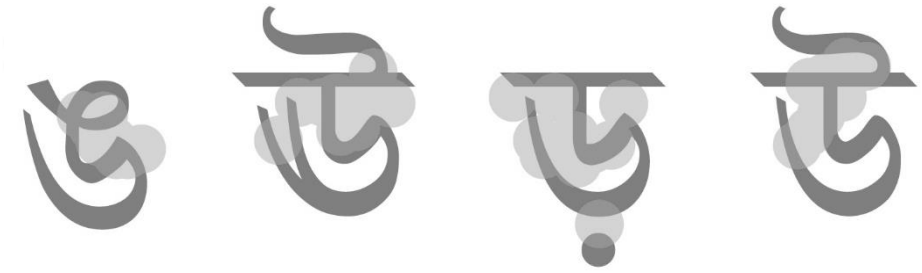
S6	61	Arm of ঢ
	62	Dot of ঢ়
	64	Terminal/ Final of ঢ
	70	Joinery of ট

6. Letters – ঢ, ট, ঠ

Participant	Fixation(s)	Exposed Letters - ঢ, ট, ঠ
S1	56	The HStem of ঢ
	59	Joinery at Matra of ট
	60	Upper Tail of ট
	61	Joinery at Matra of ঠ
S2	69	'T' Junction at Matra ঢ
	72	Joinery at Matra of ট
	74	Upper Tail of ট
	76	Joinery at Matra of ঠ
S3	58	Close Counter of ঢ
	61	'T' Junction of ঢ
	62	Joinery at Matra of ট
	63	Arm of ঢ
	65	Upper Tail of ট
	66	Joinery at Matra of ঠ

S4	65	Arm of চ
	70	Terminal/ Finial of ট
	73	Counter near Matra of ঠ
S5	38	HStem of চ
	39	VStem of ট
	41	Shoot/ Initial stroke of ঠ
	42	Terminal/ Final of ট
S6	75	Junction of Arm & HStem
	77	On VStem neat Terminal/ Finial of ট
	81	Joinery at Matra of ঠ

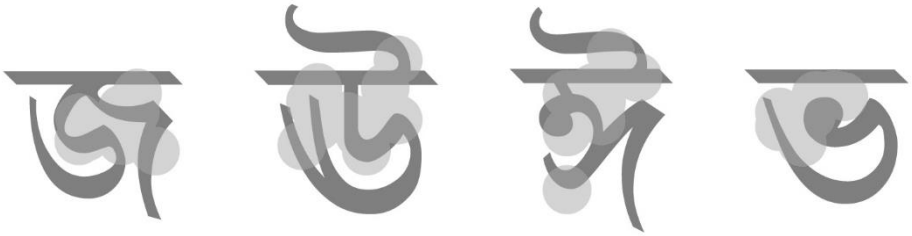
7. Letters – ঙ, ঊ, ড়, ঊ



Participant	Fixation(s)	Exposed Letters - ঙ, ঊ, ড়, ঊ
S1	67	Nose of ঙ
	68	Loop of ঙ
	69	Junction of Matra & Upper Tail ঊ
	70	Terminal/ Finial at Bowl of ঊ
	74	Short Stem of ড়
	79	'T' Junction of ঊ
	81	Terminal of ঊ
	82	Short Stem of ঊ

S2	80	Loop of ঙ
	81	Nose of ঙ
	82	Terminal/ Finial at Bowl of ঊ
	86	Terminal/ Finial at Bowl of ড়
	89	Nose of ড়
	90	Lower of Bowl of ড়
	92	Terminal/Finial at Bowl of ঊ
S3	72	Nose of ঙ
	73	Loop of ঙ
	74	Nose of ঊ
	78	Nose of ড়
	80	Upper Tail of ঊ
S4	77	Nose of ঙ
	79	Nose of ঊ
	81	Nose of ড়
	82	Bowl of ড়
	85	Short Stem of ঊ
S5	47	Nose of ঙ
	49	Nose of ঊ
	50	Lower to Bowl of ড়
	52	Terminal/ Finial at Bowl of ঊ
S6	86	Nose of ঙ
	87	Loop of ঙ
	88	Short Stem of ঊ
	90	Junction of Matra & Upper Tail of ঊ
	92	Short Stem of ড়
	96	'T' Junction of ঊ

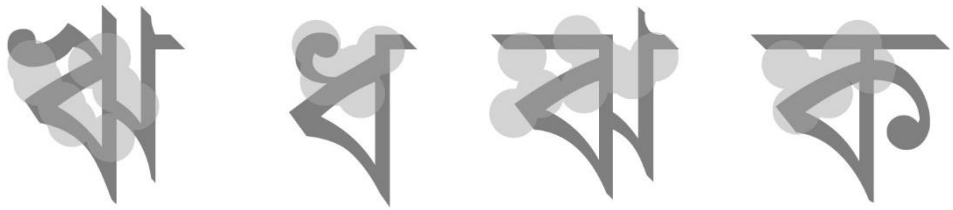
8. Letters – জ, ঊ, ঈ, ভ



Participant	Fixation(s)	Exposed Letters - জ, ঊ, ঈ, ভ
S1	85	Nose of জ
	86	Junction of Shoot & Leg of জ
	87	Terminal/ Finial of ঊ
	88	Short VStem of ঊ
	90	Side Tail of ঊ
	93	Initial of ঈ
	97	Initial of ভ
S2	96	Shoot of জ
	97	Bowl of জ
	99	Junction of Shoot & Leg of জ
	100	Terminal of ঊ
	104	Nose of ঊ
	105	Initial of ঈ
	106	Diagonal of ঈ
	109	Terminal of ভ
S3	86	Nose of জ
	87	Junction of Shoot & Leg of জ
	89	Short Stem of ঊ
	90	Upper Tail ঊ

	91	Initial of ঈ
	93	Initial of ভ
S4	90	Leg of জ
	91	Nose of ঊ
	92	Nose of ঊ
	93	Initial of ঈ
	95	Initial of ভ
S5	54	Nose of জ
	55	Bowl of জ
	56	Junction of Shoot & Leg of জ
	57	Nose of ঊ
	58	Initial of ঈ
	59	Diagonal of ঈ
	60, 61	Initial of ভ
S6	101, 102	Nose of জ
	105	Nose of ঊ
	109	Terminal/ Finial of ঊ
	110	Initial of ঈ
	112	Initial of ঈ
	114	Initial of ভ

9. Letters – ঋ, ধ, ঝ, ক



Participant	Fixation(s)	Exposed Letters - ঋ, ধ, ঝ, ক
S1	99	VStem of 'Aakar' of ঋ
	102	Junction of Delta & Shoot of ঋ
	104	Arm of ধ
	107	Initial of Matra of ঝ
	109	VStem of Wedge of ঝ
	111	Junction of Delta & Matra of ক
S2	113, 114	Junction of Delta & Shoot of ঋ
	118	Junction of Delta & Arm of ধ
	119	Initial of Delta of ঝ
	126	Junction of Delta & Matra of ক
	129	Arm of ধ
S3	97	WEdge of ঋ
	99	Junction of Shoot & Arm ঋ
	101	Arm of ধ
	103	Initial of Delta of ঝ
	104	VStem of Wedge of ঝ
	105	Junction of Delta & Matra of ক
S4	101	Wedge (second) of ঋ
	102	Junction of Delta & Arm of ধ
	104	Counter of Delta of ঝ

	106	Wedge of ঝ
	109	Junction of Delta & Matra of ক
S5	65	Junction of Shoot & Delta of ঋ
	67	Junction of Delta & Arm of ধ
	69	'<' Junction of Delta of ঝ
	72	'<' Junction of Delta of ক
S6	122	Junction of Delta & 2nd Wedge of ঋ
	124	Junction of Delta & Arm of ধ
	129	Initial of Delta of ঝ
	134	Junction of Delta & Matra of ক

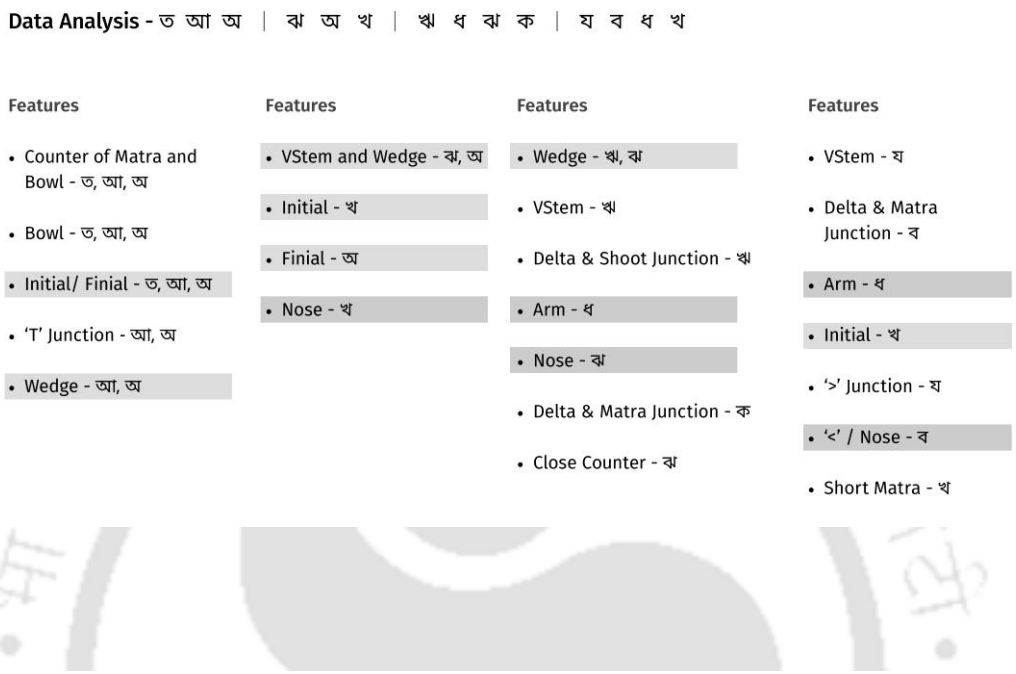
10. Letters – য, ব, ধ, খ

Participant	Fixation(s)	Exposed Letters - য, ব, ধ, খ
S1	114	VStem of য
	118	Junction of Delta & Matra of ব
	121, 122	Arm of ধ
	124	Initial of খ
S2	130	'>' Junction of য
	131	'<' Junction of ব
	138	Arm of ধ
	139	Short Matra of খ
	140	Initial of খ

S3	109	'>' Junction of য
	112	Junction of Delta & Matra of ব
	114	Arm of ধ
	117, 118	Initial of খ
S4	116	Wedge of য
	118	Initial of য
	121	Junction of Delta & Arm of ধ
	122	Arm of ধ
	123	Initial of খ
S5	78	Close Counter near Initial of য
	79	Junction of Delta & Matra of ব
	80	Junction of Delta & Arm of ধ
	81	Initial of খ
S6	143	VStem of য
	144	'>' Junction of য
	145, 146	Junction of Delta & Matra of ব
	150	Arm of ধ
	157	Initial of খ

Appendix V

Group-wise comparison of letter features that identified by eye-tracking:



Data Analysis - ঢ় ঢ ট | চ ট ঠ

Features	Features
• Terminal/ Finial - ঢ়, ঢ, ট	• Junction of HStem & Crossbar - চ
• Dot - ঢ়	• Matra & Tail Junction - ট, ঠ
• Counter - ঢ	• Upper Tail - ট
• Matra & Tail Counter - ট	• Close Counter - চ
• Arm - ঢ়, ঢ	• 5-point Cross/ Junction - ঠ
	• Terminal/Finial - ট

Data Analysis - ঙ ঊ ড় উ | জ ঊ ঈ ভ

Features	Features
• Nose - ঙ	• Nose - জ, ঊ
• Loop - ঙ	• Shoot & Leg Junction - জ
• Matra & Upper Tail Junction - ঊ	• Finial - ঊ, ঈ, ভ
• Finial - ঊ, উ	• Initial - ঈ, ভ
• Dot - ড়	• Bowl - জ
	• Diagonal - ঈ
	• Upper Tail - ঊ, ঈ
	• Leg - জ

Appendix VI

Each sample of image was processed through a channel as described in Fig. 4.12.

1. Matlab Code for Laplacian pyramid (decomposed into five planes)–

```
function [pyr1 pyr2 pyr3 pyr4 pyr5]=pyramid(I)
pyr1=imgaussfilt(I,2);
pyr2=imgaussfilt(I,4);
pyr3=imgaussfilt(I,6);
pyr4=imgaussfilt(I,8);
pyr5=imgaussfilt(I,10);
end
```

2. Code for Gaussian Mask –

```
function [mask, maskimg, imgaftermask]=
        gaussmask(gaussDim,sz,spacing,pyr,Lheight,Lwidth,numberhole)
gaussSigma = gaussDim / 3;
[xm, ym] = meshgrid(-gaussDim:gaussDim, -gaussDim:gaussDim);
gauss = exp(-(((xm .^2) + (ym .^2)) ./ (2 * gaussSigma^2)));
[s1, s2] = size(gauss);
mask=gauss;
maskimg=zeros(sz);

xg=ceil(rand(1,numberhole).*(Lheight-gaussDim*2));
yg=ceil(rand(1,numberhole).*(Lwidth-gaussDim*2));
r=xg+sz(1)/2-Lheight/2;
c=yg+sz(2)/2-Lwidth/2;


imgaftermask=190*ones(sz);
for i=1:length(r)
   maskimg(r(i):r(i)+s1-1,c(i):c(i)+s2-1)=
        max(maskimg(r(i):r(i)+s1-1,c(i):c(i)+s2-1),mask);
%    imgaftermask(r(i):r(i)+s1-1,c(i):c(i)+s2-1)=
        double(pyr(r(i):r(i)+s1-1,c(i):c(i)+s2-1)).*mask;
end
```

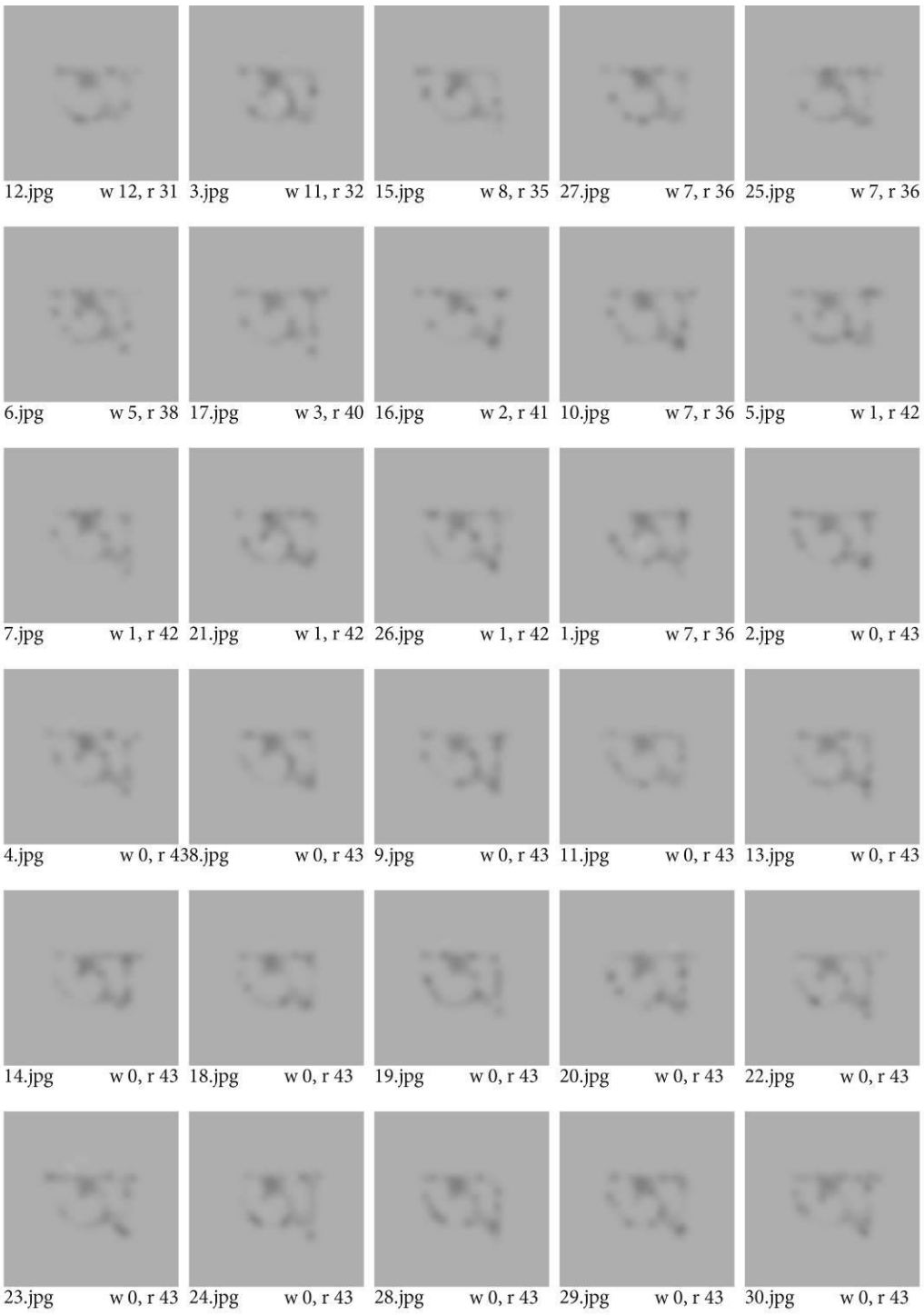
```
for i=1:sz(1)
   for j=1:sz(2)
      if(maskimg(i,j)>0.2)
      imgaftermask(i,j)=pyr(i,j);

      end
   end
end
% imgaftermask=imgaftermask.*double(pyr);

End
```

3. Code for combining masked images –

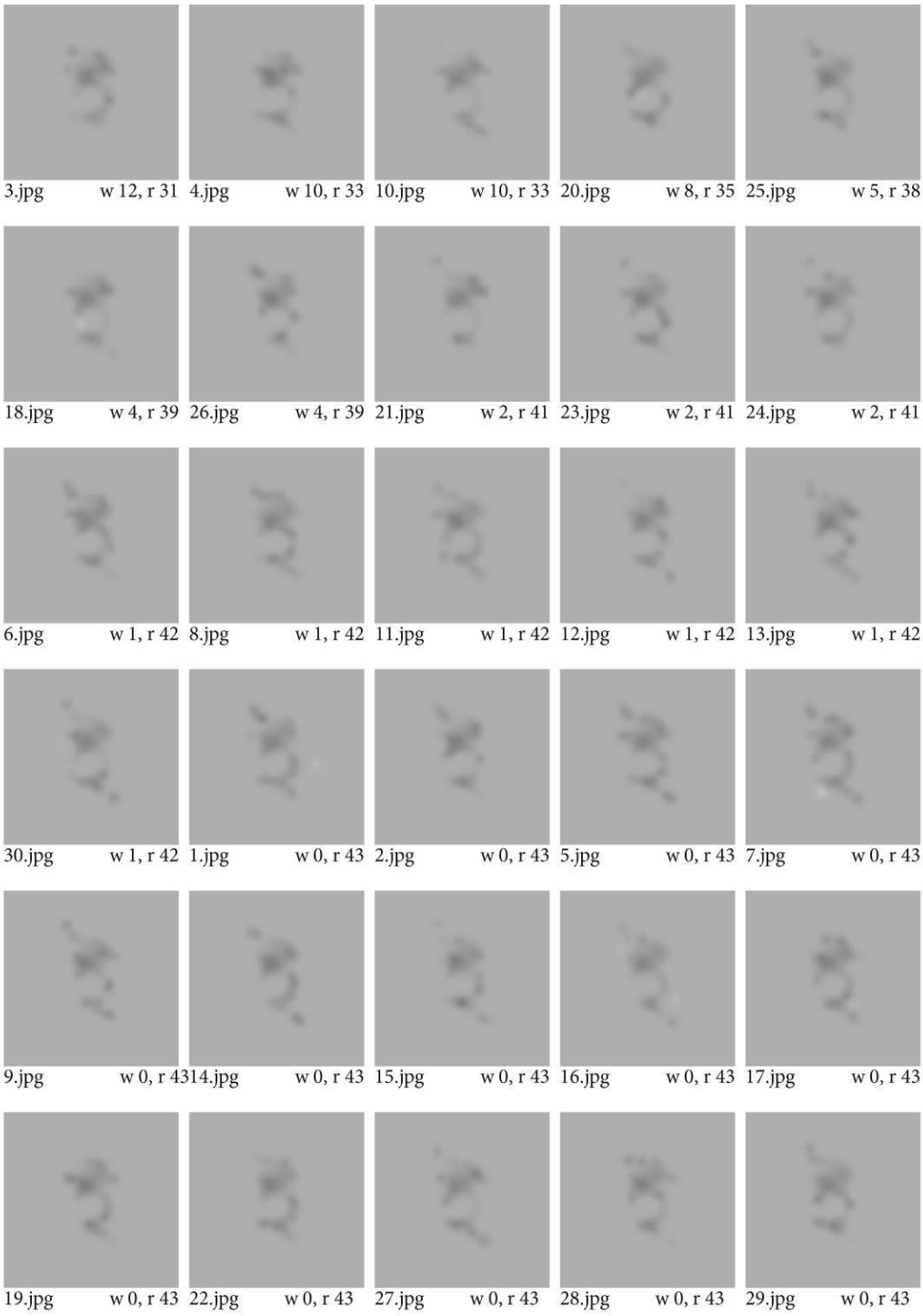
```
function finalimage=
         combineimage(imgaftermask1,imgaftermask2,imgaftermask3,imgaftermask4,i
         mgaftermask5);

array=cat(3,imgaftermask1,imgaftermask2,imgaftermask3,imgaftermask4,
           imgaftermask5);
for i=1:size(array,1)
   for j=1:size(array,2)
      finalimage(i,j)=min(array(i,j,:));
   end
end
end
```

Appendix VII

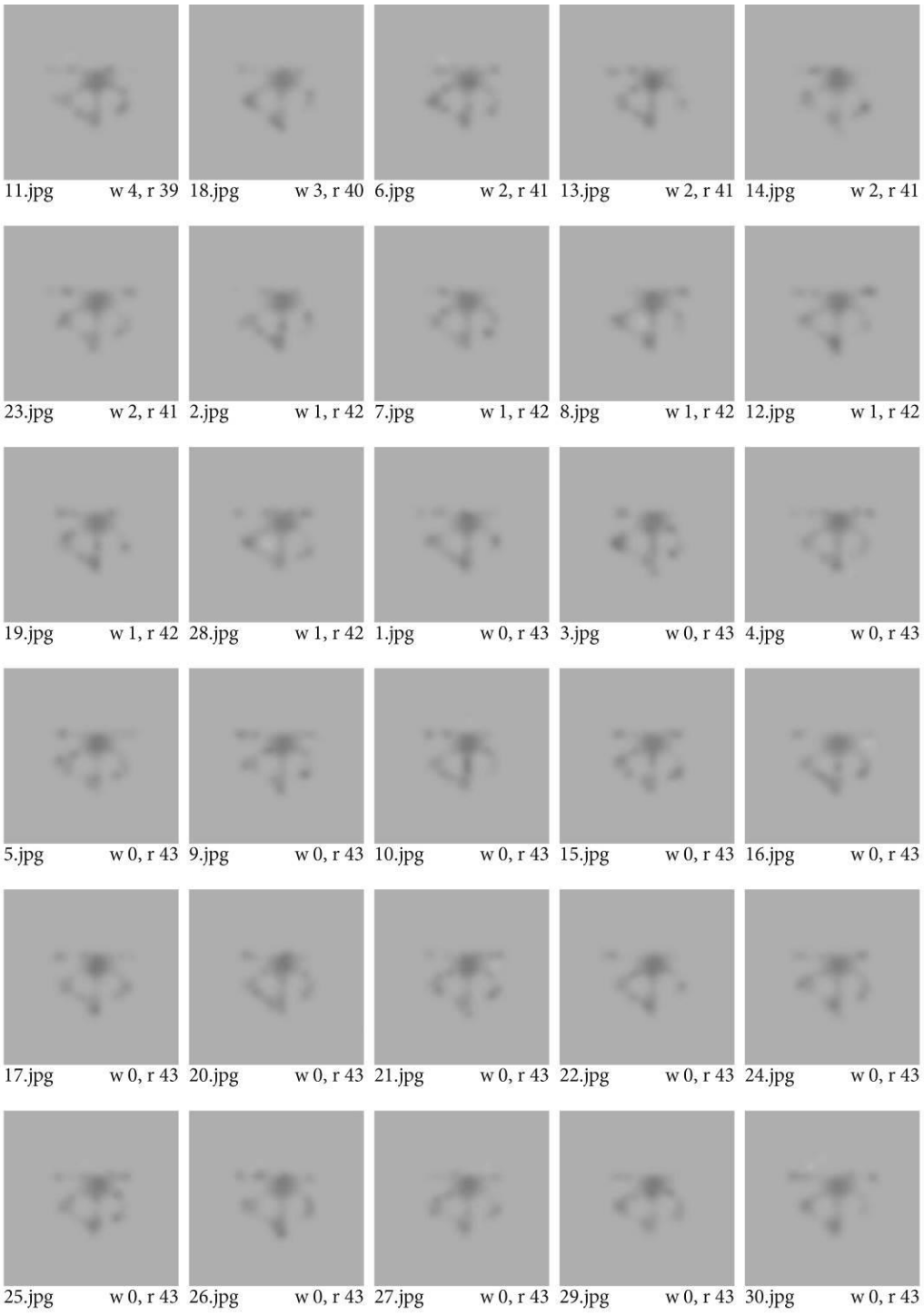
Letter 1/ A/ অ



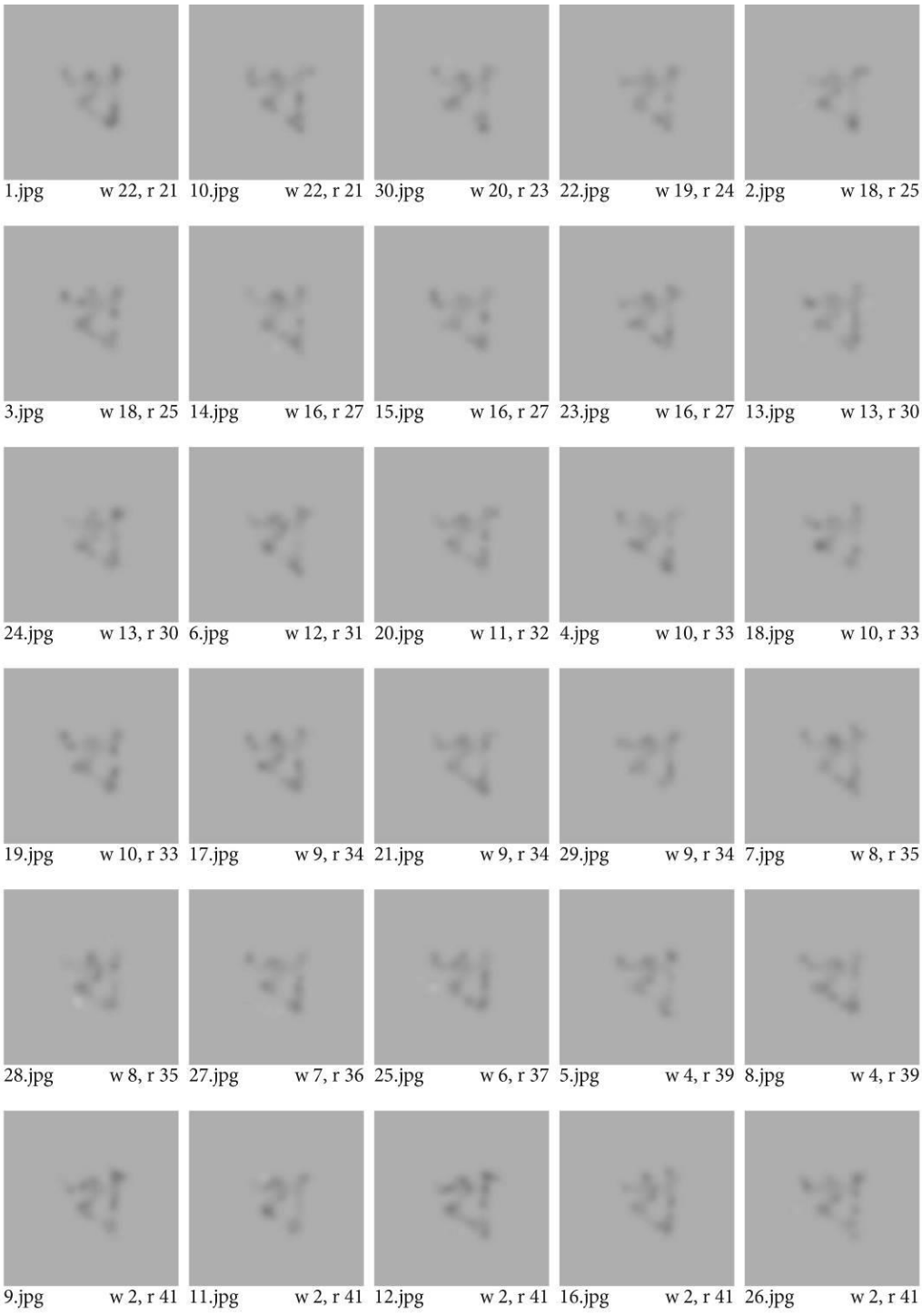
Letter 2/ E/ ਏ



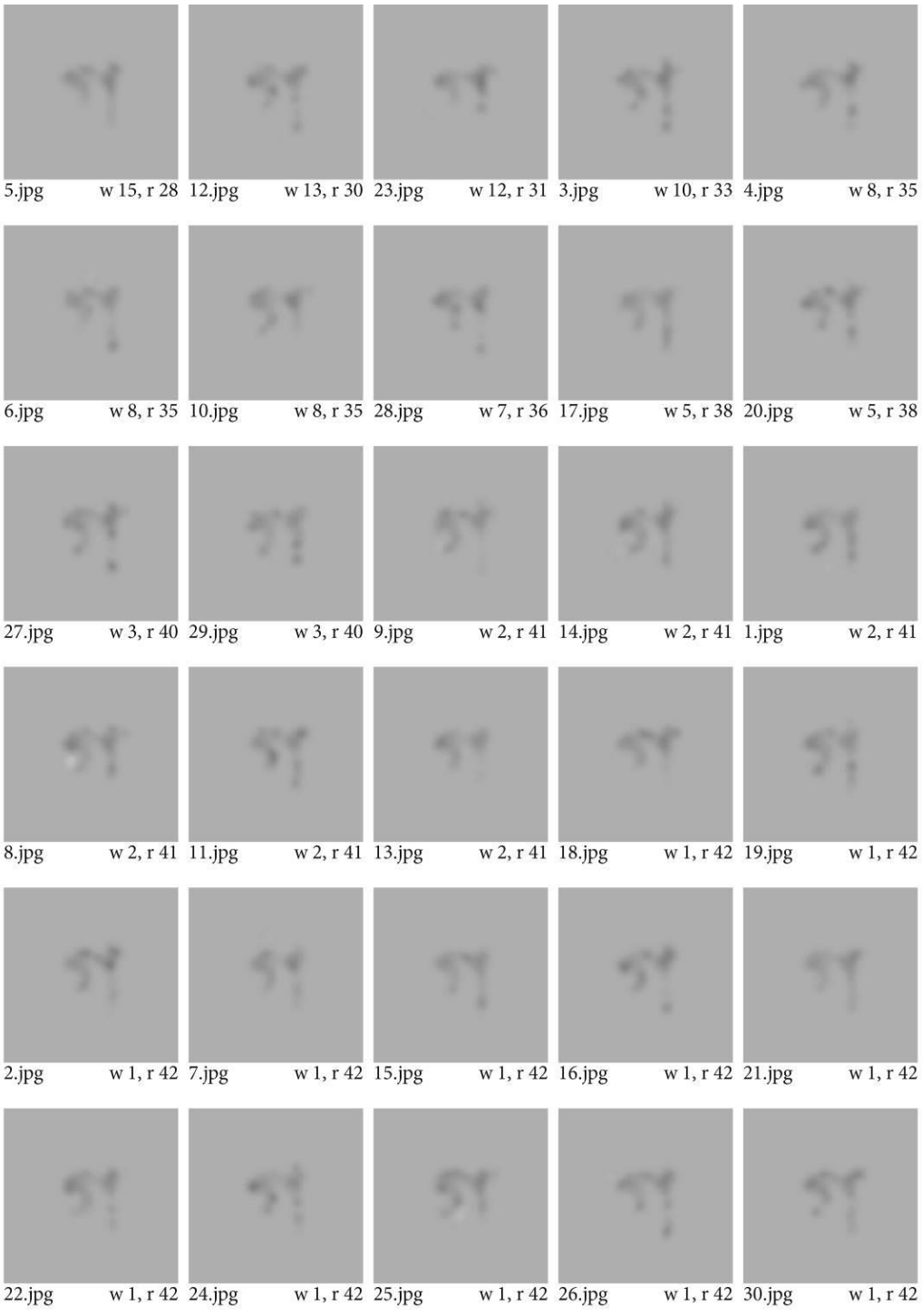
Letter 11/ Ka/ ক



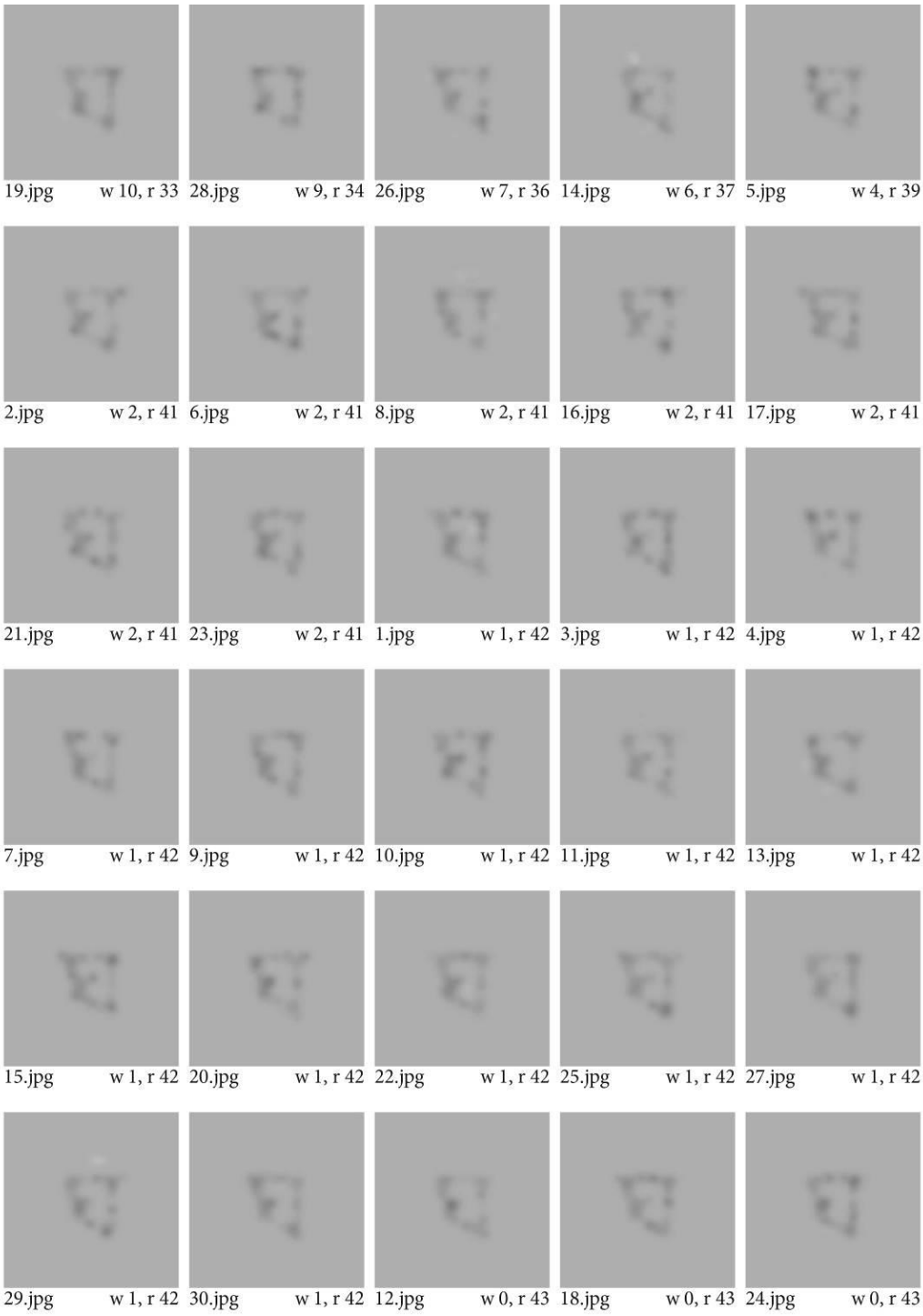
Letter 12/ Kha/ খ



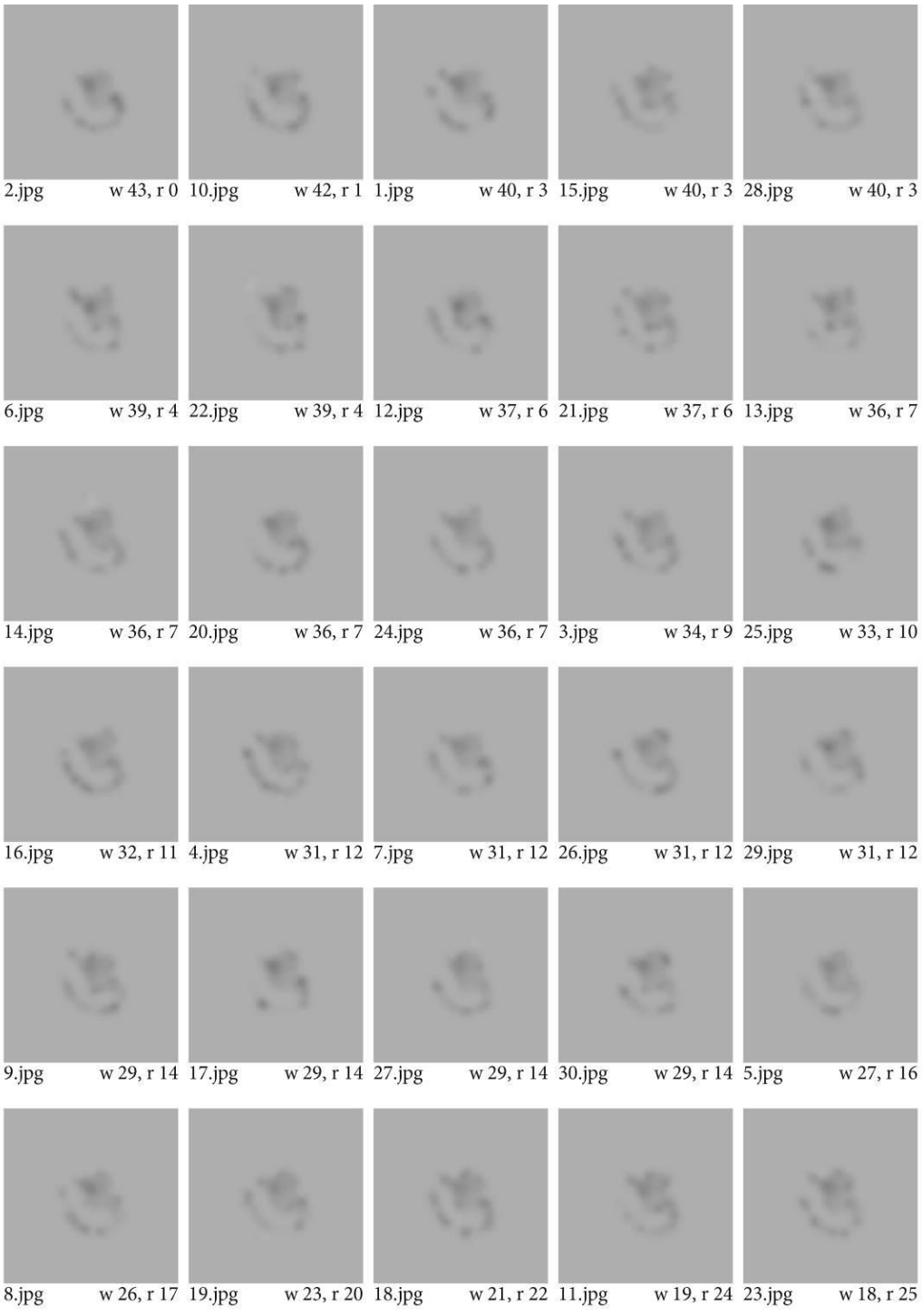
Letter 13/ Ga/ গ



Letter 14/ Ghya/ ঘ



Letter 15/ Unyo/ ঙ



Appendix VIII

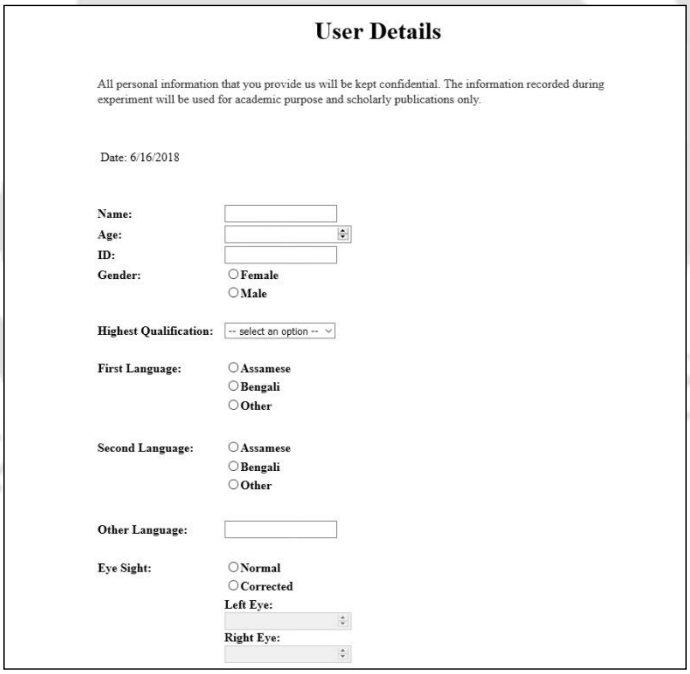
Database name: lettersdb

Tables: 1 to 47, keyflag, user

Sequence of files:
userdetails.html >> userdb.php >> random_image.php >>
*preindex.php + keyboard.php (background) >> index1.php (494 ms) +
keyboard.php (background) >> imgindex.php (200 ms) + keyboard.php
(background) >> index2.php (494 ms) + keyboard.php (background) >>
preindex.php + keyboard.php (highlight) >> response.php >> Goto preindex.php*

* refers to connected frame or loop.

Code for user details screen –



1. userdetails.html

```
<!doctype html>
<html>
<head>
<meta charset="utf-8">
```

```
<title>Untitled Document</title>
</head>
<style>
.likert li {
   float: left;
   list-style-type: none;
}
</style>

<body>
<h1 align="center">User Details</h1>
<form action="userdb.php" method="post">
 <table align="center" style="text-align:left">
<tr><td colspan="3">
<p style="color:#631D1D">All personal information that you provide us will be kept confidential. The information recorded during experiment will be used for academic purpose and scholarly publications only.</p>
<br>
<br>
 Date:
<script type="text/javascript">
<!--
var currentTime = new Date()
var month = currentTime.getMonth() + 1
var day = currentTime.getDate()
var year = currentTime.getFullYear()
document.write(month + "/" + day + "/" + year)
//-->
</script>
</td></tr>
<tr><th> </th></tr>
<tr><th> </th></tr>
  <tr><th width="162">Name:</th>
  <th width="187"><input type="text" name="name"></th><th width="377"> </th></tr>
  <tr><th>Age:</th>
  <th><input type="number" name="age"></th></tr>

  <tr><th width="162">ID:</th>
  <th width="187"><input type="text" name="id"></th></tr>
  <tr><th>Gender:</th>
  <th><input type="radio" name="gender" value="Female">Female</th></tr>
  <tr><th></th><th><input type="radio" name="gender" value="Male">Male</th></tr>
  <tr><th> </th></tr>
  <tr><th>Highest Qualification:</th>
  <th><select name="qual">
```

```
            <option disabled selected value> -- select an option -- </option>
            <option>10th</option>
            <option>10+2</option>
            <option>Bachelor</option>
            <option>Master</option>
            <option>Above Master</option>
          </select></th></tr>
           <tr><th> </th></tr>
          <tr><th>First Language:</th>
          <th><input type="radio" name="firstlang" id="r1" value="Assamese"
onClick="ShowHideDiv()">Assamese</th></tr>
          <tr><th></th><th><input type="radio" name="firstlang" id="r2" value="Bengali"
onClick="ShowHideDiv()">Bengali</th></tr>
          <tr><th></th><th><input type="radio" name="firstlang" id="r3" value="Other"
onClick="ShowHideDiv()">Other</th></tr>
          <tr><th height="27"></th><th>
          <div id="langtext1" style="display: none">
           <input type="text" name="lang1" id="langt1" />
          </div></th></tr>

          <tr><th>Second Language:</th>
          <th><input type="radio" name="secondlang" id="r4" value="Assamese"
onClick="ShowHideDiv()">Assamese</th></tr>
          <tr><th></th><th><input type="radio" name="secondlang" id="r5" value="Bengali"
onClick="ShowHideDiv()">Bengali</th></tr>
          <tr><th></th><th><input type="radio" name="secondlang" id="r6" value="Other"
onClick="ShowHideDiv()">Other</th></tr>
          <tr><th height="28"></th><th>
          <div id="langtext2" style="display: none">
            <input type="text" name="lang2" id="langt2" />
          </div></th></tr>

          <tr><th>Other Language:</th>
          <!--<th><input type="radio" name="lang" id="r7" value="Assamese"
onClick="ShowHideDiv()">Assamese</th></tr>
          <tr><th></th><th><input type="radio" name="lang" id="r8" value="Bengali"
onClick="ShowHideDiv()">Bengali</th></tr>
          <tr><th></th><th><input type="radio" name="lang" id="r9" value="Other"
onClick="ShowHideDiv()">Other</th></tr>
          <tr><th height="26"></th><th>
          <div id="langtext3" style="display: none">-->
           <th> <input type="text" name="lang3" id="langt3" />
          <!--</div>-->
          </th></tr>
           <tr><th> </th></tr>
          <tr><th>Eye Sight:</th>
```

```
        <th><input type="radio" name="eye" id="eyeno" value="Normal"
onClick="toggleTextboxdis(this)">Normal</th></tr>
         <tr><th></th><th><input type="radio" name="eye" id="eyeyes" value="Corrected"
onClick="toggleTextbox(this)">Corrected</th></tr>
         <tr><th height="40"></th><th>
         <!--<div id="sight" style="display: none">-->
          Left Eye:<input type="number" step=0.01 name="left" id="left" disabled />
          Right Eye:<input type="number" step=0.01 name="right" id="right" disabled/>
        <!--</div>-->
        </th></tr>

        <tr><th colspan="3">Please rate your control over to identify letters in Assamese
and/or Bengali</th></tr>
         <tr><th colspan="2"><ul class="likert">
          <li><input type="radio" name="scale" value="1" /></li>
          <li><input type="radio" name="scale" value="2" /></li>
          <li><input type="radio" name="scale" value="3" /></li>
          <li><input type="radio" name="scale" value="4" /></li>
          <li><input type="radio" name="scale" value="5" /></li>
          <li><input type="radio" name="scale" value="6" /></li>
          <li><input type="radio" name="scale" value="7" /></li>
          <li><input type="radio" name="scale" value="8" /></li>
          <li><input type="radio" name="scale" value="9" /></li>
          <li><input type="radio" name="scale" value="10" /></li>
          </th></tr>
         <tr><th> </th></tr>
         <tr><td colspan="3">
        The researcher appreciates your candid and direct feedback.
        </td></tr>
        <tr><th> </th></tr>
        <tr><th colspan="2" align="center">

        <input type="submit" id="details" name="Submit" value="Submit"></th></tr>

        </th></tr>
         <tr><th> </th></tr>
          <tr><th> </th></tr>
        </table>

        </form>

        </body>
        <script type="text/javascript">
        function toggleTextbox(rdo) {
           document.getElementById("left").disabled = !rdo.checked;
          document.getElementById("right").disabled = !rdo.checked;
        }
```

```
function toggleTextboxdis(rd) {
   document.getElementById("left").disabled = rd.checked;
  document.getElementById("right").disabled = rd.checked;
}
</script>
<script type="text/javascript">
   function ShowHideDiv() {
            var r3 = document.getElementById("r3");
       var langtext1 = document.getElementById("langtext1");
       langtext1.style.display = r3.checked ? "block" : "none";

            var r6 = document.getElementById("r6");
       var langtext2 = document.getElementById("langtext2");
       langtext2.style.display = r6.checked ? "block" : "none";

            var r9 = document.getElementById("r9");
       var langtext3 = document.getElementById("langtext3");
       langtext3.style.display = r9.checked ? "block" : "none";
  }
</script>
</html>
```

2. userdb.php

```
<!doctype html>
<html>
<head>
<meta charset="utf-8">
<title>Untitled Document</title>
</head>

<body>
<?php
ini_set("max_execution_time", 0);
 session_start();
$link=mysqli_connect("localhost", "root", "")or die("cannot connect");
mysqli_select_db($link, "lettersdb")or die("cannot select DB");

$name = $_POST['name'];
$age = $_POST['age'];
$id = $_POST['id'];
$gender = $_POST['gender'];
$qual = $_POST['qual'];
$firstlang = $_POST['firstlang'];
$secondlang = $_POST['secondlang'];
$lang = $_POST['lang3'];
```

```
$eye = $_POST['eye'];
$scale = $_POST['scale'];
echo $name;
if($firstlang == "Other")
{
  $firstlang = $_POST['lang1'];
}
if($secondlang == "Other")
{
  $secondlang = $_POST['lang2'];
}
/*if($lang == "Other")
{
  $lang = $_POST['lang3'];
}*/
if($eye == "Corrected")
{
//Insert Query of SQL
$left = $_POST['left'];
$right = $_POST['right'];
$query = "insert into user(user_name, age, id, gender, qual, first_lang, second_lang,
lang, sight, scale) values ('$name', '$age', '$id', '$gender', '$qual', '$firstlang', '$secondlang',
'$lang', 'left=$left:right=$right', '$scale')";
$result = mysqli_query($link, $query);
}
else
{
  $query = "insert into user(user_name, age, id, gender, qual, first_lang, second_lang,
lang, sight, scale) values ('$name', '$age', '$id', '$gender', '$qual', '$firstlang', '$secondlang',
'$lang', '$eye', '$scale')";
  $result = mysqli_query($link, $query);
}
if($result)
{
  $sql1= "select * from user where user_name = '$name'";
  $result1= mysqli_query($link, $sql1);
  $row=mysqli_fetch_row($result1);
  $user_id=$row[3];
  $res="res";
  $user_res=$user_id.$res;
  //echo $user_id;
  //exit;
  for($i=1;$i<=47;$i++)
  {
        //echo $i;
```

```
        $sql = "ALTER TABLE `$i` ADD COLUMN $user_id int(5), ADD COLUMN
$user_res int(5) ";
        $result2= mysqli_query($link, $sql);
        /*$sql2 = "ALTER TABLE `$i` ADD $user_res int(5)";
        $result3= mysqli_query($link, $sql2);*/
        }
        $_SESSION['user_id']=$user_id;
        $_SESSION['user_res']=$user_res;
        $count = '0';
      $_SESSION['count']=$count;
        $query2 = "UPDATE `keyflag` SET flag='1'";
        $result2 = mysqli_query($link, $query2);
        ?>
       <h2 align="center"> "Details entered sucessfully"</h2>
        <form style="align-content:center" action="random_image.php" method="post">
       <input type="submit" name="start" id="start" value="Start">
       </form>
       <?php
       }
      else
      {
        echo "ERROR";
      }
      ?>
      </body>
      </html>
```

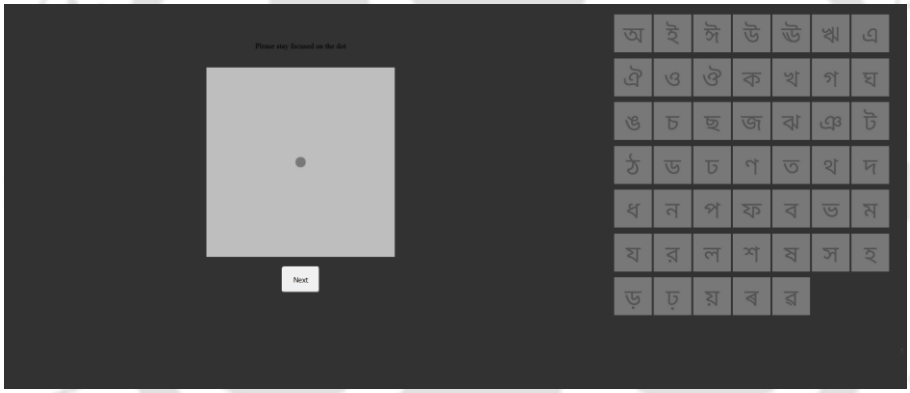
3. random_image.php

```
      <!doctype html>
      <html>
      <head>
      <meta charset="utf-8">
      <title>Untitled Document</title>
      </head>

      <body bgcolor="323232" >
      <?php
      ini_set("max_execution_time", 0);
         session_start();
         extract($_POST);
        extract($_GET);
        extract($_SESSION);
        //echo $user_id;
        //$_SESSION['count']=$count+1;
         $link=mysqli_connect("localhost", "root", "")or die("cannot connect");
```

```
mysqli_select_db($link, "lettersdb")or die("cannot select DB");
   $tot_folder = "47";
   $main_folder = "Images_after each mask";
   $f_start = "1";
   $random_folder = mt_rand($f_start, $tot_folder);
$total = "30";
$file_type = ".jpg";
$image_folder = $random_folder;
//echo $image_folder;
$start = "1";
$random = mt_rand($start, $total);
$i=0;
while($i==0)
{
$query = "SELECT * FROM `$image_folder` WHERE (name = '$random' and
$user_id = '1') or (name = '$random' and $user_id = '0')";
  $result = mysqli_query($link, $query);
  $num_rows = mysqli_num_rows($result);
if($num_rows==0)
{
$image_name = $random . $file_type;
$image = "Images_after each mask/$image_folder/$image_name";
$_SESSION['image'] = $image;
$_SESSION['image_folder'] = $image_folder;
$_SESSION['random'] = $random;
//$count++;
//echo $image;
$i++;
}
else
{
  //echo $user_id;
  //echo "error";
  $random_folder = mt_rand($f_start, $tot_folder);
  $image_folder = $random_folder;
  $random = mt_rand($start, $total);
  $image_name = $random . $file_type;
$image = "Images_after each mask/$image_folder/$image_name";
//$i++;
//exit;
//$_SESSION['image'] = $image;
//echo $image;
}
}
//echo "<img src=\"Images_after each mask/$image_folder/$image_name\"/>";
//echo $image_name;
//echo $image_folder;
```

```
        //echo "<img src=\"$main_folder/$image_folder/$image_name\"
alt=\"$image_name\" />";
        /*$image_name = $random . $file_type;
        $image = "Images_after each mask/$image_folder/$image_name";
        $_SESSION['image'] = $image;*/
        header('Location: preindex.php');
        ?>
         <!--<form style="text-align:center" action="index1.php" method="post">
         <input type="submit" name="start" id="start" value="Start" >
         </form>
         <form style="text-align:center" action="thank.php" method="post">
         <input type="submit" name="stop" id="stop" value="Stop" >
         </form>-->
        </body>
        </html>
```

4. preindex.php




```
        <!doctype html>
        <html>
        <head>
        <meta charset="utf-8">
        <title>Untitled Document</title>
        </head>
        <style>
        input[type=submit] {
            border-radius: 5px;
            border: 1;
            width: 80px;
            height:55px;
          font-size:15px;
            }
          </style>
        <body bgcolor="323232">
```

```
<?php
session_start();
   extract($_POST);
  extract($_GET);
  extract($_SESSION);
  include "keyboard.php";
  $link=mysqli_connect("localhost", "root", "")or die("cannot connect");
mysqli_select_db($link, "lettersdb")or die("cannot select DB");
$query1 = "select * from `keyflag`";
  $result1 = mysqli_query($link, $query1);
  $row1=mysqli_fetch_row($result1);
  $f1=$row1[0];
  if($f1==1)
  {
          ?>
           <br><br><br><p align="center">Please stay focused on the dot</p><br>
<img src="Frame.jpg" height="400" width="400" style="display: block; margin: 0
auto"/>
<br>
<form style="text-align:center" action="index1.php" method="post">
 <input type="submit" name="submit" id="submit" value="Next" >
 </form>
 <?php
  }
  else
  {
  ?>
   <br><br><br><p align="center">Please stay focused on the dot</p><br>
<img src="Frame.jpg" height="400" width="400" style="display: block; margin: 0
auto"/>
<br>
<form style="text-align:center" action="index1.php" method="post">
 <input type="submit" name="submit" id="submit" value="Next" disabled >
 </form>
 <?php
  }
  ?>
<!--<br><br><br><br>
<img src="Frame.jpg" height="400" width="400" style="display: block; margin: 0
auto"/>
<form style="text-align:center" action="index1.php" method="post">
 <input type="submit" name="next" id="next" value="Next" >
 </form>-->
</body>
</html>
```

5. keyboard.php

```
<!doctype html>
<html>
<head>
<meta charset="utf-8">
<title>Untitled Document</title>
<link rel="stylesheet" type="text/css" href="key.css">
</head>
<style>
.overlay {
position: absolute;
right: 0px;
top: 0;
width: 600px;
height: 600px;
}
.pointer-events-none {
pointer-events: none;
opacity: 0.5;
width: 660px;
height:640px;
float:right;
background-color:#323232;
}
.pointer-events {
width: 660px;
height:640px;
float:right;
background-color:#323232;
}
</style>
<script>
/*window.onload = function () {
document.getElementById("enable-disable-pointer-events").onclick = function () {
document.getElementById("overlay").className = "overlay " + ((this.checked)?
"pointer-events-none" : "");
};
};*/
</script>
<?php
//session_start();
   extract($_POST);
  extract($_GET);
  extract($_SESSION);
  ?>
```

```
<!--you can get the variable by either $_GET['myans'] or $_REQUEST['myans']-->
<body bgcolor="323232">
<?php
$link=mysqli_connect("localhost", "root", "")or die("cannot connect");
mysqli_select_db($link, "lettersdb")or die("cannot select DB");
$query = "select * from `keyflag`";
  $result = mysqli_query($link, $query);
  $row=mysqli_fetch_row($result);
  $f=$row[0];
  if($f==1)
  {
        echo '<div id="overlay" class="pointer-events-none">';
  }
  else
  {
        echo '<div id="overlay" class="pointer-events">';
  }
?>
<!--<div id="overlay" class="pointer-events-none">-->
   <ul class="products" style="list-style:">
        <li>
                <a href="response.php?myans=1" onClick="post"><img
src="Image_Be/Image_Be_01.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
        </li>
        <li>
                <a href="response.php?myans=2" onClick="post"><img
src="Image_Be/Image_Be_02.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
        </li>
        <li>
                <a href="response.php?myans=3" onClick="post"><img
src="Image_Be/Image_Be_03.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
        </li>
        <li>
                <a href="response.php?myans=4" onClick="post"><img
src="Image_Be/Image_Be_04.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
        </li>
        <li>
                <a href="response.php?myans=5" onClick="post"><img
src="Image_Be/Image_Be_05.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
        </li>
        <li>
```

```
                    <a href="response.php?myans=6" onClick="post"><img
src="Image_Be/Image_Be_06.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                 <li>
                    <a href="response.php?myans=7" onClick="post"><img
src="Image_Be/Image_Be_07.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=8" onClick="post"><img
src="Image_Be/Image_Be_08.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=9" onClick="post"><img
src="Image_Be/Image_Be_09.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=10" onClick="post"><img
src="Image_Be/Image_Be_10.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=11" onClick="post"><img
src="Image_Be/Image_Be_11.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=12" onClick="post"><img
src="Image_Be/Image_Be_12.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=13" onClick="post"><img
src="Image_Be/Image_Be_13.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=14" onClick="post"><img
src="Image_Be/Image_Be_14.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
```

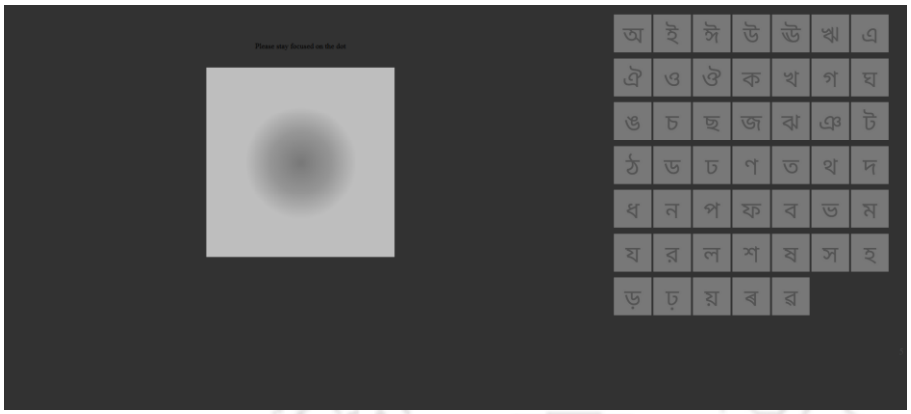
```
                    <a href="response.php?myans=15" onClick="post"><img
src="Image_Be/Image_Be_15.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=16" onClick="post"><img
src="Image_Be/Image_Be_16.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=17" onClick="post"><img
src="Image_Be/Image_Be_17.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=18" onClick="post"><img
src="Image_Be/Image_Be_18.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=19" onClick="post"><img
src="Image_Be/Image_Be_19.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=20" onClick="post"><img
src="Image_Be/Image_Be_20.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=21" onClick="post"><img
src="Image_Be/Image_Be_21.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=22" onClick="post"><img
src="Image_Be/Image_Be_22.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=23" onClick="post"><img
src="Image_Be/Image_Be_23.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
```

```
                    <a href="response.php?myans=24" onClick="post"><img
src="Image_Be/Image_Be_24.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=25" onClick="post"><img
src="Image_Be/Image_Be_25.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=26" onClick="post"><img
src="Image_Be/Image_Be_26.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=27" onClick="post"><img
src="Image_Be/Image_Be_27.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=28" onClick="post"><img
src="Image_Be/Image_Be_28.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=29" onClick="post"><img
src="Image_Be/Image_Be_29.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=30" onClick="post"><img
src="Image_Be/Image_Be_30.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                 <li>
                    <a href="response.php?myans=31" onClick="post"><img
src="Image_Be/Image_Be_31.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=32" onClick="post"><img
src="Image_Be/Image_Be_32.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
```

```
                    <a href="response.php?myans=33" onClick="post"><img
src="Image_Be/Image_Be_33.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=34" onClick="post"><img
src="Image_Be/Image_Be_34.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=35" onClick="post"><img
src="Image_Be/Image_Be_35.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=36" onClick="post"><img
src="Image_Be/Image_Be_36.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=37" onClick="post"><img
src="Image_Be/Image_Be_37.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=38" onClick="post"><img
src="Image_Be/Image_Be_38.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=39" onClick="post"><img
src="Image_Be/Image_Be_39.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=40" onClick="post"><img
src="Image_Be/Image_Be_40.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                </li>
                <li>
                    <a href="response.php?myans=41" onClick="post"><img
src="Image_Be/Image_Be_41.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>

                </li>
                <li>
```

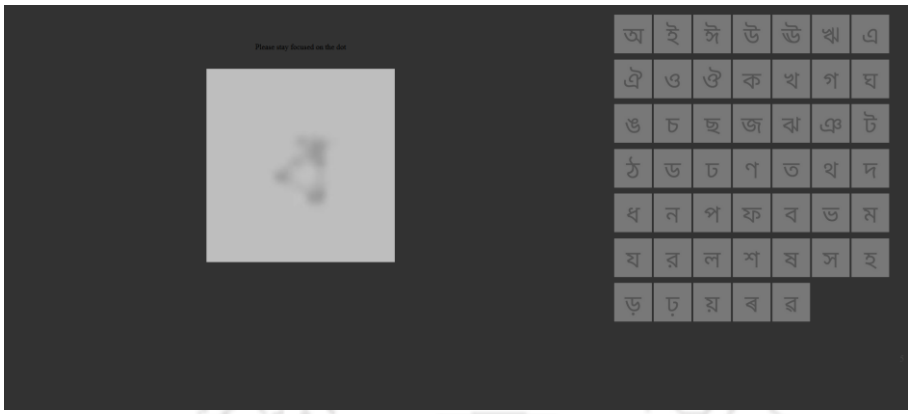
```
                        <a href="response.php?myans=42" onClick="post"><img
src="Image_Be/Image_Be_42.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                    </li>
                    <li>
                        <a href="response.php?myans=43" onClick="post"><img
src="Image_Be/Image_Be_43.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                    </li>
                    <li>
                        <a href="response.php?myans=44" onClick="post"><img
src="Image_Be/Image_Be_44.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                    </li>
                    <li>
                        <a href="response.php?myans=45" onClick="post"><img
src="Image_Be/Image_Be_45.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                    </li>
                    <li>
                        <a href="response.php?myans=46" onClick="post"><img
src="Image_Be/Image_Be_46.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                    </li>
                    <li>
                        <a href="response.php?myans=47" onClick="post"><img
src="Image_Be/Image_Be_47.jpg" height="80" width="80" border="4" style="border-color:
#323232"/></a>
                    </li>
                </ul>
            <?php
             echo '<br>
             <p align="right" style="color:#5A5A5A; font-size:20px">';
            echo $count;
            echo '</p>';
            ?>
             </div>
                <!--<p>
            <input id="enable-disable-pointer-events" type="checkbox">
            <label for="enable-disable-pointer-events">Disable pointer events for grey box</label>
            </p>-->
            </body>
            </html>
```

6. index1.php




```
<!doctype html>
<html>
<head>
<meta charset="utf-8">
<title>Untitled Document</title>
</head>
<?php
session_start();
   extract($_POST);
  extract($_GET);
  extract($_SESSION);
  include "keyboard.php";
  ?>
<body bgcolor="323232">
<br><br><br><p align="center">Please stay focused on the dot</p><br>
<img src="Mask.jpg" height="400" width="400" style="display: block; margin: 0
auto"/>
<script type="text/javascript">
      <!--
        function Redirect() {
          window.location="imgindex.php";
        }
                //document.write("You will be redirected to main page in 2 sec.");
        setTimeout('Redirect()', 494);
      //-->
    </script>
</body>
</html>
```

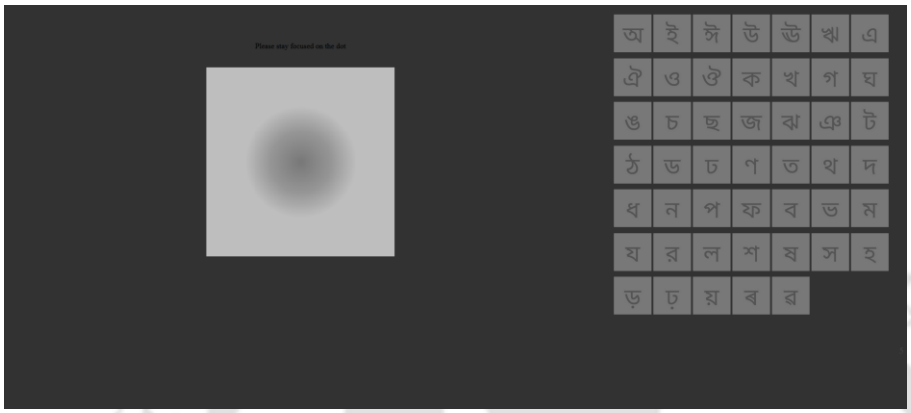
7. imgindex.php



```
<?php
  error_reporting(E_ALL ^ E_NOTICE);
  session_start();
  extract($_POST);
  extract($_GET);
  extract($_SESSION);
  include "keyboard.php";
  //$_SESSION['image']=$image;
  //echo $image;
  //echo $_SESSION['image'];
?>
<!doctype html>
<html>
<head>
<meta charset="utf-8">
<title>Untitled Document</title>
</head>
<body bgcolor="323232">
<br><br><br><p align="center">Please stay focused on the dot</p><br>
   <?php
  //echo "<img src='$image'/>";
  echo "<img src='$image' height='400' width='400' style='display: block; margin: 0
auto'/>";
  //$count++;
  $_SESSION['count']=$count+1;
  ?>
<script type="text/javascript">
      <!--
        function Redirect() {
          window.location="index2.php";
        }
        //document.write("You will be redirected to main page in 0.28 sec.");
        setTimeout('Redirect()', 200);
```

```
        //-->
      </script>
</body>
</html>
```

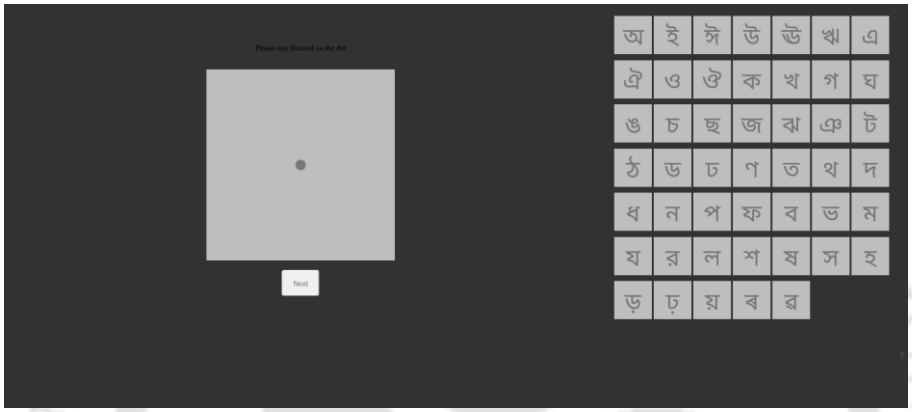
8. index2.php




```
<!doctype html>
<html>
<head>
<meta charset="utf-8">
<title>Untitled Document</title>
</head>
<?php
session_start();
   extract($_POST);
  extract($_GET);
  extract($_SESSION);
  include "keyboard.php";
  $link=mysqli_connect("localhost", "root", "")or die("cannot connect");
mysqli_select_db($link, "lettersdb")or die("cannot select DB");
$query2 = "UPDATE `keyflag` SET flag='0'";
  $result2 = mysqli_query($link, $query2);
  ?>
   <body bgcolor="323232">
<br><br><br><p align="center">Please stay focused on the dot</p><br>
<img src="Mask.jpg" height="400" width="400" style="display: block; margin: 0
auto"/>
<script type="text/javascript">
      <!--
        function Redirect() {
          window.location="preindex.php";
        }
        //document.write("You will be redirected to main page in 0.28 sec.");
```

```
            setTimeout('Redirect()', 494);
        //-->
    </script>
</body>
</html>
```

9. response.php




```
<?php
session_start();
   extract($_POST);
  extract($_GET);
  extract($_SESSION);
  ?>
<!doctype html>
<html>
<head>
<meta charset="utf-8">
<title>Untitled Document</title>
</head>
<body bgcolor="323232">
<?php
//session_start();
$link=mysqli_connect("localhost", "root", "")or die("cannot connect");
mysqli_select_db($link, "lettersdb")or die("cannot select DB");
$myans=$_GET['myans'];
/*echo $image_folder;
echo $myans;
echo $user_id;
echo $user_res;
echo $random;*/
$query2 = "UPDATE `keyflag` SET flag='1'";
  $result2 = mysqli_query($link, $query2);
if($image_folder==$myans)
```

```
        {
        $query = "UPDATE `$image_folder` SET $user_id='1', $user_res='$myans' where
name='$random'";
          $result = mysqli_query($link, $query);
        }
        else
        {
          $query = "UPDATE `$image_folder` SET $user_id='0', $user_res='$myans' where
name='$random'";
          $result = mysqli_query($link, $query);
        }
        ?>
        <script type="text/javascript">
                window.location="random_image.php";
            </script>
        </body>
        </html>
```

Appendix IX

Each 30 rows (in three groups as in all tables) are the 30 variations of masked letters.

The first 30 rows are the right (1) and wrong (0) information (with alternate identified letter) of each letter of 33 participants (as in columns p1 to p43). It is the second database created from the second set of 30 rows.

The second set of 30 rows are the right and wrong information of each letter and 43 participants. Identified letters corresponding to wrong inputs are given in the first table (first set of 30 rows).

The last set of 30 rows are the letter-wise right and wrong information of total inputs given by participants. The information about masked letter variations that confused with exposed letter are shown here. From here on, the outliers are not considered in rest of studies.

Letter 1/ A/ অ

L1.xlsx

অ

V	p1	p2	p3	p4	p5	p6	p7	p8	p9	p10	p11	p12	p13	p14	p15	p16	p17	p18	p19	p20	p21	p22	p23	p24	p25	p26	p27	p28	p29	p30	p31	p32	p33	p34	p35	p36	p37	p38	p39	p40	p41	p42	p43
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	10	1	1	1	26	1	22	1	1	1	10	1	10	1	1	1	10	1	1	1	1	1	10	10	1	1	1	10	1	1	1	1	1	1	10	1	1	1	1	10	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	26	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	18	26	1	1	1	1	1	18	1	1	1	18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	18	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	26	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	26	46	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	1	20	1	1	20	1	1	1	1	20	1	1	1	20	20	1	1	1	1	20	1	1	1	1	1	20	1	1	20	1	1	20	1	20	1	1	1	1	20	20	1	1	1
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15	20	10	1	1	1	4	1	1	1	1	1	1	1	1	1	1	1	10	1	18	1	1	10	1	1	1	1	1	10	1	1	1	1	1	10	1	1	1	1	1	1	1	1
16	1	18	1	1	1	26	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	1	1	1	1	1	26	1	1	1	1	18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	18	1
18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
19	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
21	1	1	8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
22	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
23	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
24	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
25	1	18	1	1	1	1	1	18	1	1	1	1	1	1	18	1	1	1	1	1	1	1	1	1	1	1	1	18	1	1	1	1	1	1	1	1	18	1	18	1	1	1	1
26	1	1	1	1	1	26	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
27	1	1	1	1	18	1	1	1	1	1	1	18	1	1	1	1	1	18	1	1	1	1	1	18	1	1	1	1	18	1	1	1	1	18	1	1	1	1	1	1	1	1	18
28	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
29	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
30	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

																																													no	w	%_w
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	43	1	0	0.000%
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	43	2	0	0.000%
3	1	0	1	1	1	0	1	0	1	1	1	0	1	0	1	1	1	0	1	1	1	1	1	0	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	1	1	32	3	11	25.581%
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	43	4	0	0.000%
5	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	42	5	1	2.326%
6	1	1	1	1	0	0	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	38	6	5	11.628%
7	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	42	7	1	2.326%
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	43	8	0	0.000%
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	43	9	0	0.000%
10	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	41	10	2	4.651%
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	43	11	0	0.000%
12	1	0	1	1	0	1	1	1	1	0	1	1	1	0	0	1	1	1	1	0	1	1	1	1	1	0	1	1	0	1	1	0	1	0	1	1	1	1	0	0	1	1	1	31	12	12	27.907%
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	43	13	0	0.000%
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	43	14	0	0.000%
15	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	0	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1	35	15	8	18.605%
16	1	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	41	16	2	4.651%
17	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	40	17	3	6.977%
18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	43	18	0	0.000%
19	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	43	19	0	0.000%
20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	43	20	0	0.000%
21	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	42	21	1	2.326%
22	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	43	22	0	0.000%
23	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	43	23	0	0.000%
24	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	43	24	0	0.000%
25	1	0	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	37	25	6	13.953%
26	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	42	26	1	2.326%
27	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1	1	0	36	27	7	16.279%
28	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	43	28	0	0.000%
29	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	43	29	0	0.000%
30	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	43	30	0	0.000%

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	
1	43																																															43
2	43																																															43
3	32									9												1				1																						43
4	43																																														43
5	42																									1																					43
6	38																	4								1																					43
7	42																									1																					43
8	43																																														43
9	43																																														43
10	41																									1																				1		43
11	43																																														43
12	31																			12																											43
13	43																																														43
14	43																																														43
15	35			1						5								1		1																											43
16	41																	1								1																					43
17	40																	2								1																					43
18	43																																														43
19	43																																														43
20	43																																														43
21	42							1																																							43
22	43																																														43
23	43																																														43
24	43																																														43
25	37																	6																													43
26	42																									1																					43
27	36																	7																													43
28	43																																														43
29	43																																														43
30	43																																														43
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	
	অ	ই	ঈ	উ	ঊ	ঋ	এ	ঐ	ও	ঔ	ক	খ	গ	ঘ	ঙ	চ	ছ	জ	ঝ	ঞ	ট	ঠ	ড	ঢ	ণ	ত	থ	দ	ধ	ন	প	ফ	ব	ভ	ম	য	র	ল	শ	ষ	স	হ	ড়	ঢ়	য়	ৰ	ৱ	1290

Appendix X

Matlab code for the determining 'discrete plane' or (O-dp) is below –

```
close all;
clear all
clc;
cd('F:\PhD_Analysis\Exprimental Analysis\Short Exposure\bengali\
        Images_after each mask\1');
orig_img=imread('F:\PhD_Analysis\Exprimental Analysis\
        Short Exposure\bengali\Image_Be\Image_Be_01.jpg');
orig_img=rgb2gray(orig_img);
input_correct=input('input correct plane number in []');
input_incorrect=input('input incorrect plane number in []');
%-------------------------------------------------------------------
%% --------------------correct plane
im_all=uint16(zeros(245,245));
for i=1:length(input_correct)
   img1=strcat(num2str(input_correct(i)),'.jpg');
   im1=uint16(rgb2gray(imread(img1)));
   im_all=imadd(im_all,im1,'uint16');
end
im_all=im_all/length(input_correct);
figure;imshow(uint8(im_all));
%-------------------------------------------------------------------------
%% --------------------incorrect plane
im_inc=uint16(zeros(245,245));
for i=1:length(input_incorrect)
   img2=strcat(num2str(input_incorrect(i)),'.jpg');
   im2=uint16(rgb2gray(imread(img2)));
   im_inc=imadd(im_inc,im2,'uint16');
end
im_inc=im_inc/length(input_incorrect);
figure;imshow(uint8(im_inc));
%-------------------------------------------------------------------
%% --------------------correct incorrect fusion
image_fuse=imfuse(im_all,im_inc);
image_fuse=rgb2gray(image_fuse);
figure;imshow(uint8(image_fuse));
%%
for i=1:size(im_all,1)
   for j=1:size(im_all,2)
      if(im_all(i,j)==im_inc(i,j) || im_all(i,j)>im_inc(i,j))
         image(i,j)=190;
      end
      if(im_all(i,j)<im_inc(i,j))
```

```
            image(i,j)=im_all(i,j);
        end
    end
end
figure;imshow(uint8(image));
%%  ---------------merging with original image
image1=zeros(245,245);
for i=1:size(image1,1)
    for j=1:size(image1,2)
        if(image(i,j)~=190)
            image1(i,j)=255;
        else
             image1(i,j)=orig_img(i,j);
        end

    end
end
figure;imshow(uint8(image1));
%% -------------original-corrrect
orig_correct=zeros(245,245);
for i=1:size(orig_correct,1)
    for j=1:size(orig_correct,2)
        if(im_all(i,j)>140 && im_all(i,j)<180)
            orig_correct(i,j)=255;
        else
             orig_correct(i,j)=orig_img(i,j);
        end

    end
end
figure;imshow(uint8(orig_correct));
%% -------------original-incorrrect
orig_incorrect=zeros(245,245);
for i=1:size(orig_incorrect,1)
    for j=1:size(orig_incorrect,2)
        if(im_inc(i,j)>140 && im_inc(i,j)<180)
            orig_incorrect(i,j)=255;
        else
             orig_incorrect(i,j)=orig_img(i,j);
        end

    end
end
figure;imshow(uint8(orig_incorrect));
```

Appendix XI

	Letter_No	15	46	37	47	27	34	30	43	24	44	45	39	26	17	12	25	23	16	36	19	6	21	35
	Bengali_Letter	ঙ	ৰ	র	ৱ	থ	ভ	ন	ড়	ঢ	ঢ়	য়	শ	ত	ছ	খ	ণ	ড	চ	য	ঝ	ঋ	ট	ম
Letter_No	Bengali Letter																							
11	ক	0	4	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0
10	ঔ	13	0	0	0	0	2	0	1	0	0	0	0	1	0	0	3	0	0	0	0	0	3	0
38	ল	1	0	0	0	1	2	363	0	0	0	0	0	0	0	1	8	0	0	0	0	0	0	0
3	ঈ	1	0	0	0	1	0	0	0	1	0	0	3	0	14	2	0	0	0	0	0	2	3	0
8	ঐ	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	1	35	0
41	স	1	0	0	0	1	0	13	0	0	0	0	9	0	0	0	0	1	3	2	2	2	0	98
32	ফ	2	1	0	0	10	3	1	0	1	0	7	1	0	0	4	0	0	1	15	0	1	0	1
1	অ	0	0	0	0	0	0	0	0	0	0	0	1	7	12	0	0	0	0	0	56	3	0	0
22	ঠ	0	1	0	2	0	0	0	0	1	1	0	0	3	14	0	0	1	8	0	0	0	14	0
14	ঘ	0	0	1	0	30	0	0	0	0	0	53	23	0	0	3	0	0	0	56	0	0	0	0
2	ঈ	0	0	0	0	1	0	0	1	1	1	0	2	7	16	0	3	1	0	0	0	0	24	0
40	ষ	0	4	2	1	257	0	3	0	0	1	38	55	0	0	11	1	0	1	121	0	0	0	54
4	ঊ	377	0	0	0	0	79	0	74	6	0	0	0	31	0	0	0	132	1	0	1	0	54	0
31	প	1	0	0	1	0	1	1	0	2	0	0	121	1	0	1	106	0	0	0	0	0	0	0
28	দ	1	0	0	0	0	2	1	0	1	1	0	1	0	0	0	0	0	3	0	0	0	0	0
13	গ	0	0	0	0	2	1	0	0	0	0	0	51	0	0	1	69	1	0	0	0	1	0	5
33	ব	0	700	390	200	16	2	2	1	0	0	0	0	1	6	22	6	0	0	0	1	0	0	0
18	জ	9	0	0	0	0	11	0	8	2	0	0	0	36	11	0	0	3	0	0	0	1	0	0
20	ঞ	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
5	ঊ	13	0	0	0	0	1	0	13	0	0	0	0	2	8	0	0	3	0	0	0	0	0	0
9	ও	50	0	0	1	0	7	1	0	0	1	0	0	65	3	0	0	2	2	0	2	0	0	0
42	হ	0	0	0	0	0	0	0	0	4	2	0	0	16	106	0	0	0	4	0	0	0	0	0
7	এ	1	1	0	5	0	2	0	0	0	0	0	2	1	1	0	2	0	0	0	0	0	0	0
29	ধ	3	29	25	5	94	0	0	0	0	0	0	1	0	0	9	0	0	0	2	1	5	0	0
35	ম	0	0	0	0	1	0	151	0	0	0	0	29	0	0	0	1	0	0	1	0	0	0	1099
21	ট	0	0	0	0	0	1	0	0	54	25	0	0	3	9	0	0	0	9	0	0	0	1085	0
6	ঋ	0	2	4	0	18	0	0	0	0	1	0	1	0	13	219	0	0	0	0	163	1075	0	0
19	ঝ	0	11	3	7	7	0	0	0	0	0	1	1	0	5	0	0	1	0	0	1059	189	0	1
36	য	0	0	1	0	75	0	0	0	0	0	394	8	0	2	16	0	1	0	1049	0	0	0	0
16	চ	0	0	0	0	0	1	0	1	334	176	0	0	1	3	0	0	0	1025	0	0	0	42	0
23	ড	433	1	0	1	0	408	1	429	2	10	0	2	95	19	0	0	1020	6	0	0	1	1	26
25	ণ	0	0	0	0	1	0	39	0	0	1	0	119	0	0	0	1012	0	0	0	0	1	5	0
12	খ	0	2	4	0	138	0	0	0	0	0	2	1	0	8	970	1	0	1	11	2	3	0	0
17	ছ	0	0	0	0	1	0	0	0	12	0	0	1	1	950	1	0	0	8	0	0	0	0	0
26	ত	10	0	2	0	0	40	1	7	1	0	0	0	944	8	0	0	0	0	0	1	1	0	0
39	শ	1	0	0	1	0	0	2	1	0	0	0	845	0	0	0	6	0	1	0	0	0	0	1
45	য়	0	1	19	1	3	0	0	0	1	0	783	0	0	0	2	0	0	0	13	0	0	0	1
44	ঢ়	0	0	0	1	0	4	0	0	84	782	1	0	0	27	0	0	1	17	0	0	0	4	0
24	ঢ	0	0	0	1	0	0	0	0	781	275	0	0	1	19	0	1	1	198	0	0	0	19	2
43	ড়	3	0	0	1	0	3	0	732	0	5	0	0	8	13	0	0	33	0	0	0	0	0	0
30	ন	1	0	1	1	1	0	707	0	0	2	0	6	1	0	0	68	0	0	0	0	0	1	1
34	ভ	50	0	0	0	0	704	0	16	1	1	0	0	58	14	0	0	81	1	0	1	0	0	1
27	থ	0	1	0	1	628	0	1	0	0	1	11	3	0	1	24	1	1	0	18	0	1	0	0
47	ৱ	1	7	113	615	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
37	র	0	36	607	431	0	0	1	1	0	4	0	0	0	6	1	1	0	1	0	0	0	0	0
46	ৰ	2	489	117	12	3	0	2	0	0	0	0	2	2	1	1	1	0	0	2	0	1	0	0
15	ঙ	316	0	0	1	0	16	0	4	0	0	0	1	3	1	1	0	6	0	0	0	0	0	0
Letter_No	Bengali Letter																							
	Bengali_Letter	ঙ	ৰ	র	ৱ	থ	ভ	ন	ড়	ঢ	ঢ়	য়	শ	ত	ছ	খ	ণ	ড	চ	য	ঝ	ঋ	ট	ম
	Letter_No	15	46	37	47	27	34	30	43	24	44	45	39	26	17	12	25	23	16	36	19	6	21	35
	Wrong	974	803	684	678	666	586	583	529	512	502	492	445	346	338	315	278	271	266	241	231	215	205	191
	%_Wrong	75.504%	62.248%	53.023%	52.558%	51.628%	45.426%	45.194%	41.008%	39.690%	38.915%	38.140%	34.496%	26.822%	26.202%	24.419%	21.550%	21.008%	20.620%	18.682%	17.907%	16.667%	15.891%	14.806%
	Right	316	487	606	612	624	704	707	761	778	788	798	845	944	952	975	1012	1019	1024	1049	1059	1075	1085	1099
	Total	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290
		The value of the gray coloured cells is greater than or equal to 130, i.e. >=10%																						

Identified Letter

Appendix XI

29	7	42	9	5	20	18	33	13	28	31	4	40	2	14	22	1	32	41	8	3	38	10	11	Letter_No	
ধ	এ	হ	ও	ঊ	ঞ	জ	ব	গ	দ	প	উ	ষ	ই	ঘ	ঠ	অ	ফ	স	ঐ	ঈ	ল	ঔ	ক	Bengali_Letter	
																								Bengali Letter	Letter_No
1	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	20	0	0	0	0	0	1269	ক	11
0	0	0	105	2	0	15	0	0	0	0	5	0	13	0	5	14	0	1	4	11	0	1240	0	ঔ	10
0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1239	0	0	ল	38
0	0	1	0	0	1	0	0	0	38	0	0	0	4	0	0	0	0	3	2	1238	0	0	0	ঈ	3
0	96	0	1	3	131	0	0	0	0	0	1	0	10	0	17	1	0	0	1236	0	0	21	0	ঐ	8
0	12	0	0	0	0	1	0	2	12	20	0	16	0	3	0	0	0	1235	1	16	6	0	0	স	41
16	2	0	0	0	4	2	1	2	2	0	1	2	1	2	0	0	1230	2	0	0	0	0	7	ফ	32
0	0	0	8	0	5	43	0	0	0	0	1	0	0	0	0	1230	0	2	0	0	3	0	0	অ	1
0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	1228	1	0	0	0	2	0	0	0	ঠ	22
38	3	0	0	0	0	0	1	1	0	4	0	3	0	1225	0	0	1	0	0	0	2	0	0	ঘ	14
0	0	151	0	1	0	0	0	1	0	0	0	0	1225	0	8	0	0	0	6	6	0	0	0	ই	2
53	0	0	0	0	0	0	17	1	0	2	0	1196	0	1	0	0	0	14	0	0	1	0	0	ষ	40
0	1	0	1	140	1	12	0	0	0	0	1183	0	1	0	3	1	0	0	4	4	0	11	0	উ	4
1	0	0	0	0	0	0	1	92	19	1177	0	0	0	1	0	0	0	0	0	0	3	0	0	প	31
0	0	0	0	0	0	0	0	0	1169	0	0	0	0	0	1	0	1	0	0	1	0	0	0	দ	28
0	0	3	0	0	0	0	0	1160	4	62	0	0	0	0	0	0	0	0	0	0	0	0	0	গ	13
22	0	1	0	0	0	0	1153	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	8	ব	33
1	2	0	0	0	0	1143	0	0	1	0	1	1	0	0	0	21	1	0	0	0	0	1	0	জ	18
0	3	0	2	2	1129	44	0	0	0	0	0	0	0	0	0	13	2	0	9	0	0	0	0	ঞ	20
0	0	0	2	1134	2	2	0	0	0	0	76	0	0	0	0	0	0	0	2	7	0	2	0	ঊ	5
0	15	0	1120	0	0	4	0	0	0	0	1	0	0	0	0	0	1	0	3	0	1	9	0	ও	9
1	2	1118	0	0	0	0	0	0	11	0	0	0	20	0	0	0	0	0	0	0	0	0	0	হ	42
0	1113	0	15	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0	0	এ	7
1108	0	0	2	0	0	0	19	2	1	1	0	3	0	14	12	0	0	1	0	0	1	0	1	ধ	29
0	0	0	0	0	0	0	0	1	20	1	0	41	0	0	0	0	0	26	0	0	1	0	0	ম	35
0	0	0	0	0	0	0	0	0	1	0	1	0	2	0	0	0	0	0	0	0	0	0	0	ট	21
7	0	0	0	0	3	0	1	1	0	2	0	3	0	1	0	0	1	1	0	0	0	0	0	ঋ	6
1	1	0	0	0	2	0	2	0	0	3	0	1	0	3	0	0	7	1	0	2	1	0	1	ঝ	19
6	0	0	0	0	0	0	2	9	0	0	0	2	0	36	2	0	24	0	0	1	1	0	0	য	36
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	চ	16
1	12	0	2	4	2	14	1	3	0	0	10	1	0	0	0	0	0	0	0	1	3	1	0	ভ	23
0	0	1	0	0	1	0	0	8	1	11	0	0	0	0	0	0	0	0	0	0	1	0	0	প	25
26	0	0	0	0	0	0	20	3	2	4	0	20	0	0	0	0	0	0	1	1	0	0	1	খ	12
0	2	3	0	0	0	0	2	0	0	0	0	0	0	1	2	0	1	0	0	0	1	0	0	ছ	17
1	5	4	17	0	0	0	0	0	0	0	0	0	0	0	0	8	0	1	1	0	0	1	1	ত	26
0	0	0	4	0	0	0	0	0	5	0	0	0	0	0	0	0	0	2	0	0	18	0	0	শ	39
0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	য়	45
0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ঢ়	44
0	1	1	0	0	1	6	1	0	1	1	1	0	1	1	0	0	0	0	0	0	1	0	1	ঢ	24
1	0	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	ড়	43
1	7	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	5	1	0	ন	30
0	9	1	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ভ	34
2	0	5	0	0	0	0	0	2	0	2	0	0	0	0	10	0	0	0	0	0	0	0	0	থ	27
0	0	0	0	0	0	0	16	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	ৰ	47
2	0	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	র	37
1	4	0	0	1	0	0	35	0	0	0	1	1	1	0	2	1	0	0	1	0	0	1	1	ৰ	46
0	0	1	1	1	0	4	0	0	0	0	5	0	0	0	0	0	0	1	0	0	2	0	0	ঙ	15

Presented Letter

																								Bengali Letter	Letter_No
ধ	এ	হ	ও	ঊ	ঞ	জ	ব	গ	দ	প	উ	ষ	ই	ঘ	ঠ	অ	ফ	স	ঐ	ঈ	ল	ঔ	ক	Bengali_Letter	
29	7	42	9	5	20	18	33	13	28	31	4	40	2	14	22	1	32	41	8	3	38	10	11	Letter_No	
182	177	171	170	156	155	149	137	131	120	113	107	94	65	65	62	60	60	55	54	52	50	49	21		
14.109%	13.721%	13.256%	13.178%	12.093%	12.016%	11.550%	10.620%	10.155%	9.302%	8.760%	8.295%	7.287%	5.039%	5.039%	4.806%	4.651%	4.651%	4.264%	4.186%	4.031%	3.876%	3.798%	1.628%		
1108	1113	1119	1120	1134	1135	1141	1153	1159	1170	1177	1183	1196	1225	1225	1228	1230	1230	1235	1236	1238	1240	1241	1269		
1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290		

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List of Publication

Journal:

1. Application of Semiotics in Defining the Anatomy of Bengali Typeface
(Accepted for publication)
Punctum-International Journal of Semiotics (Issue 4:1, July 2018)
Authors: S. Chandra, P. Bokil, D. Udaya Kumar

Conference Proceedings:

1. Legibility: same for all scripts!
ICoRD'17 – International Conference on Research into Design
IIT Guwahati, 2017.
Authors: S. Chandra, P. Bokil, D. Udaya Kumar

2. Typeface Anatomy: A method to construct structural formation
6th Typography Meeting, Portugal, May 2016
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3. Anatomy of Bengali Letterforms: A Semiotic Study
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4. Reading Bengali: A study of typeface readability and legibility for on-screen texts
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Authors: S. Chandra, D. Udaya Kumar

5. Lettering and Calligraphy in Bollywood Movie Titles
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Authors: Mohammad Shahid, Subhajit Chandra, D. Udaya Kumar

Conference Posters:

1. A review of legibility studies and its implication to Indic scripts
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Authors: S. Chandra, D. Udaya Kumar

2. Bengali Type: A Documentation on Bengali Typeface
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3. Lost in Translation: In the context of typographic attributes of Latin to Bengali comics Translation
22nd Himalayan Language Symposium 2016, IIT Guwahati, 2016
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