Do We Process Characters as Shapes, Nothing Special?

Mary C. Dyson & David Březina

Abstract. This paper addresses the question of whether we use general object mechanisms to process characters or more specialised processes. A multidisciplinary literature review includes examples of potential specialisations in other domains, such as speech or face recognition, introducing specific forms of expertise. A terminology which clarifies the relationships and representations in the character recognition process is used in identifying similarities and differences between attributes of shape perception and character recognition. The importance of the visual similarities among characters within a font and the retention of font information suggest that expertise in character recognition reflects modifications to our general perceptual processes, i.e., specialisation.

1. Introduction

One debate among psychologists and other scientists is whether we have a few general perceptual mechanisms that we apply to various activities, or more specialised mechanisms that have adapted to particular needs. General mechanisms provide a more parsimonious explanation of how we perceive the world and can be intuitively appealing. In applying this distinction to reading, the question is whether we have specialised mechanisms for character recognition or use general perceptual mechanisms employed in object recognition. By overlooking certain aspects of how we recognise characters when reading, we may be misled into simplifying the perceptual process.

This paper discusses attributes of characters to avoid an oversimplified description of potential character shapes. The focus is on character recognition, describing properties associated with perceptual expertise.

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The multidisciplinary review aims to demonstrate and clarify the complexity of the process and its implications for graphemics, which may also be of significance for educators in terms of language acquisition. For typographers, there is the practical objective of improving the legibility and readability of text, as well as an interest in elucidating the contribution of fonts to visual perceptual processes. Such knowledge should help eliminate, or at least question, any assumptions by investigators that characters are neutral stimuli. This tendency to treat all characters in the same way, ignoring the differences among fonts, was pointed out by Gilmore (1985) with reference to comparisons of letter confusion matrices.

The premise is that the object-based recognition system is modified to recognise characters as we learn to read. Although our review focuses on behavioural studies rather than neuroscientific research, the "neuronal recycling hypothesis" (Dehaene & Cohen, 2011) provides a helpful description of the process by which the novel function of reading recycles existing brain circuitry. We examine the nature of the perceptual processes that are peculiar to character recognition to identify potential modifications.

1.1. Related Specialisation Debates

In arguing against the special nature of speech perception, Carbonell and Lotto (2014) point out the considerable debate as to whether the accomplishment of speech perception is the result of general perceptual/cognitive mechanisms or special processes. They conclude that "speech sounds are… over-learned categories that play a functional role in a larger hierarchical linguistic system" (p3), but this does not mean that they use different processing mechanisms than other sounds.

In contrast, there has been greater consensus regarding the special status of face perception, distinguishing it from the perception of objects (e.g., Farah et al., 1998). One of the main reasons to attribute a special status to face recognition is the face inversion effect. Most objects or scenes are more difficult to recognise when they are inverted, but faces are considerably more difficult. Thompson (1980) provided a compelling demonstration of the difficulty of perceiving facial expressions in inverted faces. Spatial relations among features that are crucial in the perception of upright features are not apparent when upside down. However, this inversion effect (Yin, 1969) is not unique to face processing and might instead be attributed to expertise (Diamond & Carey, 1986; McGugin & Gauthier, 2010). In the field of design, perceptual processes may also be influenced by expertise. Typographers are more impaired in their judgements of fonts than non-typographers when the characters are inverted relative to upright (Dyson & Stott, 2012).

Both speech and face perception can be considered examples of perceptual over-learning and expertise, with typographic training leading to a more specific expertise. Skilled reading is also a form of expertise.

2. Character and Word Recognition Models

There is broad agreement amongst reading researchers that word recognition is letter-based. Expert readers identify individual letters in parallel. These letters are matched against potential candidate words. In this paper, we focus on character recognition, i.e., the three levels at the bottom of Figure 1.

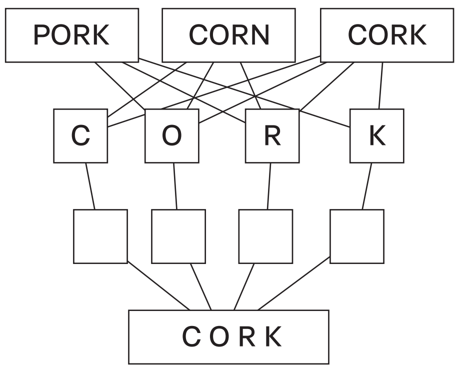

FIG. 1. Word recognition model (after Larson, 2005). The first level represents the stimulus or specific material instance (see below), the next level up is the features used to recognise individual characters (not dealt with in this paper), and the third level is the character detectors. The last, bottom, level represents the identified word.

2.1. Terminology Across Disciplines

Graphematics, psychology, epigraphy, and typography use somewhat disparate terminologies to explore the nature of the relationships and representations involved in the character recognition process. They, naturally, take into account considerations relevant to their respective fields and not necessarily those of the other fields. Graphematics focuses on mapping the units of language and writing systems to their visual representation (see Figure 2). Depending on the source, terms such as “glyph,” “graph,” or “character” can become more or less general and blur the distinction between the general/abstract and material representations that is highly relevant here. We use a hybrid approach, a terminology of visual communication expanded to account for other fields, in order to be sensitive to the effects of production and perception (see Figure 3).

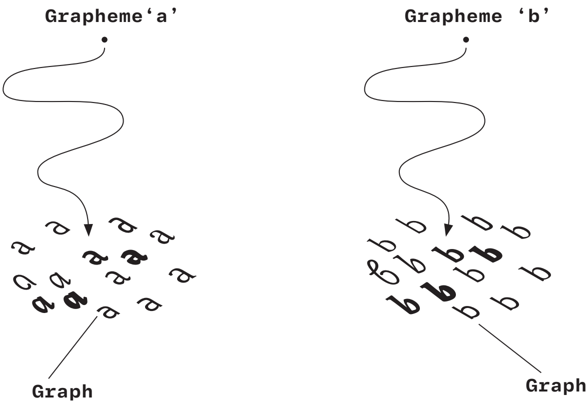

FIG. 2. Linguistic units mapped to images/shapes

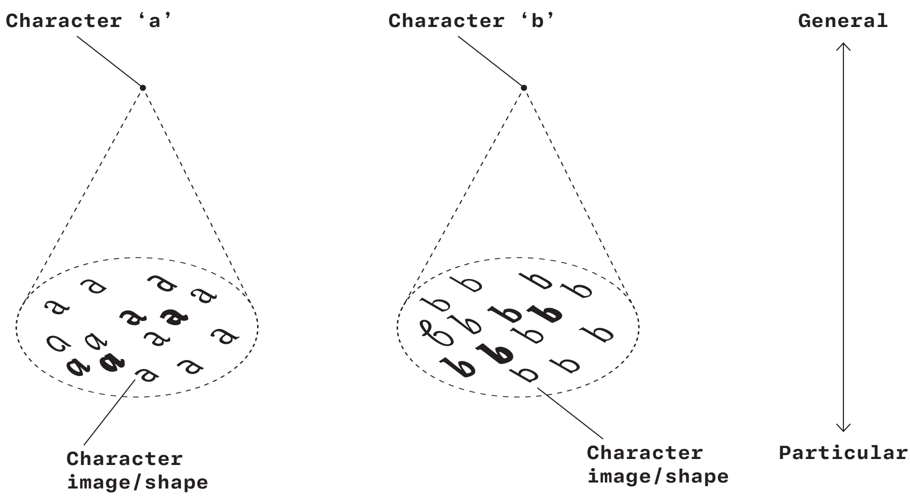

FIG. 3. Hybrid terminology used in this paper clarifies the differences between particular material instances and more abstract character representations.

The term *character image* represents the image on the retina or the specific material instance, while *character shape* refers to the perceptual representation. The *character* is the most general term referring to the whole class of images/shapes used to represent a particular linguistic unit (comparable to *basic shapes* in Meletis, 2020).

There are class → instance/token relationships among some of the terms. With respect to external processes such as production or analytical modelling, it is: character → character image. With respect to perception, recognition, and internal processes, the orientation is reversed, from instances to classes: character image → character. Characters defined this way are general and visual entities without any inherent linguistic value. One or more characters are associated with one or more linguistic units (e.g., phonemes, syllables, words) from a language by means of a writing system and graphemes (Meletis, 2020).

3. Invariance and Perceptual Constancy

Our perceptual world is more constant than would be predicted by the visual information. An important attribute of object recognition is our ability to perceive an object as having the same shape when viewed at different angles, i.e., shape constancy (Pizlo, 1994). Shape is a visual property of objects that can be used to recognise them.

Readers can cope with many types of visual distortions, e.g., scaling, mirror reflection, rotation, perspective distortions, or environmental effects such as poor lighting or fog, and take account of these distortions during character recognition (see Figure 4). Perceptual constancy describes how we respond to invariants in the physical world.

Readers can also recognise most letters quickly regardless of the font used or style of handwriting (see Figure 5). Consequently, a variety of character images leads to the same character identity. Constancy enables the different character images to be translated from their variant visual forms into invariant representations, referred to as abstract letter identities (Grainger, Rey, & Dufau, 2008).

However, distortions and design variety can lead to uncertainty regarding character identities. In Figure 6, Palmer (1999) illustrated that readers use context to affirm character identities. In the McClelland and Rumelhart (1981) interactive activation model, this is described as top-down processing from the word level interacting with bottom-up processing from the feature and letter level to determine our perceptions.

3.1. From Invariance to Discrimination

Some invariances are problematic for Latin characters, where we should not be applying our normal object recognition processes. Unlike objects, manipulations to visual forms which change orientation, i.e., mir-

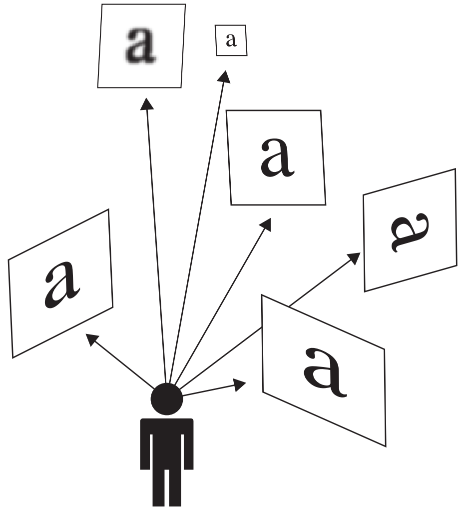

FIG. 4. Distortions caused by different viewing angles and distances

ror imaging (<b> vs. <d>) or plane rotation (<n> vs. <u>) cannot be ignored (Dehaene, 2009; Torres et al., 2021). Although these are not always precise mirror images (see Figure 7), they are sufficiently close to cause problems when the characters need to be discriminated and not perceived as variants of the same form.

From a developmental perspective, Perea, Moret-Tatay, and Panadero (2011) found that by ten years old, children are similar to adult readers in their ability to discriminate between mirror-reversed letters. They propose that learning to read involves "functional tuning of the letter identification system" (p. 244). In the course of literacy acquisition, there is debate as to whether mirror invariance is unlearned, suppressed, or inhibited (Fernandes, Arunkumar, & Huettig, 2021). Unlearning mirror invariance for letters is regarded as a byproduct of neuronal recycling induced by reading (Pegado et al., 2014).

3.2. Is Mirror Discrimination Specific to Latin Readers?

Given the role of reading development in the suppression of mirror generalisation, a pertinent question is whether readers of a script without mirrored characters (e.g., Tamil) develop mirror-image discrimination. By comparing illiterate, Tamil monoliterate, and Tamil-Latin-alphabet bi-literate adults, Fernandes, Arunkumar, and Huettig (2021) concluded that mirror-image discrimination depends on learning to read regardless of script. Tamil monoliterates showed good explicit mirror-image

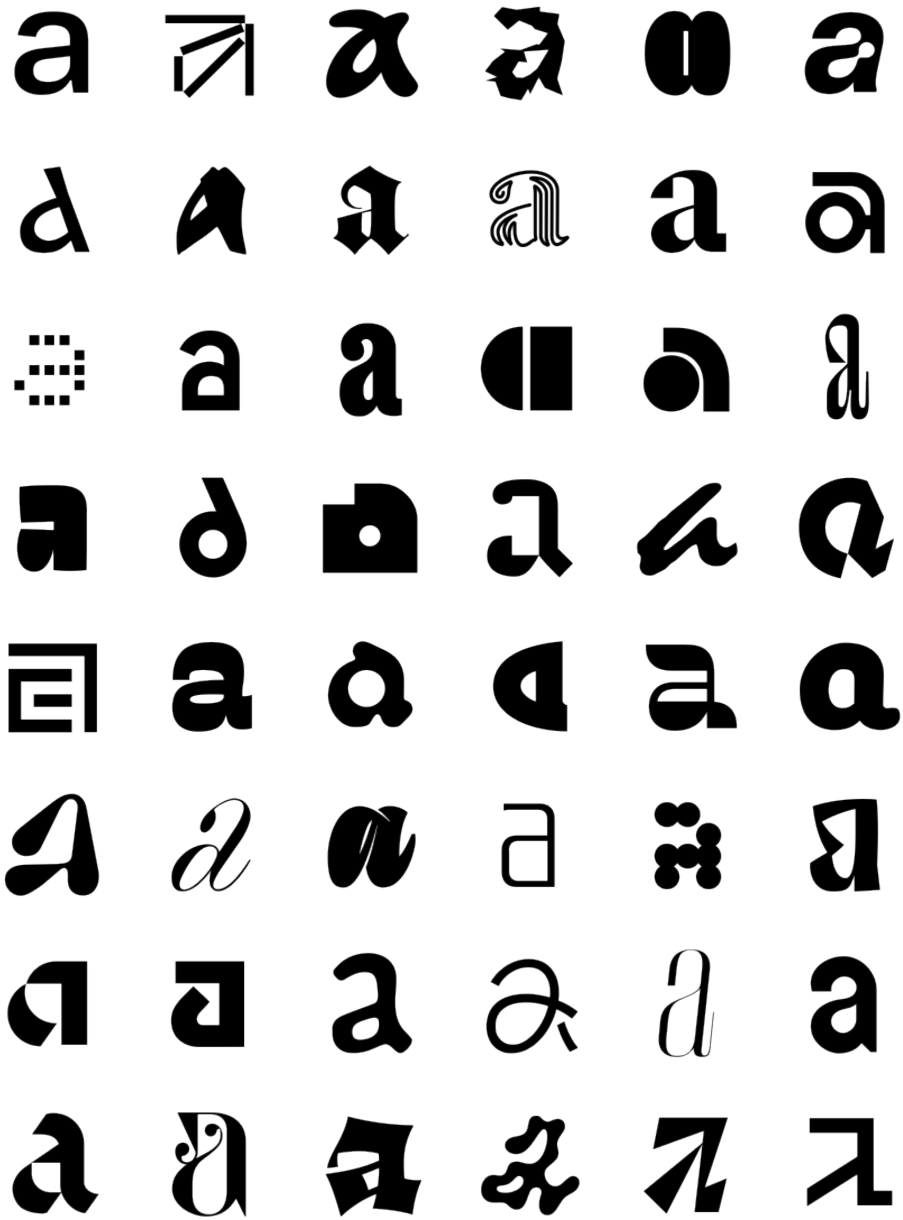

Fig. 5. An inclusive collection of shapes for the letter <a> from various contemporary fonts (Březina, 2024; after Hofstadter & McGraw, 1998)

Fig. 6. The same shape is used to represent <H> and <A> thanks to its uncertain character identity (after Palmer, 1999). We are able to fluently oscillate between two different character identities thanks to our knowledge of the English language.

Fig. 7. The letter <b> is not an exact mirror image of the letter <d>. Similarly, the letter <p> is not an exact mirror image of the letter <q>. In both examples, the third letter is the correct form.

discrimination. The authors propose that the ability to discriminate is trained when learning to read because of the specific reading direction. This is supported by a study which found faster responses to Latin characters oriented to the right, when required to judge whether the character was oriented correctly (Patro, Gross, & Friedrich, 2024). The results were consistent across age groups ranging from around seven years to adults.

However, Fernandes, Arunkumar, and Huettig (2021) did find that automatic mirror-discrimination, when not relevant to the task, depends on learning a script with mirrored characters; training from the reading direction is insufficient. They propose that learning a script with mirrored graphs is the strongest force for breaking mirror invariance. Mirror images need to become "graphemically contrastive" (de Heering & Kolinsky, 2019).

4. Visual Coherence

4.1. Type Design

Březina (2018) studied the visual coherence of fonts, i.e., the structure of visual similarities among characters (see Figure 8). He showed that there is a correspondence between the craft practices and the similarity relationships perceived by readers; that the apparent coherence is created deliberately.

ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz
Comic Sans typeface

ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz
Times New Roman typeface

Fig. 8. Visual coherence among character shapes produced by a font makes shapes from the same font look more related to each other than to character shapes produced by a different font (Březina, 2018)

4.2. Character Recognition

We can capitalise on this coherence within a font during character recognition. Expert character recognition takes advantage of the particular characteristics of a font to facilitate recognition, described as a "font-regularity effect" or "font tuning" (Sanocki, 1987). Character processing becomes more efficient because the perceptual system tunes itself to exploit the regularities within a font. The consistency in font styling can be used to translate different character shapes into an invariant (abstract) form. An emphasis on the distinctiveness of characters can overlook the contribution of character uniformity, a view of character processing that considers principles from the field of type design (Sanocki & Dyson, 2012). Although characters may be more distinctive when mixed, they are not easier to read (Figure 9).

If you don't continue reading the rest of this paper, you will miss finding out more about why characters might be special.

Fig. 9. An extreme example of mixing fonts where we need to adjust the frame of reference for alternating characters.

The original research conducted by Sanocki (1988) used the crude technology of the time to explore font tuning (Figure 10). Subsequently, researchers pursued other enquiries: testing the speculation that font tuning distinguishes character recognition from object recognition (Gauthier et al., 2006); looking at the time course of font tuning (Walker, 2008); using font tuning as a means of exploring the effectiveness of different type variants in emphasising text (Dyson & Beier, 2016).

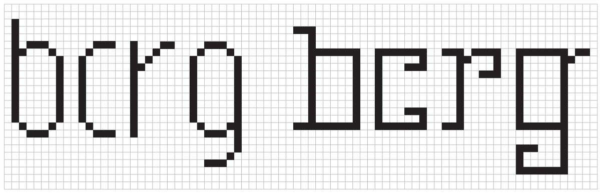

FIG. 10. Fonts used by Sanocki

These studies have employed very different tasks, but all involved brief presentations of characters or words, and readers were required to respond as quickly and accurately as possible. This time pressure is necessary as character recognition is very rapid. Gauthier et al. (2006) make explicit that the artificial tasks are "designed to reduce the impact of the knowledge of orthographic and phonological regularities that develop with reading experience." (p543).

Sanocki (1988) displayed four character images very briefly, in mixed or consistent fonts. Characters were identified more accurately when the font was consistent.

Many years later, Gauthier et al. (2006) used a search of a matrix where characters were displayed in mixed fonts or all in the same font. Mixing decreased accuracy and increased the time to locate target characters. Evidence for the process of font tuning is mainly based on Latin, but the researchers conducted additional experiments with Chinese characters. They questioned whether experience with characters (reading expertise) is necessary to tune to the stylistic regularities within a font by comparing Chinese and non-Chinese readers. This task required the identification of three characters, presented briefly on a screen. The novice readers were trained with the verbal labels for the Chinese characters before the experiment. They found that non-Chinese readers do not tune to stylistic regularities. Readers who are not familiar with the script appear unable to take advantage of the font regularity and perceive meaningless shapes, rather than characters. They conclude that characters are not processed in the same manner as shapes.

Walker (2008) elaborated upon the concept and nature of font tuning, describing the process as deriving and implementing font-specific rules which map visual features (style-specific) onto structural descriptions (font-invariant). His experiments revealed that we may have some control over the time course of font tuning. In these studies, a random string of consonants was displayed above or below a word or pseudoword. The task was to identify whether there was a word or not and to ignore the string of consonants. When the consonants were in a (very) different font from the target, responses were slower. Varying the frequency of font repetition across trials appears to influence whether the font-specific translation rules are retained in working memory for reimplementing with the next portion of text.

The study of font tuning by Dyson and Beier (2016) aimed to determine the type of stylistic variation and how much variation is tolerated before character recognition becomes more difficult. This knowledge has practical relevance in text design, where italic or bold type distinguishes a word from the surrounding text. The variation among six fonts was controlled as these were created by Sofie Beier, a type designer. Rapid Serial Visual Presentation of a string of 15 words, with a possible pseudoword inserted, was used to assess the speed and accuracy of detecting the pseudoword. Alternating between a regular and italic font did not show a font-regularity effect, i.e., responses were not slower than a single font. However, alternating regular with a heavier weight, bold, did show this effect. The practical implications for designers are that words in italic can distinguish text elements without significantly disrupting reading. Bold is likely to be more appropriate than italic for headings by making words stand out.

4.3. Objects

Walker (2008) concludes his paper by surmising as to whether object recognition might also be facilitated by the equivalent of font tuning. He uses the example of sets of cutlery in the same design (a similar example appears in Figure 11). Is it easier to identify items within the same set, rather than mixed? To our knowledge, whether stylistic features aid the recognition of objects has not yet been tested.

Fig. 11. Two sets of cutlery (after Walker, 2008): Liner (left) and Provençal (right) from `https://www.davidmellordesign.com/cutlery`

5. Modelling Object vs. Character Recognition

The study described above by Gauthier et al. (2006) concluded that character recognition can be distinguished from object recognition based on font regularity. An alternative means of addressing the distinction between domain-specific (character) and domain-general (object) features concludes that object-based features account well for character perception (Janini et al., 2022). This study used machine learning to model features and focused on the set of features that determine distinctiveness, looking for a match with behavioural data that measured perceptual similarity between characters.

5.1. Perceptual Similarity

In using two behavioural tasks to measure similarity, visual search and letter categorisation, Janini et al. (2022) are assuming that similarity is the inverse of distinctiveness and that this is sufficient to explain the accuracy of character recognition. The discussion of font tuning based on the coherence of characters within a font questions this assumption. Furthermore, Mueller and Weidemann (2012), through a review of legibility literature, experiments, and modelling, refer to the term "perceivability" which they equate with "legibility," concluding that perceivability should be considered as independent from similarity. Machine learning does not speak directly to which features readers use to recognise characters when reading. This limitation is acknowledged by Janini et al. (2022, p. 13): "Future studies are required to determine the extent to which our findings generalize to the context of reading".

6. Characters in the Context of Reading

The above studies explored or modelled character recognition through studies of single characters or words, focusing on the early stages of word recognition, primarily the bottom-up processes. This emphasis disregards any potential residual effects of font style information beyond the creation of abstract letter identities. Although there is consensus on the inclusion of abstract letter identities in character identification, this does not preclude the existence of other forms of representations (Walker & Hinkley, 2003).

There is some evidence that font style information can linger beyond the creation of abstract letter representations. In the first experiment conducted by Lewis and Walker (1989) they examined whether the visual style of the characters in a word would be encoded unintentionally and whether this might affect semantic judgements. This was confirmed as reaction times to words were slower if the perceptual qualities of the font were inconsistent with the meaning of the word, e.g., the word “heavy” in a “light” font (Figure 12). Their second study widened the scope to include animal words where participants were required to indicate whether the animal was fast/slow or light/heavy as quickly as possible (see Figure 13). These effects suggest that there are some top-down influences on character and word recognition, included in interactive models of reading (McClelland & Rumelhart, 1981).

Consistent	**heavy**	*light*
Inconsistent	*heavy*	**light**

FIG. 12. Responses were slower if the perceptual qualities of the fonts were inconsistent with the meaning of the words (Lewis & Walker, 1989)

	Fast	Slow	Light	Heavy
Consistent	*fox*	**cow**	*rat*	**pig**
	deer	**bear**	*mouse*	**rhino**
Inconsistent	**fox**	*cow*	**rat**	*pig*
	deer	*bear*	**mouse**	*rhino*

FIG. 13. Participants were slower to identify if the animal was fast/slow or light/heavy if the font was inconsistent with this quality (Lewis & Walker, 1989)

This type of inconsistency or incongruence is based on the Stroop task (Figure 14), where we are required to name the colour of each word.

However, the Lewis and Walker implementation is a reverse Stroop effect, as you need to ignore the font and respond to the word's meaning.

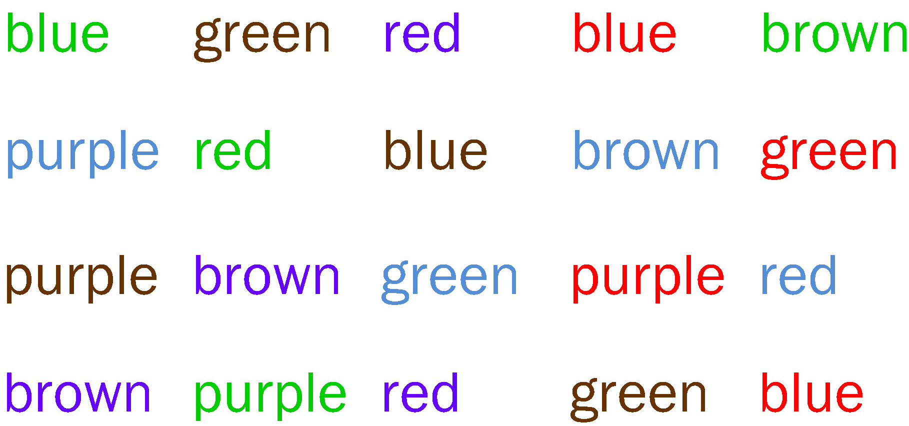

FIG. 14. The original Stroop effect, where participants are slower to name the colour of the word when the meaning is inconsistent with the colour of the ink.

A study concerned with memory for the visual appearance of words found evidence of the "long-term retention of superficial details (i.e., typography)" (Sheridan & Reingold, 2012, p. 255). The study included measurements of eye movements while reading sentences with a low-frequency target word (e.g., banjo) in "distorted typographies". Fixation times for the second presentation of the target word (in a different sentence) were shorter when the visual style was consistent with the first presentation. This effect was found within the relatively short time span of an experiment and with a gap of one week. However, difficult-to-read or unusual fonts were required to demonstrate the effect after a one-week lag. The apparent memory advantage for less legible fonts, which take longer to read, is an example of the reported effects of perceptual disfluency (see Dyson, 2022, for a review).

In a further study concerned with memory for the visual appearance of words, there was some indication that font styling is retained in memory (Dyson & Březina, 2022). Changing the font of an item between an initial lexical decision task (word or non-word) and subsequent presentation impaired recognition. This behavioural data is supported by an event-related potential study showing a response in the brain to the font at a later stage, beyond the assumed point of abstracting letter identity (Keage et al., 2014).

The possibility of stylistic features of characters being retained beyond character recognition and interacting with semantic information would seem to distinguish characters from mere shapes.

7. Conclusion

Table 1 summarises attributes of shapes and characters, identifying similarities and differences. The differences indicate processes that may have been introduced during neuronal recycling, while the similarities indicate processes that appear to be shared. The review highlights that readers retain relevant semantic information from characters outside their direct linguistic function. Stylistic features are used to facilitate recognition across characters from different linguistic categories. The perceptual constancy inherent in object/shape recognition is useful in character recognition when mapping the variant forms onto a single representation. However, where character recognition requires discrimination between different orientations, learning to read introduces modifications to the treatment of invariance. Skilled readers develop a perceptual expertise that reflects the demands of the task.

In graphetics, the world's scripts are usually viewed as character inventories. The mutual visual relationships of characters within scripts are often described informally. Exploration of the component perceptual processes seems to be a good point of departure for a deeper formal analysis of character relationships and their regularity.

TABLE 1. Similarities and differences between some of the perceptual processes involved in shape and character recognition, indicating potential effects of neuronal recycling

	Shapes	Characters
Size, rotation, position invariance	+	+
Invariance to visual style	+	+
"Unlearned" mirror invariance	x	Latin script
Capitalizes on coherence	?	+
Secondary semantic information	−	+

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