The Influence of Stroke Width on Legibility for Low Vision Adults: Integrating Scientific & Design Knowledge on Typeface Boldness

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A thesis submitted in partial fulfilment of the requirements of the Royal College of Art for the degree of Doctor of Philosophy

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AUTHOR'S DECLARATION

Some of the contents of Chapters 1-3 have previously been published in a paper for the *Include 2009* conference entitled 'Innovation in Inclusive Typography: A Role for Design Research' (von Ompteda, 2009a). Further, some of the contents of Chapters 3, 5, and 6 have previously been published in an article for *Grafik Magazine* entitled 'Typo Transparencies' (von Ompteda, 2011a). The reviews and analyses presented in this thesis are significantly more extensive, as well as updated to 2021.

This thesis represents partial submission for the degree of Doctor of Philosophy at the Royal College of Art. I confirm that the work presented here is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

During the period of registered study in which this thesis was prepared the author has not been registered for any other academic award or qualification. The material included in this thesis has not been submitted wholly or in part for any academic award or qualification other than that for which it is now submitted.

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ABSTRACT

This PhD thesis investigates the influence of typeface stroke width on reading performance for low vision adults. While scientific evidence suggests that an increased stroke width—or bolder typeface—can improve legibility, optimal values are not well understood. In keeping with this, existing accessible design guidelines in the United Kingdom recommend a large range of typeface weights from regular to bold. The goal of this PhD research is to inform print design guidelines with a higher degree of specificity, and thereby increase the proportion of the population able to access text.

This research is based upon an initial inquiry formulated around one main question: What is the optimal typeface stroke width for low vision adults? In order to address this question, an integration of knowledge drawing from vision science and typographic design is undertaken. The majority of research into typeface legibility exists within vision science, while the creation of typefaces and expertise in their use exists within the discipline of design. This PhD responds to the lack of interdisciplinary approaches to typeface legibility research, which has resulted in limited application of scientific research to design practice.

This practice-based communication design PhD addresses the research question through a quantitative analysis of text typefaces. This involves the measurement of typeface proportions and the analysis of this typeface data through information visualisation. Typeface data is initially gathered with the purpose of designing a typeface for experimental testing. It is through this typeface design practice that the methods for the quantitative analysis of typefaces emerge, which then become the focus of the research. This PhD investigation develops a foundation of interdisciplinary—science and design—typographic knowledge, based on typeface data.

This research consolidates scientific knowledge on the influence of boldness on legibility in the context of low vision. Ten scientific legibility studies are analysed. This entails measuring and visualising the stroke width values of

typefaces that have been experimentally found to have higher and lower legibility.

Design knowledge is formalised by measuring and visualising the stroke width values of typefaces commonly used in design practice. This is a *design phenomenology* study as defined by Nigel Cross, investigating design knowledge residing in artefacts themselves. By integrating scientific and design knowledge as proposed, interdisciplinary knowledge on typeface legibility for low vision adults is developed. My original contribution to knowledge includes visualising how the stroke widths of typefaces experimentally found to improve legibility relate to the stroke widths of typefaces commonly employed in design practice.

This thesis concludes that typefaces with stroke width values ranging from 22-33% (percent of x-height) improve legibility in the context of low vision. The analysis further indicates that sans serif regular typefaces range from 13.5-19.8% stroke width and are not optimal for low vision reading. The analysis also indicates that sans serif bold typefaces range from 18.9-40.0% stroke width, and that many, but not all, may improve reading performance for adults with low vision. This research is intended to be useful for legibility researchers and the development of evidence-based accessible design guidelines.

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CHAPTER 1. INTRODUCTION

1.1 INTRODUCTION

This research is motivated by the unprecedented aging of the world's populations (United Nations, 2020) and the associated increased risk of visual impairment (RNIB, 2019). The majority of people with visual impairments are not blind, having significant remaining vision known as low vision (Arditi, 2004). Difficulty with reading is a central concern for people living with low vision (Legge, 2007), suggesting an increased need for designers to produce accessible communications. Existing print guidelines regarding typographic design for low vision readers are defined by larger size recommendations, with guidance on the choice of typefaces themselves being broad, from for example the UK Association for Accessible Formats (UKAAF, 2019). Vision science research illustrates the influence of typeface characteristics on legibility (Legge, 2016), suggesting that greater specificity in typeface recommendations could increase the proportion of the population able to access printed text.

This practice-based research is based upon an initial inquiry formulated around one main question: What is the optimal typeface stroke width for low vision adults? The focus is on stroke width—also known as weight—because scientific evidence suggests that a bolder typeface can improve legibility (Arditi, 2004), however optimal values are not well understood (Bernard et al., 2013; Legge, 2016). This research is also focused on low vision legibility in the context of print, as printed (versus digital) text cannot be customised by the reader making its legibility crucial. In order to address this research question, an integration of knowledge from vision science and typographic design—the two major disciplines concerned with the topic of typeface legibility—is undertaken. I am able to perform this interdisciplinary research based on my training in both science (MSc Biology) and design (BDes Graphic Design).

The development of interdisciplinary typographic knowledge is approached through a quantitative analysis of typefaces. This approach is comprised of two main methods: the measurement of typeface proportions and information visualisation. These methods are utilised to integrate scientific knowledge generated through legibility research experiments with design knowledge residing in the form of typefaces themselves. The methods employed to determine which scientific studies to include in the analysis and which typefaces to measure are presented in the practice chapters within this thesis (Chapters 4-6). Scientific and design knowledge construction are addressed in Chapter 3 (section 3.3), with reference to design researchers including Professor Nigel Cross (2007).

The purpose of this research is to evidence and build a foundation for inclusive typographic knowledge. I define *inclusive typography* as the area of communication design focused on increasing the number of people with low vision able to access text. Inclusive typographic knowledge serves to contribute to both future legibility research and print design guidelines for low vision readers. As such, the audience for this thesis is both legibility researchers focused in this area, and communication design practitioners seeking knowledge on typographic design for low vision readers.

This PhD research began in 2007 and has therefore been undertaken across a timespan of more than a decade. The research presented within this thesis reflects the context which gave rise to the investigation, as well as the contemporary context within which it is published. The thesis demonstrates that the research question remains relevant and the need for interdisciplinary approaches to typographic research persists to this day.

1.2 KEY THEMES AND TERMINOLOGY

1.2.1 LOW VISION

Low vision compromises sight through blurring, patchiness, and loss of central or peripheral vision. In 2010, low vision was estimated to affect approximately 246 million people worldwide (Mariotti, 2012). In the United Kingdom, over two million people are estimated to be living with sight loss severe enough to have a significant impact on their daily lives (RNIB, 2018).

The main causes of sight loss in adults are age-related macular degeneration (AMD), glaucoma, cataract, and diabetic retinopathy (RNIB, 2019). Risk of sight loss increases with age, with one in nine people aged 60 years and over affected in the United Kingdom, one in five people aged 75 years and over, and one in two people aged 90 years and over (RNIB, 2018). Younger adults can also have low vision, and in this thesis *adult* is defined as aged 18 and above. The number of people in the United Kingdom with sight loss is predicted to increase dramatically over the coming decades (RNIB, 2018).

Low vision can be defined functionally as a visual impairment resulting in the inability to read the newspaper at a standard distance (40 cm) with best optical correction (i.e. prescription lenses) (Legge, 2007). Access to text is fundamental to participation in modern society, and the primary goal of vision rehabilitation is improving access to written materials (Arditi, 1996). The design community has an increasingly critical mitigating role to play in this context through the production of inclusive typographic design.

1.2.2 INCLUSIVE TYPOGRAPHY

Inclusive design is a response to the diverse demands of today's consumers, especially those who are elderly or disabled (Clarkson et al., 2003). This increasingly pervasive approach to architectural, product and communication

design, seeks to meet the needs of the largest user-group possible, whilst taking into consideration the goals of commerce (Clarkson et al., 2003). As stated in section 1.1, I define inclusive typography as the area of communication design focused on increasing the number of people with low vision able to access text.

An inability to access text cannot be solely attributed to the visual abilities of a reader. It is the congruence between visual abilities and typographic design that ultimately determines effective reading (Legge, 2007). The inclusive design community has aptly named such mismatches as “disabled by design” (Clarkson et al., 2003, p.1). Therefore, the design community has a role to play in increasing the percentage of people with low vision that can access written materials.

Inclusive typography is increasingly being adopted by practicing designers for two major reasons beyond ethical issues surrounding social equality. First, there is an economic imperative to meet the needs of the so-called ‘grey market,’ made up increasingly of the affluent and discriminating ‘baby boomer’ generation (Evamy & Roberts, 2004). Second, designers must increasingly operate within a legislative context advocating for the rights of people with disabilities. Under the Equality Act 2010, businesses or organisations in the United Kingdom are legally required to make reasonable adjustments (or changes) to avoid putting people with disabilities at a substantial disadvantage (RNIB, 2020). A key requirement of the Equality Act is the provision of accessible information, which service providers must follow (UKAAF, 2019).

1.2.3 LEGIBILITY AND LEGIBILITY RESEARCH

To date, inclusive typography guidelines are based largely on legibility research conducted within the vision science community. The term *legibility* in this discipline—and in this thesis—refers to the perceptual properties of text that influence readability (Legge, 2007). Therefore, issues of content that

can render text difficult to read, do not in any way influence its legibility. Legibility of a text depends on both its local and global properties (Legge, 2007); local properties are characteristics of individual letters or groups of letters (e.g. typeface), while global properties are layout characteristics (e.g. line length). The vision science definition of legibility is distinct from that employed within the design community. The typographic design community distinguishes between *legibility* referring to the ease of recognition of letters and words, and *readability* referring to the ease and pleasantness of reading text (Felici, 2012). Note that James Felici's *The Complete Manual of Typography* (2012) is employed throughout the thesis as a standard reference for the definition of typographic terms. Within this thesis the term legibility encompasses all measures of reading performance as long as they depend on the physical properties of text (local or global). While this term may appear broad, in most circumstances legibility becomes defined more specifically according to the particular methods employed to measure it.

Legibility research within the vision sciences is conducted using what are called psychophysical methods. *Psychophysics* is the study of the relationship between physical stimuli and perceptual responses (Norton et al., 2002); in this case, the relationship between the physical properties of text (e.g. stroke width) and reading performance (Legge, 2007). The psychophysical study of reading commonly employs three legibility metrics: reading acuity, reading speed, and critical print size (CPS), which are discussed in greater detail in Chapter 2 (section 2.2.2). While legibility research is primarily conducted within the scientific community, there are increasing interdisciplinary contributions from the design research community (e.g. Bessemans, 2012; Beveratou, 2016; Dyson & Beier, 2016). Within this PhD thesis, interdisciplinary design research is included within reviews and analyses, and is referred to as scientific research if the knowledge is generated through scientific methods.

1.2.4 INCLUSIVE TYPOGRAPHY GUIDELINES

The challenge of reviewing scientific research and translating it into practical recommendations for designers is primarily undertaken by visual impairment organizations including the Royal National Institute of the Blind in the United Kingdom (RNIB, 2017), Lighthouse International in the United States (Arditi, 2018), and the Canadian National Institute for the Blind (CNIB, 2020). The UK Association for Accessible Formats, an industry association, also publishes guidelines (UKAAF, 2019) which RNIB links to from its website. Designers are also involved in this process, for example the joint publication between RNIB and the International Society of Typographic Designers (RNIB & ISTD, 2007). The print guidelines referenced above are reviewed in Chapter 2 (section 2.4) and represent a Canadian, United States, and United Kingdom perspective.

Inclusive typography guidelines do not yet rest upon a strong scientific foundation. A review of typography for readers with low vision in the *Journal of Visual Impairment and Blindness* concludes that “research has not produced consistent findings and thus that there is a need to develop standards and guidelines that are informed by evidence” (Russell-Minda et al., 2007, p.402). Criticism of guidelines is also found within empirical papers. Rubin et al. (2006, p.545) state that “the scientific basis for the guidelines is elusive at best”. Tarita-Nistor et al. (2013, p.57) remark that “no solid evidence has been provided to support these recommendations”. Hedlich et al. (2018, p.398) state that “Most recommendations addressing font styles are not evidence based.” Designers are also critical of guidelines, for example recommending that RNIB’s Clear Print guidelines “need good supporting evidence, interpreted in terms of practical document design strategies, before they become the basis for public policy” (Waller, 2011, p.11). Scientific legibility research related to low vision reading is reviewed in Chapter 2 (section 2.4). The studies included in the review are focused on a high-resolution context and utilise both print and screen-based media for legibility testing.

1.3 FOUNDATIONAL RESEARCH

This PhD builds upon a foundation of knowledge contributed by scientists and designers whose research is referenced throughout the thesis. The work of three researchers is particularly influential: Gordon E. Legge, Charles Bigelow, and Aries Arditi. The vision scientist Gordon E. Legge's research contributes crucial foundational knowledge in this subject area. Legge's book *Psychophysics of Reading in Normal and Low Vision* (2007) provides an overview of twenty seminal research papers by Legge and his colleagues on the psychophysics of reading in normal and low vision, published between 1985 to 2002. The book includes a chapter entitled "Displaying Text" which discusses the literature on the subject. More recently, Legge (2016) reviews vision science knowledge on low vision and reading, in the context of opportunities presented by digital formats. Chapter 2 (section 2.4.3.5) and Chapter 4 (section 4.3.6) examine one of the seminal research papers; *Psychophysics of Reading XV: Font Effects in Normal and Low Vision* (Mansfield et al. 1996).

Legge also collaborates with typeface designer and academic Charles Bigelow on an interdisciplinary investigation. Legge and Bigelow (2011) present evidence that the distribution of print sizes in historical and contemporary publications falls within the range of text sizes which can be read at maximum speed. Bigelow's contributions are influential for this PhD research, most notably his interdisciplinary collaborations. Chapter 2 (section 2.3.3) describes a laboratory typeface designed by Bigelow specifically to investigate the influence of serifs on legibility (Morris et al., 2002). Note that the term *laboratory typeface* is utilised within this PhD thesis, which I define as a typeface designed specifically for experimental legibility research. Chapter 4 (section 4.3.9) analyses another scientific legibility research study to which Bigelow contributes (Xiong et al. 2018).

The work of vision scientist Aries Arditi is also influential for this PhD research. Arditi is a leader in the creation of laboratory typefaces for low vision legibility research (e.g. Arditi, 2004). Chapter 2 (section 2.3.3)

examines one of his research studies which employs a laboratory typeface to assess the influence of stroke width on legibility. Chapter 5 describes a laboratory typeface that I design, which builds upon the work of both Arditi and Bigelow.

1.4 PHD RESEARCH SCOPE AND TYPOGRAPHIC TERMINOLOGY

This investigation is focused on the typeface characteristic stroke width (see Figure 1), which is also known as weight. Within the design literature, *weight* is utilised to refer to "the thickness of the strokes that make up the characters of a typeface" (Felici, 2012, p.328). Within the scientific literature, this concept is referred to as *stroke width* (Legge, 2007). Within this thesis, both terms are used depending on the context. Generally, the term *stroke width* is prioritised when referring to typeface proportions and numerical values, and *weight* is used when referring to typefaces used in design practice.

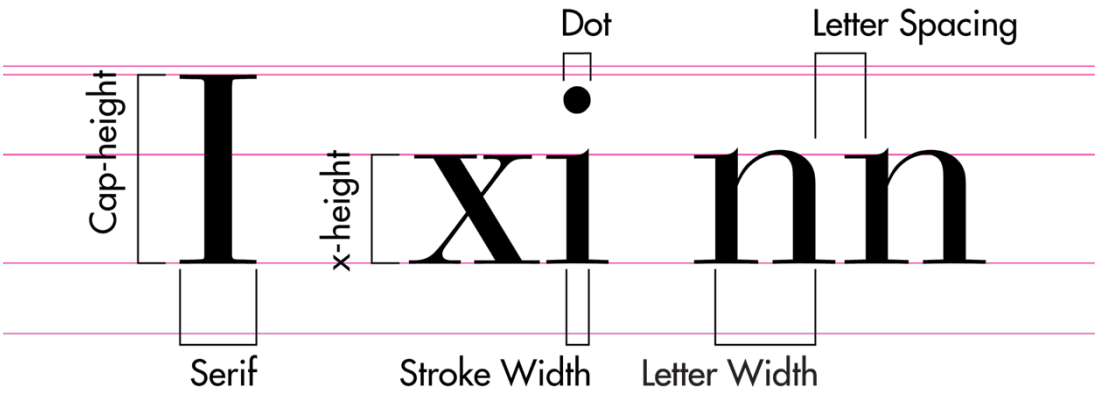

Figure 1: Typeface anatomy and letters employed for measurements, illustrated using the typeface Bodoni.

Letter width is also investigated in this thesis (see Figure 1), because this typeface characteristic varies alongside stroke width (section 2.3.1) and influences legibility (section 2.4.3.4). In the scientific literature, the term *aspect ratio* is used, referring to the width to height ratio of a character (Arditi, 1996). Within this thesis, the term *letter width* is used and refers to

letter width as a proportion of letter height (i.e. synonymous with aspect ratio).

To a lesser degree, letter spacing is analysed (see Figure 1). *Letter spacing* refers to the spacing between letters as defined within a typeface (Felici, 2012). Similar to letter width, letter spacing varies alongside stroke width (section 2.3.1) and influences legibility (section 2.4.3.6). Letter spacing data is not visualised in the thesis, however it is discussed in cases when this aids in interpreting the influence of stroke width on legibility (e.g. section 4.3.6).

The investigation is primarily focused on sans serif typefaces. *Sans serif* typefaces have strokes which end in blunt terminals (Felici, 2012). *Serifs* are short lines at the ends of horizontal and vertical strokes (Cheng, 2005) (see Figure 1). Chapter 2 (section 2.4.3.2) presents evidence that sans serif typefaces are more legible for low vision adults. Chapter 4 and Chapter 6 include analyses of serif typefaces, in order to be as comprehensive as possible in the research.

The analysis focuses on text typeface families. *Text typefaces* are designed for use in long texts (Felici, 2012), with text typeface families including a range of weights and widths. A *typeface family* describes a group of typefaces that share a common root name and design characteristics (Felici, 2012), for example Helvetica Regular, Helvetica Bold, Helvetica Condensed, etc. Within this thesis, the term *text typeface* is used to mean *text typeface family*.

Lowercase versus uppercase characters are the focus of analyses, as these predominate in most English texts (Jones & Mewhort, 2004). Numerals are excluded from the investigation. *Reversed* type—white text on a black background—is also excluded from the investigation, as printed reading material is usually set black on white. Lastly, the research focuses on *Latin characters*; the characters on which Western and most Eastern European languages are based (Felici, 2012).

1.5 TYPEFACE WEIGHT: ORIGIN AND CONTEMPORARY PRACTICE

Bold typefaces have their roots in the Industrial Revolution and the birth of advertising (Haley, 2020). By the early 19th century there was a demand for display typefaces (Dodd, 2006) designed to be used at large sizes to "grab the reader's attention" (Haley, 2020). The majority of typefounders in Britain were issuing bold display typefaces by the 1820s (Twyman, 1993). The earliest of these was known as the fat face (Twyman, 1993), the invention of which is credited to the British typefounder Robert Thorne (1754-1820) (Dodd, 2006) (Figure 2). Although the publication of *New Specimen of Printing Types, Late R. Thorne's* dates his fat faces to 1821, it is thought that he designed the first of these in 1803 (Meggs & Purvis, 2006). Thorne took advantage of the popularity of modern typefaces (Dodd, 2006) and significantly expanded the thickness of the heavy strokes, increasing the weight and contrast (Meggs & Purvis, 2006). *Contrast* refers to the difference between the thick and thin portions of the strokes (Felici, 2012). The fat faces are described as "Bodoni or Didot designs on steroids" (Bigelow & Holmes, 2015) (see Figure 1).

Figure 2: A contemporary fat face (Solotype).

Not until the early 20th century did typefounders begin to integrate bold weights into typeface families (Bigelow & Holmes, 2015). By the late 20th century, the majority of new typeface families and revivals (e.g. Garamond) included at least two bold weights (Bigelow & Holmes, 2015). In the 21st century, new typefaces often include at least four weights (Bigelow & Holmes, 2015). For example, typeface weights for Neue Helvetica—in order from lightest to heaviest—include: Ultra Light, Thin, Light, Roman, Medium, Bold, Heavy, and Black (Linotype, 2021).

Typeface weight names are usually subjective and vary between different typefaces and languages (Bigelow, 2019). These names “give an ordinal sense of boldness” within a typeface family, with no standardisation between typeface families (Bigelow & Holmes, 2015). While this PhD research is focused on the print context, it should be noted that the World Wide Web Consortium (W3C) defines typeface weight on a numerical scale from 100 to 1000, from lightest to boldest (Bigelow, 2019). However, the scale is “imprecisely intuitive and ordinal” (Bigelow, 2019, p.166) and similar to weight names, does not describe a typeface’s numerical stroke width.

The primary use of bold typefaces in setting text is for emphasis or hierarchy (Haley, 2020). The latter refers to the creation of different levels of importance through typeface choice and text arrangement (Haley, 2020). For example, setting headings in a bold typeface is common within typographic practice (Haley, 2020). This PhD investigation demonstrates that bolder typefaces improve reading performance in the context of low vision reading. It thus encourages expanding the use of bolder typefaces within typographic practice beyond emphasis and hierarchy, in order to increase the percentage of people able to access text.

1.6 PHD RESEARCH JOURNEY

This research is conducted *through* design (Frayling, 1993), taking advantage of the unique insights gained through design practice (Godin & Zahedi, 2014). The starting points for this type of research are often issues arising from the researcher’s own practice, that can also be recognized as valid in the wider professional context (Gray & Malins, 2004). This research falls under the category of practice-based research, defined as “an original investigation undertaken in order to gain new knowledge partly by means of practice and the outcomes of that practice” (Candy, 2006, p.1). In this way, the creation of design artefacts is central to the research process, with knowledge gained through the making process, as well as being embedded within the artefacts themselves.

The impetus for this research emerged seventeen years ago. After completing my MSc in Biology in 2003, I embarked upon a new path toward becoming a graphic designer. During my first semester of design school, I woke up one morning with everything appearing darker through one of my eyes. I was diagnosed with optic neuritis—an inflammation of the optic nerve—which passed in a few weeks. The next year, I experienced central vision loss and was legally blind in one eye for weeks, during which time I was diagnosed with multiple sclerosis. Optic neuritis is a common presenting symptom of the disease, and I experienced this on a few occasions. My eyes have never been the same, and in those first years of the disease I found reading particularly difficult. I became deeply interested in communication design for people with visual impairments.

In my third year of design school, I undertook a full-year project focused on developing a (mock) visual identity for CNIB. CNIB had just published their *Clear Print Accessibility Guidelines* (CNIB, 2006), which provided my first exposure to such recommendations. I was surprised by the lack of information and specificity in the guidelines, much of which is considered simply ‘good design’. For example, the guidelines recommend “don’t crowd your text”, accompanied by a photograph of illegible text with letters touching and overlapping (CNIB, 2006, p.15). As I had a good understanding of typography, many recommendations were not useful for the development of my practice, and I remained unclear how to design for a visually impaired audience. I felt compelled to contribute to the development of inclusive typography practice.

In the final year of my undergraduate degree, I applied to the Royal College of Art (RCA) with a proposal to design a typeface for people with low vision as a research degree by project. I was inspired by the typeface Read Regular designed for people with dyslexia by Natascha Frensch (2003) at the RCA. I believed my research project was feasible based on my training in science and design, and that such a typeface would be an important contribution to the field, providing a tool for designers creating accessible communications as part of their practice. During this final year of my

undergraduate degree, I began preliminary work in this area through two typeface design courses. As I familiarised myself with the scientific legibility research literature and attempted to apply it to my typeface design practice, it became clear that the scientific knowledge that would underpin a typeface for low vision did not exist.

In 2007 I began my PhD research at RCA with a new proposal; to design a laboratory typeface specifically for experimental testing. My PhD proposal directly addressed the lack of information to be found on the subject, revealed through my earlier attempts to design a typeface for low vision users. My research centres on typeface weight as this typeface characteristic had been experimentally found to influence low vision legibility (Arditi, 2004), though was not well understood. This gave rise to my main thesis research question: What is the optimal typeface stroke width for low vision adults?

My goal was to design a laboratory typeface based on both scientific and design knowledge, addressing the thesis research question experimentally. During my first year of doctoral research, I intuitively began examining typefaces like a biologist would study organisms yet doing this with the typographic knowledge of a designer. Based on my understanding of typeface anatomy, I began measuring the proportions of typefaces (section 4.2.2). I was particularly interested in measuring the typefaces that had been used as experimental test material in scientific legibility research papers, for example Franklin Gothic tested in a study by Sheedy et al. (2005). I also began measuring the proportions of text typefaces that I had become familiar with through my design training (e.g. Helvetica). I entered this data on typeface proportions into a spreadsheet and began visualising it (i.e. graphing), based on my scientific training in data analysis. Through my interdisciplinary practice (discussed in Chapter 3) and the resultant visualisations, I was finally able to make sense of the scientific legibility research literature and understand what typeface proportions were associated with improved reading performance for people with low vision. For the first time, I was also able to understand the proportions of commonly

used text typefaces. This scientific and design knowledge became the basis for developing my laboratory typeface (presented in Chapter 5).

Reflecting on this research, the laboratory typeface itself was less important than what my practice had revealed. I now saw the potential to develop a foundation of interdisciplinary—science and design—typographic knowledge through information visualisation. My interdisciplinary practice had given rise to the quantitative analysis of typefaces that would become central to my PhD research. In 2009 I made a final iteration to my PhD direction and focused my research on the consolidation of scientific knowledge, generation of design knowledge, and development of interdisciplinary knowledge through information visualisation. This change in direction was also influenced by the rise of information visualisation as a creative practice occurring within graphic design (section 3.4.6.1), which has continued to the present.

Based on my scientific training, I employed information visualisation as an analytical tool (Hand, 2008) within the PhD research. For example, visualisations reveal the stroke widths of typefaces found to have higher legibility. As a design practitioner, I approached information visualisation as a communication design medium. I endeavoured to create visualisations that were not only clear in their communication, but also visually interesting and aesthetically rich. While the main audience for the visualisations is researchers and designers focused on low vision legibility, my design practice facilitated the dissemination of this research to the wider communication design community. My goal was to create visualisations that would offer a new understanding of typeface design practice, as I had experienced. My practice and information visualisation as a research method are discussed in more detail in Chapter 3 (section 3.4).

1.7 CONTRIBUTION TO KNOWLEDGE

This PhD research contributes to the area of inclusive typography through the development of interdisciplinary—scientific and design—knowledge on typeface legibility for low vision adults. Through the quantitative analysis of typefaces, scientific knowledge generated through legibility research experiments is integrated with design knowledge residing in the form of typefaces themselves. This involves the measuring of typeface proportions and the visualisation of this typeface data. The analyses focus on typeface stroke width and letter width, because these characteristics vary alongside one another.

Analysing typeface proportions may seem a natural approach to legibility research, however characterising typefaces entirely in quantitative terms is not common within either the scientific or design community. Scientific studies generally report on the relative legibility of typefaces without describing them numerically, for example reporting a low vision reading speed advantage for Courier Bold versus Times Roman (Mansfield et al., 1996). Designers similarly refer to typefaces through naming systems, for example Arial Bold 12 point, with neither weight nor point size having an accurate numerical meaning. Without numerical values associated with typefaces, questions are raised such as: how can legibility researchers develop hypotheses regarding the underlying cause for performance differences? How can legibility researchers compare results across experimental studies that test different typefaces? How can inclusive typography guidelines relate legibility research findings to commercial typefaces that may share proportions with those tested within scientific experiments?

The quantitative analysis of typefaces therefore serves to clarify and consolidate scientific research, formalise design knowledge, and facilitate the integration of knowledge across disciplines. More specifically, ten scientific studies which test the influence of stroke width on legibility are analysed. This entails measuring and analysing the stroke width and letter width of

typefaces used as experimental test material. This analysis serves to elucidate the proportions of typefaces that have been found to improve reading performance based on experimental studies (i.e. scientific knowledge). This also allows for comparison across experimental studies, consolidating scientific knowledge. This consolidation of scientific knowledge addresses the thesis research question: What is the optimal typeface stroke width for low vision adults?

In order to formalise design knowledge, the stroke width and letter width of text typefaces used in design practice are measured. This is a *design phenomenology* study as defined by Nigel Cross (2007), investigating design knowledge residing in artefacts themselves (section 3.3). Typeface weight names (i.e. nomenclature) utilised in design practice are also analysed in order to assess their relationship with stroke width numerical values. This allows for an evaluation of typeface weight recommendations (e.g. “bold” for emphasis) within inclusive typography guidelines (e.g. UKAAF, 2019). Through an integration of scientific and design knowledge as proposed, this PhD research examines how the stroke width and letter width values of typefaces found to have higher legibility relate to those of text typefaces used in design practice. This addresses the research question in the context of design practice, investigating optimal typeface weights for low vision adults.

The analyses described in this section are executed through information visualisation. Information visualisation is also employed as a communication tool (Hand, 2008), facilitating the dissemination of knowledge to both legibility researchers and practicing designers. The visualisation of typeface data constitutes the central practice-based outcomes of this PhD by project. My contributions to knowledge include visualisations of:

(1) Scientific knowledge: Stroke width and letter width values of typefaces experimentally found to have higher and lower legibility;
(2) Design knowledge: Stroke width and letter width values of sans serif text typefaces used in design practice;

(3) Interdisciplinary knowledge: Relationship between stroke width and letter width values of typefaces found to have higher legibility (scientific knowledge) and typefaces utilised in design practice (design knowledge).

1.8 THESIS OVERVIEW

This thesis consists of seven chapters. Chapter 1 introduces the reader to the context—social, scientific, and design—of the investigation, the research methods, and the major outcomes and contributions to knowledge of the PhD. Chapter 2 reviews inclusive typography guidelines, the research literature on typeface legibility for low vision adults, and typefaces designed specifically for low vision reading. This chapter also presents key legibility research concepts and background, and a critical discussion of how experimental test material (i.e. the typefaces tested) impacts the application of research to design practice.

Chapter 3 describes the methodology for interdisciplinary typographic knowledge construction employed within the PhD. The chapter begins with a review of the theoretical issues regarding interdisciplinary approaches to typeface legibility. A case is made for the integration of design knowledge into scientific legibility research, and scientific knowledge into design practice. Knowledge construction within design practice is also discussed, and the investigation of ‘designerly ways of knowing’ through design artefacts—*design phenomenology*—is addressed (Cross, 2007). Lastly, practice-based research and the specific methods of practice employed within the PhD investigation are discussed including typeface design, typeface measurement, and information visualisation.

Chapter 4 presents a scientific review on the influence of stroke width on legibility in the context of low vision readers. Distinct from a literature review, this is a quantitative analysis of ten scientific studies. This entails the measurement and visualisation of stroke width and letter width values of

typefaces experimentally found to have higher and lower legibility. Based on this consolidation of scientific knowledge, recommendations are made for inclusive typography guidelines and future legibility research.

Chapter 5 presents the design of a laboratory typeface, based on both scientific and design knowledge. The laboratory typeface is designed to test the stroke width and letter width values measured in typefaces found to have higher legibility, based on the consolidation of scientific knowledge undertaken in Chapter 4. The laboratory typeface is also based on design knowledge and reflects the stroke width and letter width values of sans serif text typefaces. The formalisation of this design knowledge is presented, specifically the measurement and visualisation of stroke width and letter width values of sans serif text typefaces used in design practice.

A rigorous approach to formalising typeface design knowledge is undertaken in Chapter 6. A points-based survey of design sources (e.g. typeface best-sellers lists) is employed to determine a group of typefaces to serve as the basis for investigation. The stroke width and letter width of twenty sans serif text typefaces are measured and visualised, and the relationship between typeface nomenclature (e.g. “bold”) and numerical values is determined. In an important culmination of the practice chapters, Chapter 6 presents the visualisation of interdisciplinary knowledge. These visualisations illustrate the relationship between the stroke width and letter width values of typefaces found to have higher legibility (scientific knowledge) and those of typefaces utilised in design practice (design knowledge).

Finally, Chapter 7 summarises the scientific, design, and interdisciplinary knowledge on typeface legibility for low vision adults contributed through the PhD investigation. The findings from each of the practice Chapters 4-6 are presented, and the contributions to knowledge are described in the context of future legibility research and the development of evidence-based inclusive typography guidelines. Chapter 7 ends by examining the limitations of this investigation and proposing future directions for legibility research.

The overall thesis structure represents my design process, and the chapters can be understood as chronological. However, because this research was conducted over a timespan of more than a decade, each chapter has been consistently updated to reflect contemporary research and practice. For example, while the scientific review (Chapter 4) was conducted before creating the laboratory typeface in 2009 (Chapter 5), I returned to the scientific review in 2020 adding four more legibility research studies.

The introductory chapter set out to provide an overview of the PhD research, the main research question, contributions to knowledge, and the context within which the research is undertaken. Next, we turn to Chapter 2 which presents a more detailed contextualisation of this research, through a literature and practice review focused on legibility and low vision. This provides the broader context through which gaps in knowledge are identified.