Brainy Type: *a look at how the brain processes typographic information*

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ABSTRACT

Despite a growing body of knowledge around how readers interact with texts, our understanding of how the brain processes that information is relatively limited. This multidisciplinary (typography and cognitive neuroscience) study examines how the brain processes typographic information using EEG technology and shows the value of neuroscience methodologies to legibility research. By measuring the brain's response to a range of typographic stimuli, we have shown that it is more difficult for the brain to process single letter information presented in harder to read compared to easier to read typefaces. This effect was evident at both the most basic levels of letter identification (0–300 milliseconds from stimuli onset) and also during sustained activity involving the working memory (after 300ms). This has implications for our understanding of legibility and how legibility research is further explored with the aim of developing a body of knowledge that has a wider application to how typographic design is practiced.

KEYWORDS

legibility, letter identification, neuroscience, EEG

INTRODUCTION

If we think about the act of reading, it seems as though it is nearly effortless; cast your eyes over a passage of text and information is somehow absorbed with little thought or consideration to the processes involved. If you are a typographer you may consider or examine what visual circumstances have contributed to the ease of reading: a clean open typeface, the relationship between the letter, word, and line spacing, margin space, line length, etc. Since reading is such an integral part of our culture and education, it can be argued that the primary concern of any typographer should be to produce texts that are as legible as possible in order to facilitate easy and accurate letter and word identification, reading, and comprehension. Although letterforms are also objects of beauty and expression, it is the decoding of texts that is the primary function of typography for reading. This means type or typographic design that interferes with this process is unsuccessful regardless of the aesthetic qualities of the letters or their composition (Beier, 2012).

Legibility research has seen contributions from both typography and psychology, but historically there has been relatively little evidence of collaboration (Beier & Dyson, 2013; Dyson, 2013). This may be due to differing objectives with a typographer's primary concern focused on the 'what' and a psychologist's with the 'how' of reading (Dyson, 2013). Since both the 'what' and the 'how' are essential to our understanding of reading processes, multidisciplinary teams may be better placed to improve our knowledge about what affects the legibility of texts. In a collaboration of typographic and cognitive neuroscience researchers, we used a novel approach to legibility research and explored the discriminative processing[1] of letters across a range of typefaces. Understanding how the brain responds to typographic stimuli may enable the development of a more thorough understanding of what features of letters are essential for accurate identification and what variations of form improve legibility. The potential impact of this research may also contribute to the ability of typographic designers to produce more legible typefaces and texts, which can then influence how easily readers are able to access content, whether they are fluent readers, developing readers, or those who experience any range of reading difficulties, including dyslexia. In the broader context of design for reading, when this knowledge is considered in combination with the theory of working memory as a limited capacity system (Baddeley, 1992, 2002), texts that are developed with the aim of reducing the cognitive load required for basic tasks like letter identification may enable more of this limited capacity system to be designated for performing higher-order tasks related to comprehension and assimilation. Thus, it is argued that with the application of neuroscience methodologies, typographic designers will be able to develop a better understanding of the variables contributing to legibility, enabling them to produce more legible typefaces and texts. Even with the exploratory nature of this study we have been able to demonstrate that typeface can influence how the brain processes letter information.

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[1] Discriminative or preconscious brain activity refers to the time before an individual is consciously aware of what they are looking at. This is typically between 0 and 300 milliseconds from stimulus onset.

LETTER RECOGNITION IN THE BRAIN

Cognitive neuroscience is a branch of psychology[2] that focuses on the brain structures and functions and how they relate to behaviour and mental processes (e.g. memories, language, reasoning, decision making, learning, and our ability to recognise and identify objects and people). This is a science that is based on inferences made about how the brain works by using technology such as Electroencephalography (EEG), which records the brain's neuronal activity during specific cognitive tasks, like letter recognition, through an electrical measurement taken at the scalp (Gage & Baars, 2013).

EEG measures electrical impulses generated by the brain with increased task specific activity showing more electrical activation (Gage & Baars, 2013). Although behavioural methodologies are able to tell us about how readers respond to specific reading materials, fluent readers are typically quite efficient with the task, and it can be difficult to design test scenarios that are sensitive enough to show differences in performance based on typographic variation. EEG is able to provide data on brain activity from the moment a visual stimulus is presented (i.e. to the millisecond), including that window of time before a participant is consciously aware of it. With this ability to track activity in the brain to the millisecond, it becomes increasingly easy to infer how specific typographic variables influence letter processing and legibility.

FIGURE 1

Demonstration of an EEG testing scenario. Participants wear a version of the electrode cap shown above for the duration of the task. The electrodes map to regions of the brain and record neural electrical impulses generated during the task.

A typical test scenario is shown in Figure 1. Participants are required to wear a cap with sensors that monitor electrical activity at the scalp. Distractions must be limited as much as possible to isolate the brain's response to the tested variables. As a result participants are typically required to sit in a small empty room. This may not resemble a realistic reading scenario, but is necessary to this sort of data collection. Knowledge gained here can be used in combination with that collected by other means to develop a clear picture of reading and readers more generally.

Our knowledge about how typographic variation influences letter recognition in the brain is relatively limited, but Rey, et al. (2009) have identified an ERP component[3]

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[2] The psychology of the brain is different from the biology of the brain, which refers more specifically to neuroscientific studies that explore the physical structure, neurological pathways, and where in the brain specific content is processed.

[3] Event-related potential (ERP) is an average measure of EEG activity collected over multiple participant trials. Once averaged this data tends to reveal very regular patterns, which can then be used to determine whether the recorded brain activity is a response to specific stimuli (Gage & Baars, 2013).

that depicts letter-processing in time, illustrated in Figure 2. They have shown low-level processing related to feature analysis, which consists of a basic response to the fact that something has appeared in the visual field and that it is an object recognised as an exemplar of a known category (e.g. 'a letter'), takes place at 100–200ms after stimulus onset. Between 120 and 180ms higher-level processing, likely related to feature detection and essential to letter and object recognition commences. At this point, the letter representation is high-level case-specific (a letter f). At around 220ms abstract case-independent letter identity representations are activated that transcend specific visual representation (the letter f), and after 300ms participants show behaviour responses indicating the object is recognised and its meaning processed sufficiently to consciously respond to a task related activity (Rey, et al., 2009). With this framework for letter recognition in the brain, we can determine how typeface influences neural recruitment, referring to how many neurons are need to complete a task during discriminative processing, and had not been done before our study, first reported in Keage, Coussens, Kohler, Thiessen, and Churches (2014).

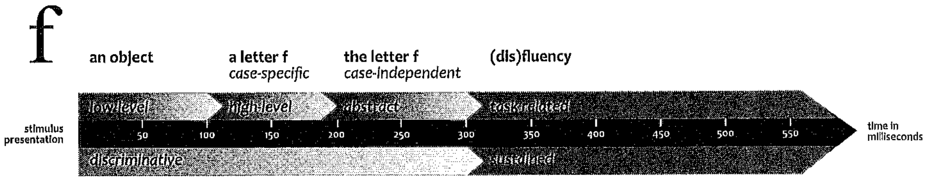

FIGURE 2

Object recognition in the brain over time (in milliseconds). High-level processing involves the use of letter attributes that are specific to the letter variation (e.g. upper or lowercase and variant forms); whereas, abstract processing is related to more general identification of the letter unit (e.g. all forms of the letter f). Discriminative processing is related to object/letter identification and sustained activity to its use and maintenance in the working memory. It is during sustained/task related activity that the fluency effect can be measured.

The use of EEG is seen as particularly valuable to legibility research, and specifically here since we are interested in letter identification, because it is able to show instantaneous data related to neural recruitment; however, it is limited by the fact that it can only provide data related to what regions of the brain are active rather than pinpointing the specific neural clusters. On the other hand, technology related to functional magnetic resonance imaging (fMRI) can help clarify which specific neural clusters are active by observing blood flow but is limited in that it has a lag time of approximately six seconds (Gage & Baars, 2013). However, for sustained cognitive tasks, fMRI may be a profitable data collection method as demonstrated in Nishimura, et al. (2007). This study shows the value of fMRI, and the less invasive functional near-infrared imaging (fNIR) variation, during a task where participants were asked to read a pair of sentences and determine whether the combined statement was plausible. The test stimuli were presented in a range of typefaces that differed in level of visual degradation from high legibility (no degradation) to low legibility (extensive degradation). The results showed that more neural recruitment was necessary to decipher the degraded typefaces suggesting the brain must work harder to identify words as shown in the visual processing areas of the brain but that the region associated with language processing (Broca's area) was not affected by typeface legibility.

LETTER RECOGNITION

Recent interest in legibility has seen exploration in a range of areas, including perceptual, cognitive, and, in this paper, psychophysiological processes, that influence the way we decipher and interpret texts. In a review of literature, Dyson (2013) brings to attention the differences in disciplinary approaches but aims to highlight, as we do here, that both typographers and psychologists share goals and points to a mutually beneficial approach of collaboration as a means to further our understanding of typography, typeface design, and design for reading. It is, however, pertinent to mention that there also appears to be a gap between the knowledge generated through research and its application in typographic practice. This may be because legibility studies are typically guided by the interests of those undertaking the work and who are motivated by the issues that are relevant in their area of expertise (e.g. psychology or engineering) and because these interests do not typically extend to visual features and variations of letterforms relevant to typeface design (Beier & Dyson, 2013). Unfortunately, this can also include limited consideration of the experiential knowledge of the typographic practitioner and the practicalities of the profession resulting too often in the reluctance of practitioners to take up the knowledge generated by these studies. For example, Pelli, Burns, Farell, and Moore-Page (2006) were able to suggest that there is an early feature detection stage in letter identification where readers draw on multiple features to aid with accurate identification, using a system of template-matching. A simple and logical conclusion may then be, if fonts are developed that can accentuate these essential features the legibility of texts may be improved. However, the type variations tested do not represent realistic letterforms, having been developed based on the arrangement of pixels on a 3x4 or 4x4 grid, making the interpretation of the results difficult to translate to how texts and typefaces are actually designed and used. Due to this impractical comparison, these data are too vague to inform design, which has also been suggested by Dyson (2013). Knowledge generated with the use of more familiar and conventional letterforms may be more useful to typographic practice because it may be able to provide more specific information about which features are most relied on and how differences are used by the reader in an effort to inform the overall typeface design.

Several studies have examined issues concerning letter identification and determined that readers rely more heavily on certain features of a letter over others and that more salient features are accessed before less distinctive ones during the identification process (Beier & Larson, 2010; Fiset, et al., 2009). Since specific features are used not only to identify letters in isolation (Finkbeiner & Coltheart, 2009; Grainger, Rey, & Dufau, 2008; Pelli, et al., 2006; Rey, Dufau, Massol, & Grainger, 2009) but also in context, i.e. words (Sanocki & Dyson, 2012), understanding whether it is more or less difficult for the brain to process letter and word information across a range of type classes will improve our understanding of what makes letters more or less legible. It makes sense to conclude that if each letter is identified by specific unique features, then typefaces that somehow accentuate those features would make this process easier. In an attempt to isolate the parts of letters that are more useful in identification, Beier and Larson (2010) developed several variations from a single typeface skeleton (or template). These variant forms of the same letter were then tested for letter recognition under short exposure times. Beier and Larson found letter width to be an influential factor in identification since wide variations were recognised more accurately compared to the narrow and ascending and descending features are also influential. Double-storey characters were shown to be more legible than their single-storey counterparts, but Beier and Larson were unable to conclude whether letter openings were essential distinguishing features in identification; i.e. letterforms with wider openings did not increase their legibility compared to those with narrow openings. This is an interesting observation since wide letter openings have traditionally been considered a feature that improves legibility (a summary of early research can be found in Beier, 2012).

Although it is clear that each letter within the alphabetic system must be unique to ensure accurate identification, reading efficiency is supported by similarities across the set of letters (Beier, 2012; Sanocki, 1988; Sanocki & Dyson, 2012; Walker, 2008). A typeface designer, therefore, aims to develop fonts that consist of a series of letters that have unique distinguishing shapes but that also have a certain level of continuity between letterforms. By sharing certain visual features, a rhythm and flow across the letter set is developed that contributes to the overall look and feel, or 'personality', of a typeface (Cheng, 2005). For this reason, the forms within a single font will be developed based on considerations such as the proportions of both the vertical and horizontal measurements of a letter, the relationship between stroke width and variation and counter space across the entire alphabet, as well as the use of similar and shared shapes (Beier, 2012). All of these contribute to an overall sense of unity, which aids reading efficiency. This effect is apparent in studies that show reading times improve because a reader's visual processing system is able to 'tune' itself to the particular consistent visual features of a font design and uses this information for identification (Sanocki, 1988; Sanocki & Dyson, 2012; Walker, 2008).

In summary, typefaces that balance distinct and related visual features are likely to be more legible because they may do more to facilitate accurate letter identification, as well as capitalising on the consistency needed for font tuning; however, we are still only able to say with moderate certainty which features are essential since only several specific features have been isolated in research, such as vertical and horizontal strokes, width, or ascending and descending features (Beier & Larson, 2010; Fiset, et al., 2009; Fiset, et al., 2008; Grainger, et al., 2008; Pelli, et al., 2006; Sanocki & Dyson, 2012). It is proposed that the application of neuroscience methodologies is likely to provide the evidence we need to address this gap and inform the design of more legible typefaces and texts.

READER EXPECTATION AND COGNITIVE PERFORMANCE

Although the ability to identify letterforms and efficiently read texts is essential to the design of written content, reading is also influenced by preference and expectation. The overall appearance of documents – which includes visual attributes related to layout as well as typeface – can influence the reader's impression of the content, and this may extend to the perception of the elements such as difficulty, importance, seriousness, or trustworthiness of the content (Gonzales Crisp, 2012; Moys, 2014; Schriver, 1997). For example, in an examination of typeface, Song and Schwarz (2008, 2010) demonstrated that their participants thought tasks were harder (i.e. requiring more skill) or took longer to complete when set in a more visually complex typeface compared to one that was conventionally easier to read. In addition, participants were less willing to undertake described tasks that were set with a harder to read typeface. Conversely, content that was easy to read was thought to be more familiar or less risky, more trustworthy or truthful, and described a task that would be easier to complete. Interestingly, participants did not consciously link the typography to their impression of the text.

Since reading is an important part of our culture and a primary source of information transfer, it is essential to develop a more thorough body of knowledge around this subject. Data collected through neuroscientific methods are far more sensitive and less subjective compared to those seen in behaviour studies, and this may allow us to show definitive differences in performance based on typographic presentation (i.e. how hard the brain is working in response to variations in typographic presentations). However, it is important to understand that reading environments change, scenarios vary, and goals shift. Although data collected by observing brain functions can inform our understanding about reading in a way that we have not been able to achieve before, it is important to understand that this is only one piece of the puzzle and that the most thorough understanding will likely only come through a combination of both neurological and behavioural methodologies. The study discussed here is limited in its scope to single letter identification across broad type categories and does not examine the recognition of letters in context (e.g. words), which may produce varying results. Nonetheless, this study demonstrates the value of neuroscience methodologies and the potential of the data they generate, with the use of technology such as EEG, to our developing body of knowledge about legibility.

THE INFLUENCE OF TYPOGRAPHIC INFORMATION ON BRAIN ACTIVITY[4]

The application of neuroscientific techniques can provide a measurement sensitive enough to provide a picture of how hard the brain is working to process a range of typographic information that varies from easy to difficult to read. Working as a multidisciplinary team of typographic and cognitive neuroscientific researchers, we examined the effect of typographic information on brain activity within a 600ms window of first seeing a letter stimulus. We looked at a range of typefaces representing broad categories of classification that have traditionally been considered more or less legible in order to determine whether differences in processing were apparent. We hypothesised that more neural recruitment would be measured, i.e. the brain will work harder, at low-level processing or stimuli categorisation (>100ms) and abstraction (220–300ms) to identify letterforms that are displayed in typefaces with low legibility compared to those with high legibility. Finally, since processes after 300ms should not be affected by visual form because they are related to sustained activity rather than to identification, we hypothesised there would be no differences in recruitment at this stage.

We worked with 26 fluent readers (university undergraduates) that were all right-handed[5] and had normal or corrected-to-normal vision. Each participant identified letters across 4 different typefaces that were grouped according to whether they had characteristics considered to be more or less legible: 2 typefaces made up the high legibility[6] group and 2 the low legibility group. These characteristics were identified by conventional standards[7, 8]. Since this was an exploratory study, we were concerned primarily with determining whether differences in processing occur across broad type categories with very different visual features traditionally considered to contribute to legibility. We examined representations from the basic typeface classifications serif, sans serif, blackletter, and script. For the purposes of this study, text typefaces, a serif and a sans serif, represent the high legibility category. The low legibility typefaces were selected from more decorative or display options, a blackletter and a script. This is not to say that all serif or sans serif typefaces are highly legible or that all examples of script and blackletter have low legibility; however, these categories do tend to sit on either side of the spectrum as a result of their visual features and intended use, whether it is for text or display. Future work using our methodology can start to narrow down the criteria and examine what specific features within each category influence letter recognition in the brain.

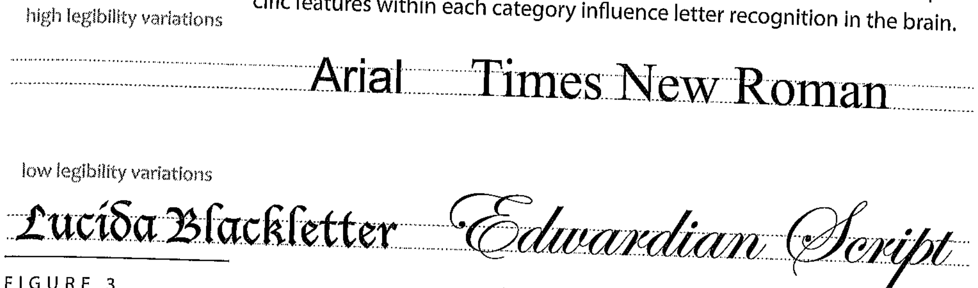

FIGURE 3

The tested typefaces. Lower case letters that were either x-height with straight and curved strokes and of standard width (a / c / e / o) or cap-height with a single vertical stroke and of narrow width (f / i / l / t) were typeset with an x-height of 90px in each of the four typefaces shown. Each letter was presented individually onscreen with a viewing distance of 60cm. The participants were placed in groups based on test stimuli. Group 1 saw only the x-height characters and Group 2 saw only the cap-height characters. Each participant saw stimuli set in each of the four typefaces.

The specific typefaces selected were Arial and Times New Roman representing the high legibility variations and Lucida Blackletter and Edwardian Script the low legibility options. For reference, examples are shown in Figure 3. In order to ensure that this study could be easily replicated and to improve the accessibility of the results, we selected typefaces for testing from those within the Microsoft suite. This also ensures that a visual reference of the typefaces can be easily found, reducing the abstract nature of the material for individuals without typographic backgrounds.

All participants completed a one-back task[9] in which they were shown one letter at a time sequentially once every 1.5 seconds, on average. They were instructed to press a response button with one index finger when they saw the same letter twice in a row regardless of which typeface it was presented in and another button with the opposite index finger if the letters were not the same, again, regardless of typeface. Each participant completed the task in 2 blocks of approximately 8 minutes in length. Each block contained 240 stimuli of either x-height (o, a, e, c) or capital height (f, i, l, t) characters. The order in which participants saw the letters was pseudo-randomised so that high and low legibility letters were mixed, but each block of stimuli contained only x-height or capital height character sets. This was to minimise inter-letter visual variation (Grainger, et al., 2008). Figure 4 shows a representation of a stimulus train for a one-back

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[4] A summary of the study procedure is presented here for the purposes of this discussion. For full details refer to Keage, et al. (2014).

[5] The fact that they were all right-handed means that the primary language processing component was more strongly located in the left-hemisphere of the brain and enabled us to compare data across hemispheres.

[6] Features such as unique and distinctive shapes, large x-height, letter width, open counters, and even stroke treatment are traditionally considered to improve legibility of letters; whereas, those such as extensive shape repetition and minimal letter distinction, closed counters, narrow width, small x-height, flourishes, and highly variable stroke treatment are thought to contribute to low legibility. It should be mentioned that although generous letter openings have traditionally been considered to aid legibility, Beier and Larson's (2010) study did not find this to be an influential feature in identification. More work or study replication is needed to verify these results.

[7] Baines and Haslam (2005) raise the important point that what is considered within the spectrum of legibility is largely dependent on what is considered to be 'normal' and what readers, as a collective group, are familiar with, making our idea of what is legible largely based on convention. This perception has changed over history and is likely to continue to shift, particularly with the digital age. This makes the inclusion of typographers and typographic researchers, with their practical experience and expertise working with texts, on teams investigating legibility a necessity for improving our knowledge of the practical application of that work.

[8] Discussions about the legibility of individual letters are limited, which may be due to the fact that it is more informative to discuss legibility of form as it pertains to its context of use: how a system of letters works in words, sentences, passages, etc. A letter in isolation may perform very differently compared to when it appears in a word. A typographic designer, therefore, must consider both individual and global features of letters simultaneously (Beier, 2012). Beier (2012) provides a discussion of early studies, such as those conducted by Tinker (Tinker, 1963, 1965), that were able to isolate specific parts, such as ascending and descending features or taller x-heights as being helpful to recognition. Early researchers were also able to identify groups of forms that are frequently misread due to similarities in form, like the letters h and b or e and c. From this work typographers were able to draw conclusions and establish a set of principles for what features aid with legibility.

[9] A one-back task is a common paradigm to cognitive neuropsychology experiments in which measurements of the neural activity involved during activation of the working memory are taken. It consists of showing participants a continuous sequence of stimuli and asking them to respond (e.g. press a button) when matching images appear. This behavioural response is not linked to the neurological data collected, providing an uncorrupted response.

task with target letters highlighted in green. The brain activity of each participant was measured using EEG. Behavioural data related to response and error rate were also recorded, although this did not form part of our main analysis.

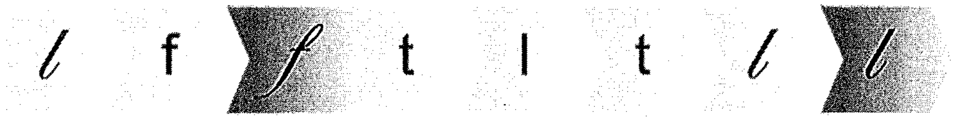

FIGURE 4
Example of a stimulus train for a one-back task.

RESULTS[10] AND DISCUSSION

We were primarily interested in preconscious or discriminative processing: 0–300ms from stimulus onset. Shown in the diagram in Figure 2, we collected object recognition data on low-level (an object), high-level case-specific (a letter f), and abstract case-independent (the letter f) processing. We also analysed the data collected during sustained task related activity after 300ms, at which time integration and maintenance in the working memory becomes apparent (Madec, Rey, Dufau, Klein, & Grainger, 2012).

In summary, the results showed (Keage, et al., 2014):

1 _ Significantly (p<0.001) more neural activity when participants were shown test stimuli in low compared to high legibility typefaces during low-level processing (0–100ms).
2 _ Significant (p<0.001) differences during abstraction (220–300ms) indicating a larger effect for the low legibility typefaces compared to the high legibility.
3 _ A trend (p=0.05) for low legibility typefaces requiring more effort for integration into the working memory (indicated by differences measured during sustained activity after 350ms).
4 _ Neural recruitment during sustained late activity that was larger for the low compared to high legibility typefaces.
5 _ No significant differences (p>0.05) in time or accuracy of the participant's behavioural response between the high and low legibility typeface variations.

It is, therefore, apparent that typefaces with low legibility capture more attention and are more difficult for the brain to abstract and maintain within working memory than those with high legibility suggesting that the visual complexity may reduce legibility at the most basic processes of reading (Keage, et al., 2014). This is a result that is in line with those presented in Nishimura, et al. (2007) using fMRI/fNIR technology. However, in opposition, we also observed a larger effect of typeface at low-level processing in the language dominant left hemisphere compared to the right, implying that more effort is required for the brain to process basic tasks related to letter identification when harder to read typefaces are used. This suggests the need for more investigation since increasing the cognitive load needed to perform basic tasks may imply there is reduced cognitive capacity for higher-order functions that take place later and are related to abstraction and sustained activity, as well as the assimilation of knowledge (Baddeley, 1992, 2002). Nishimura, et al. suggest their study is limited by the fact that their task was not a natural reading scenario and may have been too short to produce more conclusive results.

IMPLICATIONS FOR THE DESIGN OF TYPEFACES AND TEXTS

The ability to easily ascertain essential distinguishing features is important for accurate letter identification where these features are first identified and then used to determine the complete letterform (Grainger, et al., 2008; Pelli, et al., 2006). This implies that the easier these unique or distinguishing features are to access, the less cognitively demanding letter recognition will be. Our data also shows that typeface can influence this process since the brain must work harder to abstract letter units when less legible typefaces are used. We have not yet examined which features are essential to identification and can only suggest that clarity of form and reduced visual complexity influences identification. Future research aims to explore this in more detail, as well as build on the knowledge developed by behavioural studies such as Beier and Larson (2010) and Fiset, et al. (2008) who have investigated distinguishing features of letters as a means to improve our understanding here.

It is also important to consider that the observed increase in effort needed to maintain letter information presented in typefaces with low legibility may be influenced by the familiarity and common use of our high legibility variations: Arial and Times New Roman. Although all our test stimuli were selected for their wide availability, Arial and Times New Roman are among the most commonly used fonts, and our participants were bound to be more familiar and have substantially more experience reading these compared to our low legibility choices: Edwardian Script and Lucida Blackletter. However, this effect may be counteracted once a reader has tuned to the unfamiliar font (Sanocki, 1988; Sanocki & Dyson, 2012; Walker, 2008), which is commonly believed to take only a few seconds (Beier & Larson, 2013). Further investigation that explores the effect of font tuning is needed before more specific conclusions can be drawn about its influence on how the brain processes typographic information.

Our study has shown that differences in letter identification that are influenced by typeface do occur at the most basic levels of object recognition. These results may be expected based on the broad range of visual stimuli that we tested, and individuals with typographic expertise may view this study as reinforcing what we know through experience. We see this as part of this study's value. We have been able to confirm knowledge that has previously been limited because of its subjectivity and thus estab-

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[10] Again, the study results are summarised here as they pertain to the discussion and focus of this paper. For full details of the ERP results refer to Keage, et al. (2014).

lished the value of neuroscientific methodologies to legibility research. We can now, with future work, build on this knowledge and begin to examine a narrower range of differences to determine exactly what the tolerance for good legibility is and what elements are contributing factors, as well as potentially isolate specific features that are essential for accurate letter identification. Future work will also explore whether typeface has an influence on word recognition and examine both letter and word recognition in developing readers (i.e. children), both those learning at a typical rate and those who experience difficulties, like dyslexia or low vision. This approach can inform typeface design generally but also improve our knowledge of how to generate texts, and, with more exploration, how interacting variables such as space, size, line length, and typeface impact legibility and accessibility.

CONCLUSION

This study has shown the value of neuroscience to legibility research and to typographic practice. We have been able to produce systematic data that would not otherwise be known by examining how the brain processes typographic information; this approach will likely prove invaluable to furthering our understanding of reading and reading processes. Despite a growing body of knowledge around how individuals interact with texts, the influence of typeface on how the brain deciphers and processes visual information during reading is relatively limited. This study has shown that the brain works harder to identify letterforms when they are presented in harder to read typefaces compared to those that have characteristics that are traditionally considered to be more legible. Although the typeface categories we examined for this initial stage of research were very broad, it is easy to see the value that the implementation of cognitive neuropsychology methodologies can have for legibility research and the potential to improve our understanding of how readers interact with texts more generally. Cognitive neuroscience methods are typically unrepresentative of actual reading scenarios because they must take place in a laboratory and any distractions limited as much as possible. However, if this approach is used in combination with behavioural methodologies, we are sure to develop a rich understanding of reading, reading processes, and readers. Since the ability to decipher written language is such an essential part of our modern world, making that process and its content as accessible as possible, whether an individual is a typical or impaired reader, should be a primary concern.

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