Font Tuning: A Review and New Experimental Evidence

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Abstract

This paper reflects on the kinds of evidence able to confirm that letter and word identification in reading can be supported by encoding the underlying visual structure of the text, and specifically by deriving structural descriptions for letters. It is proposed that structure-driven processes are intimately linked to the implementation of font-specific rules for translating visual features into elements of a letter’s structural description. Evidence for such font tuning comes from studies exploring the impact of font-mixing on reading fluency, and from studies showing how the benefits of experience with a novel typeface can generalise to letters that have yet to be seen in the typeface. After reviewing this evidence, three new experiments are reported which explore font tuning in the context of the lexical decision task. The time course of font tuning, which is monitored by changing the time interval between successive test stimuli, is shown to be sensitive to the overall probability with which successive stimuli appear in the same typeface. In addition, font tuning is shown to reflect item-by-item fluctuations in this probability. Finally, the effects of font-switching are shown to generalise beyond the particular letters present in the text, and to be confined to 1-back transitions. It is concluded that font tuning reflects the implementation of a set of font-specific translation rules held in working memory, and is moderated by the reader’s implicit knowledge of the constraints present in the sequencing of successive portions of text.

Keywords: word reading, letter identification, typeface, font tuning, implicit knowledge of typographic variation.
Font Tuning: A Review and New Experimental Evidence

Words can be encoded visually in different ways during reading, thereby providing initial access to different types of representation in memory. For example, a printed word can be encoded as a 2-D visual pattern (image), and word identification can proceed by finding a matching visual pattern in memory. Studies manipulating the visual format of text (e.g., by mixing letter case) have confirmed that encoding the visual patterns created by multi-letter strings can enhance reading fluency (e.g., Braet & Humphreys, 2006; Hall, Humphreys, & Cooper, 2001; Lete & Pynte, 2003; Martens & de Jong, 2006; Mayall & Humphreys, 1996; Mayall et al., 2001; Mayall, Humphreys, & Olson, 1997; Whiteley & Walker, 1994; 1997).

Alternatively, a printed word can be encoded as a set of visual cues to the underlying structure of the word, and word identification can proceed by finding a matching structural description in memory. Deriving a structural description for a word requires the corresponding visual cues to be discriminated (and irrelevant cues ignored), and for these to be translated into a structural description according to a set of rules for doing so. Though, in principle, the units of analysis for structure-based word identification can be anything from individual letters to whole words, they are normally considered to be individual letters. Figure 1 illustrates one conceptualisation of word reading that incorporates pattern-driven and structure-driven elements.

Several recent studies provide evidence confirming that words can be identified during reading by discriminating the underlying structure of their component letters. In particular, Sanocki has provided evidence confirming that the visual cues readers use to derive the underlying structure of letters, and the rules they implement to achieve this, are
adjusted according to the typeface in which text appears (e.g., Sanocki, 1987; 1988; 1991; 1992). Further evidence for such font tuning has been provided recently by Gauthier, Wong, Hayward, & Cheung (2006).

This recent evidence for font tuning prompted the author to attempt three things in the present paper. First, to reflect on the types of evidence able to confirm that letter and word identification can be structure-based, and not just pattern-based. Second, to review existing evidence providing some confirmation of this. And third, to present three experiments yielding preliminary evidence regarding the time course of font tuning, and the extent to which this is under a reader’s strategic control. Because much of the existing evidence hinges on format repetition effects in word reading, the author also provides a review of evidence for pattern-based repetition effects in reading, and identifies the factors determining when these are, and are not, expected to be observed (e.g., word and n-gram frequency, and typeface distinctiveness). This review, which appears in the Appendix, permits the reader to understand better how format repetition effects reflecting structure-based encoding can be distinguished from those reflecting pattern-based encoding.

**Fonts, font tuning, and letter identification**

The surface form of a piece of text can vary markedly according to the typeface in which it appears. When presented in a novel and distinctive typeface, the surface appearance of the words will differ from anything seen before. Despite this, reading is likely to proceed relatively unhindered, indicating that words can be identified on the basis of their underlying visual structure, which remains in place despite the superimposition of font-specific visual features.

The underlying structure of a letter comprises a set of component forms, which we might call *strokes*, and the spatial arrangement of these strokes. Letter structure is defined in
abstract, categorical terms, such as TWO LONG VERTICAL STROKES PLUS A HORIZONTAL CONNECTING STROKE PART-WAY UP, for the most common version of the capital letter H. A little reflection will confirm that some letters of the alphabet normally have a different structural description for their uppercase and lowercase forms (e.g., Aa, Gg, Qq), whereas others retain the same structure regardless of case, differing only in relative size (e.g., Oo, Ss, Vv, Xx, Zz). By cultural convention, each letter of the alphabet has a prototypical structural description, and typefaces that adhere closely to these (e.g., Helvetica) are the most frequently used in publications for continuous reading (e.g., newspapers and novels), and in publications designed for children who are learning to read. These typefaces also tend to be free of decorative visual features that are irrelevant with regard to communicating a letter’s underlying structure.

When a typographer creates a typeface, they create a set of rules for translating the prototypical structural features of every letter of the alphabet into a printed surface form. Adopting the same set of translation rules for all letters of the alphabet gives a typeface a consistent and coherent appearance regardless of the particular text being realised. The reader has the task of discovering the translation rules for the text they are reading, and engaging with them in the reverse direction, so that they can go from the surface forms of letters to descriptions of their underlying structure, allowing the letters to be identified. In the case of display fonts (i.e., fonts designed for other than continuous reading), typographers will often add visual features to make a typeface appropriate for use in a particular context (e.g., Laughin Plain, Rodeo Roundup, and Toy Blocks, illustrated in Figure 2). Such visual features, the most obvious of which is color, do not provide cues regarding underlying letter
structure, and so readers, when they engage with a new piece of text, have the immediate task of deciding which visual features are diagnostic of letter structure, and which are not.

The translation rules embedded in a typeface need to specify a range of surface visual features that will provide readers with cues about the underlying structure of each letter. For example, some rules will specify how individual strokes are to be realised in surface form and, as Figure 3 illustrates, the range of possibilities is vast. Other rules will specify how VERTICAL and HORIZONTAL in a letter’s structural description are to be realised in surface form. For regular fonts, VERTICAL in a letter’s structural description will translate into vertical on the page, where this is defined by the letter’s immediate visual environment (including the edges of the page and, most notably, the virtual lines on which the text is arranged). For some fonts, however, the translation of VERTICAL is not so transparent, and this is the case with italic fonts. For other fonts, the translation of VERTICAL and HORIZONTAL is more complex (see, for example, Buster, Youngsook, Dimentia Black, and ToyBox Blocks, in Figure 4). In Buster, letters are depicted as 3-D structures lying face up on a flat surface, and this sets the scene for an unusual translation of VERTICAL onto the page. In Youngsook, HORIZONTAL strokes are realised by visual features that are consistently slanted on the page. And in Dimentia Black and ToyBox Blocks, where letters are depicted as facets of objects that are variously oriented in 3-D space, VERTICAL and HORIZONTAL are specified on a letter-by-letter basis, largely according to each object’s intrinsic spatial frame of reference.
It seems likely that the structural descriptions for many letters incorporate more features than need be explicitly represented in their surface form for them to be identified (e.g., see Schomaker & Segers, 1999). As a result, identifying a letter probably will not require all of the elements in its structural description to be reflected in its surface form, and different fonts will make different elements more or less evident. For example, the prototypical structural descriptions of some letters will include a specification that certain of their strokes are CURVED, and that these connect with other strokes to create an ENCLOSED SPACE (e.g., as in the letter P). However, for some fonts, CURVED in a structural description does not translate into curved in a letter’s printed form, because the fonts utilise straight contours exclusively (see, for example, Displayced JNL and Pixel D, in Figure 5). These fonts require readers to suspend their reliance on the curvature of contours as a cue to the curvature of a letter’s underlying structural elements, and to rely exclusively on other cues to the letter’s identity. Similarly, in some fonts (e.g., stencil fonts), the points of contact between different structural elements of a letter are not always explicitly realised in its surface form, and so any elements of the structural description making reference to AN ENCLOSED SPACE will not be so clearly signalled in print (see, for example, Advera Stencil and Suchow, in Figure 5). And, as a final example, elements of a letter’s structural description concerning the points of termination of its strokes are not always explicitly represented in the surface form of a typeface, as in the case of some script fonts (e.g., Lucida Handwriting). Again, therefore, the reader will need to assign less weight to visual features that would normally signal the presence/absence of these structural features, and more weight to other visual features, such as the presence and locations of ascenders and descenders.
Indeed, Schomaker and Segers (1999) have demonstrated that whereas removing the visual features signalling the presence of ascenders and descenders does not impede the reading of typed text, it does impede the reading of handwriting. In addition, they illustrate that blurring typed text also can increase a reader’s reliance on visual features signalling the presence of ascenders and descenders. Thus, when text is blurred, it becomes more difficult to read words that share their pattern of ascenders and descenders with many other words, than to read words with a unique pattern of ascenders and descenders.

Figure 5 about here

An isolated letter appearing in a novel and distinctive typeface is unlikely to provide the reader with sufficient information to distinguish diagnostic from non-diagnostic visual features, or to deduce the full set of translation rules embedded in the typeface. Where the evidence is not sufficient, readers will have to apply a frequently utilised (default) set of rules which might, or might not, lead to correct letter identification. However, as additional letters of the alphabet are made available to the reader, the translation rules will become more apparent. We can appreciate one reason, therefore, why typographers normally adopt the same translation rules for every letter of the alphabet, and why presenting letters in the context of other letters in the same typeface aids letter identification. For example, the reader might find that the letters in Figure 6 are more difficult to identify when they appear in the context of a mix of fonts, than when they appear in the context of a single font (see Gauthier et al., 2006, for evidence).

Figure 6 about here
Structure-based letter identification: Font tuning and font-specific repetition effects.

When a reader begins to read a piece of text presented in a novel and distinctive typeface, a first requirement is that they pick up the translation rules embedded in the typeface. They will need to determine which visual features are diagnostic of letter structure, what the translation rules are, and how they should be differentially weighted. While they are doing this, reading is likely to proceed more slowly, and to be more error prone, than would be the case with a familiar typeface. Even when the text a reader begins to read appears in a distinctive typeface that is familiar, reading fluency might be expected to be temporarily reduced until a previously assembled set of translation rules is retrieved from long-term memory (assuming translation rules are preserved in long-term memory). Despite such a temporary reduction in reading fluency, we can see how the availability in long-term memory of previously used translation rules will allow readers to be more fluent (less impeded) when beginning to read text appearing in a familiar typeface, than when beginning to read text appearing in an unfamiliar typeface. It seems reasonable to assume that the set of translation rules for a familiar typeface will take less time to retrieve from long-term memory than to discover afresh.

Pattern-based accounts of visual word identification also predict that reading will be temporarily impaired when text appears in an unfamiliar typeface (see the Appendix for a review). It must be asked, therefore, how the effects arising from structure-based processes might be distinguished from those arising from pattern-based processes. One possibility is that the time course of the effects will differ. Although it is difficult to be specific, it is possible that it will take longer to accumulate a collection of font-specific visual patterns for
a novel typeface, that is large enough to impact significantly on reading, than to discover the font-specific translation rules embedded in the typeface. On this basis, reading fluency would be expected to recover to the levels associated with a familiar typeface more quickly when the recovery is mediated by structure-based processes rather than pattern-based processes.

Structure-based and pattern-based processes in word identification have different implications for the extent to which reading text in a novel typeface can yield benefits that will extend to textual elements that have yet to be seen in the typeface. If we consider a rather extreme situation, in which experience with a new typeface is restricted to a subset of the letters of the alphabet, then it is clear that any benefits gained from accumulating visual patterns linked to the typeface will largely be restricted to the patterns that have been encountered, and so will not generalise to new letters. In contrast, given that typographers design typefaces with the same translation rules applying to all letters of the alphabet, then at least some of the benefits gained from experiencing a subset of letters should generalise to new letters.

Structure-based and pattern-based processes in word identification also have differing implications regarding the impact on reading fluency of switching typefaces across successive portions of text (e.g., successive letters, words, sentences). If switching between familiar, rather than unfamiliar, typefaces is considered, then all the visual patterns created by the text will be available in long-term memory, regardless of the nature of any typeface switching that might be occurring. Because of this, the cost to reading fluency arising from typeface switching is expected to be minimal as far as pattern-based processes are concerned. However, for structure-based processes, each change in typeface will require the translation rules in current use to be replaced with rules retrieved from long-term memory (assuming that only one set of translation rules can be in current use). While this is happening, reading
fluency will be temporarily impaired. Furthermore, although there will be costs associated with each switch from one familiar typeface to another, there will be no costs associated with any earlier switches (i.e., typeface transition effects will be confined to 1-back transitions). In addition, the cost to reading fluency will not diminish with practice reading text in which font switching occurs, because there will always be the same need to retrieve the appropriate translation rules from long-term memory. Finally, the degree of similarity among the typefaces being switched should be influential. Thus, where the typefaces are very similar, it is possible that the same translation rules will be able to continue to support fluent reading. However, where the typefaces are very dissimilar, the same translation rules will not be able to sustain letter identification, and some cost to reading fluency will be experienced. In other words, not only does a structure-based account predict costs associated with switching fonts, it also predicts different levels of cost according to the dissimilarity of the fonts being switched.

Several studies provide evidence bearing on these arguments. For example, Sanocki (1991) required participants to identify the letters contained in a briefly presented string of letters. He demonstrated that changing the typeface between blocks of trials impeded performance. Sanocki (1992) refined this study by arranging for experience with an unusual font to be confined to a subset of letters. The subset of letters from which letter strings were generated was then switched after a block of trials. In one condition, the same typeface was retained for both blocks of trials, whereas in a second condition the typeface also was changed. The question of most interest in the present context was whether any benefits from experiencing the typeface in the first block generalised to letters that had yet to be seen in that typeface (i.e., whether there was a font-specific, but letter-independent, enhancement of reading). The answer appears to be yes. Thus, although there was a temporary impairment to
reading fluency associated with switching to a new set of letters in the same typeface, this was less pronounced than the impairment observed when the typeface also was changed. In other words, there was evidence that the benefits gained from experiencing the novel typeface in the first block of trials generalised to letters that had yet to be seen in the typeface. This is just what would be expected if participants were becoming familiar with the translation rules embedded in the typeface. It is not what would be expected if the font-specific enhancement of reading arose exclusively from the accumulation in long-term memory of records of the visual patterns created by different elements of text.

Corcoran and Rouse (1970) asked their participants to identify each of a succession of individual words presented tachistoscopically. Each word appeared either in a regular typeface (not specified by the researchers), or in handwriting. In one condition, all the words created in a particular format appeared within the same block of trials. In a second condition, the format changed frequently and unpredictably from one word to the next. Corcoran and Rouse observed poorer levels of identification when the format of the text changed from one word to the next. Klitz, Mansfield, and Legge (1995) required readers to read short passages as quickly as possible. Each passage could appear entirely in one of two typefaces, or in a mix of two typefaces, with the typefaces switching across successive words. Five distinctive typefaces were used, and all possible pairings of the typefaces were used to generate the mixed-typeface passages. Klitz et al. observed reading to be slowed when a passage appeared in a mix of typefaces, and the extent of the interference with reading reflected the degree to which the typefaces being mixed were dissimilar to each other.

In two experiments, Gauthier et al. (2006) required participants to read a matrix of 100 letters as quickly as possible. In one condition, all the letters in each row of the matrix appeared in the same unfamiliar typeface, but the font changed to a new one for each
successive row. In a second condition, the allocation of a typeface to a letter was not constrained by row in this way, but was random. As a result, participants had many more changes in typeface to contend with as they scanned the letters in a left-right/top-bottom manner. Gauthier et al. observed slower reading times in the second condition, where readers had to deal with more switches between typefaces. In a further experiment, in which participants read letter triplets, Gauthier et al. used just two typefaces, and designed these to differ with regard to specific letter features. For example, one pair of typefaces differed only in their aspect ratio, whereas another pair differed only with regard to the orientation of VERTICAL strokes (i.e., whether these were tilted clockwise or anticlockwise on the page). Gauthier et al. again observed font mixing to impair reading fluency, and this was most marked when the typefaces differed in their aspect ratio.

Sanocki (1987, 1988) required participants to identify the letters contained in a briefly presented string. The letters within a string (typically four) could appear in one of two typefaces. In one condition, the four letters within a string appeared in the same font. In a second (mixed) condition, two letters appeared in each of the two fonts. Sanocki observed letter identification to be impaired by font mixing, and the degree of impairment did not diminish with practice. This is consistent with the idea that the cost associated with switching typefaces emanates from the need to replace the current translation rules with rules retrieved from long-term memory, a need that should not diminish with practice at the task. Furthermore, with regard to situations in which all the letters in a string appeared in the same typeface, Sanocki confirmed that letter identification was also impeded when the font changed between trials, confirming that tuning to a particular font can remain in place for at least some time after the corresponding text has been removed from view. Finally, in a further experiment, Sanocki selected pairs of fonts that differed to varying extents with
regard to one of a number of specific letter features (e.g., length of ascenders and descenders relative to the x-height, and whether letter loops were curved or square). The detrimental effect of font mixing increased as the difference between the fonts increased.

To conclude, it is possible to reveal structure-driven effects on reading fluency, and to distinguish these from pattern-driven effects. The best evidence thus far for structure-based effects on reading fluency comes from studies examining the effect of font-switching across successive portions of text, and from studies showing how the benefits of experience with a novel typeface can generalise to letters that have yet to be seen in the typeface. Clearly, however, further work is required to confirm the reality of font tuning, and to clarify its modus operandi. The experiments reported below provide evidence regarding the time course of font tuning, and the extent to which this is under a reader’s strategic control.

**Experiment 1**

A question concerning font tuning that has yet to be addressed is the focus of the three experiments reported here. The question is, under what circumstances, if any, will the translation rules applied to the most recent portion of text be retained in working memory for implementation with the next portion of text? One extreme possibility is that their retention for this purpose is obligatory, regardless of the time elapsing before the next portion of text is encountered, and regardless of the potential utility of re-implementing them (e.g., regardless of the probability that the next portion of text will appear in the same typeface). Another possibility is that readers have some control over the retention of translation rules in working memory. If so, and if their retention is judged not to be useful, then some additional questions arise. Will readers remove the translation rules from working memory, and how quickly will this take effect? And if they abandon the rules, will they replace them with a default set of rules (perhaps corresponding to a prototypical typeface), or will they not replace them, so that
no rules will be available in working memory for implementation with the next portion of text?

In the first two experiments, a situation was created in which there was little incentive for participants to retain the current translation rules for re-implementation with the next portion of text. This was achieved by arranging for portions of text to appear with equal probability in either of two typefaces, and for immediately successive portions of text to be equally likely to appear in the same typeface, or in alternative typefaces. Will the translation rules applied to one portion of text be removed from working memory before the next portion of text is dealt with? And if so, how quickly will this occur? Specifically, as the time separating successive portions of text is increased, will the effects of font-switching disappear, and how quickly will this happen?

Experiment 1 explored a situation in which the temporal separation between successive portions of text was minimal. That is, different portions of text appeared simultaneously on the same page (screen). Participants were presented with a test stimulus that was either a word or a pseudoword, along with a string of consonants. These two stimuli appeared one above the other, and it was unpredictable which stimulus would appear in the upper/lower of the two spatial locations used throughout. Participants had to refrain from responding to the consonant string, and decide if the test stimulus was a word or pseudoword. It was assumed that the two stimuli appearing together would be dealt with separately, and that on a significant proportion of trials the consonant string would be dealt with first. In light of Sanocki’s observations regarding the impact of font-mixing on the identification of letters in a string, font-mixing was expected to have a detrimental effect on responses to the word/pseudoword.
Method

Words and pseudowords were presented as stimuli in the lexical decision task. A set of 128 words was selected from the MCW Orthographic Word Form Database (www.neuro.mcw.edu/wordgen/). The words were 6 and 7 letters long, and had high frequency counts (120 - 2000 per million). Because all the words and pseudowords were to appear entirely in lowercase, proper nouns were not included. The pseudowords were created by changing one letter (and very occasionally two letters) in each of a comparable set of 128 low frequency words (30 – 35 per million). The non-words so created were orthographically legal and pronounceable.

Each of the 256 test stimuli appeared in one of two familiar, but dissimilar, typefaces: Cooper Black and Palatino Italic (see Figure 7). The assignment of one of these typefaces to each word/pseudoword was undertaken on a random basis, with the constraint that half the words and half the pseudowords appeared in each typeface. A complementary set of 256 test stimuli was created by arranging for each word and pseudoword to appear in the other typeface, and the two sets of test stimuli were equally likely to be selected for a participant.

Each word/pseudoword appeared together with a string of consonants. Participants were instructed to ignore the consonant string, and to respond to the lexical status of the word/pseudoword. Each consonant string comprised a random selection of consonants, and the number of consonants matched the number of letters in the word/pseudoword it accompanied. The consonant string appeared in either one of the two typefaces, and this was equally likely to match, or mismatch, the typeface in which the word/pseudoword appeared. The word/pseudoword and consonant string selected for a trial appeared in black, one above
the other in the centre of an otherwise white screen, separated vertically by 5 mm, and each
with an x-height of 4 mm. The average length of the words was 2.0 cm which, with a viewing
distance of 70 cm, corresponds to 1.67 deg of visual angle. The word/pseudoword was
equally likely to appear in the upper or lower of the two locations used throughout. Thus, in a
2 x 2 x 2 x 2 within-participants design, the following four factors were combined
orthogonally: lexical category of the test stimulus, the typeface in which the test stimulus
appeared, the typeface in which the consonant string appeared, and whether the
word/pseudoword appeared in the upper or lower of the two spatial locations.

Stimulus presentation and response monitoring utilised PsyScript (an in-house
experiment generator written by S. Slavin, www.psych.lancs.ac.uk/software/psyScript),
running on an Apple PowerMac G5 (Dual 2GHz), with a 20 inch flat cinema screen.
Generated in this way, the visual quality of the text approached the levels achieved with
printed materials. Each display remained visible until participants made their lexical decision
by pressing one of two keys (i.e., the ‘z’ or ‘/’ key). Assignment of word and pseudoword
responses to the left or right hand was counterbalanced across participants. The stimuli were
removed from view immediately participants responded, and a blank interstimulus interval
(ISI) elapsed before the next pair of stimuli appeared. The ISI was set at 0.75 s. No feedback
was provided regarding the accuracy of each response. Following four practice trials, each
participant completed two blocks of 128 trials each, separated by a brief rest interval, with an
equal number of words and pseudowords appearing in each typeface in each block. The order
in which the test stimuli appeared was randomised on-line, and was different for each
participant.
Participants

Twelve female and four male undergraduate and postgraduate students from Lancaster University completed the experiment. Their ages ranged from 19 to 24 years, and English was their first language.

Table 1 about here

Results

The overall error rate was 7.8%, and the average correct reaction time (RT) was 983 ms. The main thrust of the analyses in this and the experiments to follow concerned RTs. RTs associated with incorrect responses were excluded from the analyses, and a cut-off value was set at 2 SDs above a participant’s average correct RT. RTs exceeding this were replaced with the cut-off value. Though the error rates were relatively low, these also were analysed. An alpha level of 0.05 was used for all statistical tests.

Effects across successive trials.

Reaction time. The only transition effect across successive trials (screens) that was significant involved the spatial location of the word/pseudoword and, specifically, whether this was the same or different across successive trials. A two-way ANOVA was conducted, with the spatial location of the current word/pseudoword (upper location vs. lower location), and its location relative to the location of the preceding word/pseudoword (same location vs. different location) as within-participants factors. The main effect of current spatial location was significant, $F (1,15) = 29.87$, $MSE = 31$, $\eta^2_p = .67$, $p < .001$, with participants responding more quickly when words/pseudowords appeared in the upper location than when they appeared in the lower location ($M = 955$ and 999, respectively). The main effect of relative location across successive trials also was significant, $F (1,15) = 12.12$, $MSE = 22$, $\eta^2_p = .45$, $p$
= .003, with participants responding more quickly when the current word/pseudoword appeared in the same location as the immediately preceding word/pseudoword (\(M = 958\) and 996, respectively). Finally, there was a significant interaction between these two factors, \(F(1,15) = 9.82, \text{MSE} = 6, \eta^2_p = .40, p = .007\). This interaction is summarised in Table 1, from which it can be seen that after responding to a word/pseudoword in the upper location, participants remained set to respond to a further test stimulus in that location. However, after responding to a word/pseudoword in the lower location, participants’ attention was set more equitably across the two locations, perhaps because it was being directed at the centre of the screen in preparation for the next display, or because, coincidentally, it was passing over the centre of the screen on its way to the upper location just as the next display appears. These effects of the spatial location of the word/pseudoword on response speed help to confirm that participants dealt separately with the consonant string and word/pseudoword and, on a significant proportion of trials at least, interrogated the consonant string before responding to the word/pseudoword.

Accuracy. In this and all subsequent analyses of performance accuracy, the outcome was the same whether or not the data were first subjected to arcsine transformation. In this instance, analysis of accuracy failed to confirm the significance of either factor, or the interaction between them.

\[\text{Table 2 about here}\]

Effects within a trial.

Reactivity time. A three-way ANOVA was conducted, with the spatial location of the test stimulus, the lexical category of the test stimulus (word vs. pseudoword), and typeface correspondence (i.e., whether the test stimulus and the consonant string appeared in the same
A supplementary analysis of the RTs examined the extent to which the effect of font correspondence was contingent on the consonant string and word/pseudoword sharing some of their constituent letters. The procedure to determine how many letters were shared by the two stimuli did not take within-string position into account, and trials where there were no letters shared by the two stimuli were contrasted with trials where there was at least one letter shared by the two stimuli. The former trials are referred to as no overlap trials, the latter as overlap trials. This analysis was feasible because there were a sufficient number of trials ($n = 74$) where the word/pseudoword and consonant string had no letters in common. (The percentage of trials involving 0, 1, 2, 3, and 4 letters in common was 29, 42.4, 19.6, 8.2, and 0.8, respectively.) A two-way ANOVA was conducted, with typeface correspondence and letter overlap (no overlap vs. overlap) as within-participants factors. There was a
significant main effect of letter overlap, $F(1,15) = 5.64, MSE = 7.4, \eta^2 = .27, p = .03$, reflecting the fact that participants responded more quickly when some letters were shared by the word/pseudoword and the consonant string, than when no letters were shared by them ($M = 965$ and $986$, respectively). Importantly, however, there was no interaction between typeface correspondence and letter overlap, $F < 1$.

**Discussion**

Although only the word/pseudoword had to be responded to overtly, as a test stimulus in the lexical decision task, the consonant string had to be identified as such, at least on those trials where it was interrogated first and a decision made to ignore it. Participants were slower to respond when the two letter strings appeared in different typefaces, than when they appeared in the same typeface. This suggests that participants were having to adjust to a change in typeface as they switched from considering the consonant string to considering the word/pseudoword.

The outcome of a supplementary analysis of participants’ performance provided some confirmation that the effects of font-mixing reflected the implementation of font-specific translation rules associated with the structure-based processing of letters. Thus, displays varied according to whether the word/pseudoword shared letters with the accompanying consonant string, and the impact of this on lexical decision times was assessed. Structure-based processing would not be expected to be especially sensitive to the presence of letter overlap, because the same translation rules can be signalled by different letters of the alphabet. Notwithstanding the caution always required when responding to a null result, the fact that the impact of font-mixing on lexical decision times was insensitive to letter overlap is consistent with the involvement of structure-based letter processing.
**Experiment 2**

Experiment 2 was designed to assess how the impact of font-switching on reading fluency is sensitive to the time interval separating successive portions of text. This was achieved by presenting words/pseudowords individually (i.e., without being accompanied by a consonant string), and by arranging for the ISI to be set at either 0.75 s (i.e., the same as in Experiment 1), or 0.1 s, for different groups of participants. The sets of words and pseudowords were extended to include 140 examples of each. The number of trials across which successive words and pseudowords had no letters in common was too low (mean $n = 23$, corresponding to 8%) to sustain the same analysis of letter overlap reported for Experiment 1.

**Participants**

Fourteen female and seven male undergraduate and postgraduate students from Lancaster University completed the experiment. Their ages ranged from 19 to 32 years, and English was their first language. Eleven participants were assigned, at random, to the 0.75 s ISI condition, and 10 participants were assigned to the 0.1 s ISI condition.

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Table 3 about here

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**Results**

The overall error rate was 4.5 %, and the average correct RT was 678 ms.

*Reaction time*

A four-way ANOVA was conducted, with ISI (*short vs. long*) as a between-participants factor, and with typeface transition (*same typeface vs. different typeface* across successive trials), lexical category transition (*same lexical category vs. different lexical*
category across successive trials), and lexical category (word vs. pseudoword), as within-participants factors.

The only factor yielding a significant main effect was lexical category, $F(1,19) = 69.83, \text{MSE} = 39.8, \eta^2_p = .79, p < .001$, with participants responding more quickly to words than to pseudowords ($M = 629$ and $726$ ms, respectively). Though the main effect of typeface transition was not significant, $F(1,19) = 2.35, \text{MSE} = 16.6, \eta^2_p = .11, p = .14$, typeface transition interacted significantly with ISI, $F(1,19) = 6.90, \text{MSE} = 4.9, \eta^2_p = .27, p = .017$ (cf. Table 3A). This interaction arose because typeface transition had a significant effect at the shorter ISI, $F(1,9) = 8.31, \text{MSE} = 5.8, \eta^2_p = .48, p = .018$, but not at the longer ISI, $F < 1$. Finally, at the shorter ISI, typeface transition did not interact with lexical category, $F < 1$.

The facilitation due to typeface correspondence measured 15 and 19 ms for words and pseudowords, respectively.

The Typeface Transition X Lexical Category Transition interaction was significant, $F(1,19) = 16.59, \text{MSE} = 11.5, \eta^2_p = .47, p = .001$, reflecting the fact that participants responded more quickly when the same/different status of the typeface transition agreed with the same/different status of the lexical category transition (i.e., both same or both different), than when they disagreed (i.e., when one transition was same, and the other was different) (cf. Table 3B). The three way interaction with ISI was marginally significant, $p = .11$, reflecting the fact that though the Typeface Transition X Lexical Category Transition interaction was significant at the longer ISI, $F(1,10) = 23.53, \text{MSE} = 12.0, \eta^2_p = .70, p = .001$, it was not significant at the shorter ISI, $F(1,9) = 2.13, \text{MSE} = 19.0, \eta^2_p = .19, p = .18$.

**Accuracy**

With regard to performance accuracy, there was no effect of typeface transition, and no interaction between this and ISI, $F < 1$ in both cases.
Discussion

The results reveal that the cost to reading fluency associated with switching fonts across successive words/pseudowords was removed when the time interval separating them was extended from 0.1 to 0.75 s. If we assume that the impact of font-switching reflects the inappropriateness of carrying forward the typeface translation rules from the immediately preceding text, then the results indicate that these rules are removed from working memory shortly after the corresponding text has been responded to and/or removed from view. The results are mute with regard to whether their removal is obligatory or under strategic control. In Experiment 2, there was little incentive to retain the translation rules, since successive portions of text were as likely to appear in different typefaces as to appear in the same typeface. Additional work is needed to assess the extent to which readers have control over the retention and implementation of translation rules in working memory, and this is the focus of Experiment 3.

When typeface transition and lexical category transition were in agreement (i.e., both signalled no change to the status of the stimulus/response, or both signalled change), participants responded more quickly than when they were in disagreement (i.e., one signalled change, the other no change). One way of describing this effect is to say that participants were slower to repeat the same response across successive trials when the typeface changed, and slower to change their response across successive trials when the typeface remained the same. The fact that this change signals effect was significant in the longer ISI condition confirms that, despite the absence of a main effect of typeface transition with the longer ISI, a record of the visual appearance of each preceding test stimulus was still available in memory. Thus, the absence of a font-switching effect at the longer ISI is not due to participants having no memory for the first of the two typefaces.
Experiment 3

The absence of a font-switching effect in the 0.75 s ISI condition of Experiment 2 contrasts with Sanocki’s (1987, 1988) observation that font-switching between blocks of trials impairs reading fluency. One way of reconciling these results is to assume that readers can exercise control of the retention and re-implementation of font-specific translation rules, and that whereas there was incentive to exercise such control in Sanocki’s study, there was no such incentive in Experiment 2.

To provide an initial assessment of the degree to which readers have strategic control of the retention of font-specific translation rules in working memory, Experiment 2 was repeated, but with changes to the stimulus sequencing. The revised sequencing was designed to provide participants with extra incentive to carry the translation rules forward from one test stimulus to the next. This was achieved by arranging for a typeface to be retained for a run of 3 or 4 successive stimuli before font-switching occurred. Because run lengths of 3 and 4 were equally frequent, each of the two typefaces was more likely to be re-used for immediately successive stimuli than to be swapped (0.7 vs 0.3, respectively, compared with 0.5 vs 0.5, respectively, in Experiment 2). In this way, the revised sequencing created a situation in which participants would benefit overall by holding the most recent font-specific translation rules in working memory for re-implementation with the next stimulus. If the effect of font-switching in Experiment 2 was restricted to the 0.1 s ISI condition because the sequencing provided no incentive for participants to preserve the translation rules for re-implementation across successive trials, then the revised sequencing in Experiment 3 would be expected to induce an effect of font-switching regardless of ISI. After completing the experiment, each participant was questioned to reveal the extent to which they were aware of
the sequencing constraints involving typeface (i.e., that after each change in typeface, the same typeface would be used for the next few trials).

**Participants**

Nineteen female and eight male undergraduate students completed the experiment. Their ages ranged from 18 to 42 years, and English was their first language. Twelve participants were assigned, at random, to the 0.1 s ISI condition, and fifteen participants were assigned to the 0.75 s ISI condition.

None of the participants revealed any awareness of the constraints in the sequencing of test stimuli. They all believed the sequencing, including the choice of typeface for each stimulus, to be entirely random across successive trials.

The overall error rate was 4.1%, and the average correct RT was 712 ms.

**Reaction time**

There was a significant main effect of lexical category, $F(1, 25) = 40.89$, $MSE = 74.0$, $\eta^2_p = .62$, $p < .001$, with participants responding more quickly to words than to pseudowords ($M = 653$ and 771 ms, respectively). There was also a significant main effect of typeface transition, $F(1, 25) = 24.97$, $MSE = 3.1$, $\eta^2_p = .50$, $p < .001$, with participants responding more quickly when the current word/pseudoword appeared in the same typeface as the immediately preceding word/pseudoword, than when it appeared in a different typeface ($M = 705$ and 720, respectively) (cf. Table 4). Typeface transition did not interact significantly with ISI, or lexical category, $F < 1$ in both cases. The facilitation due to typeface correspondence measured 19 and 17 ms for words and pseudowords, respectively.
Accuracy

The main effect of typeface transition failed to achieve significance, $F (1, 25) = 3.03$, $MSE = .23$, $\eta_p^2 = .12$, $p = .09$, and on this occasion there was an overall tendency for participants to respond less accurately when the preceding word/pseudoword appeared in the same typeface as the current word/pseudoword ($M = 95.5$ and $96.6\%$, respectively). The effect of typeface transition did not interact significantly with ISI, $F < 1$.

Typeface transition, ISI, and Experiment. The strength of the typeface transition effect on RT was compared across Experiments 2 and 3, separately for each value of ISI. Though there was no difference in the strength of the effect across the two experiments at 0.1 s ISI, $F = 0$, there was a significant difference at 0.75 s ISI, $F (1, 24) = 6.07$, $MSE = 10.0$, $\eta_p^2 = .20$, $p = .02$.

Serial position. A different way of revealing the impact of introducing regular runs of 3 or 4 stimuli in the same typeface is to examine the mean correct RT at each serial position within a run. The mean correct RTs for serial positions 1 to 4 were 720, 701, 705, and 709 ms, respectively. Serial position 1 relates to trials that were preceded by a different typeface. The fact that the mean RT for this serial position is relatively slow confirms the effect of font-switching. ANOVA confirmed the significance of the main effect of serial position, $F (3, 75) = 4.35$, $MSE = 3.4$, $\eta_p^2 = .15$, $p = .007$, and the significance of the contrast between serial position 1 and serial position 2, $F (1, 25) = 18.85$, $MSE = 9.1$, $\eta_p^2 = .43$, $p < .001$. With regard to serial positions 2 to 4, ANOVA failed to reveal a significant effect of serial position, $F < 1$. The results were next partitioned according to whether a run was preceded by a run of just 3 trials involving a single typeface, or a run of 4 such trials (cf. Figure 8). In the latter case, the constraints on the sequencing guaranteed that at serial position 1 the typeface would differ from the preceding trial, whereas in the former case the typeface was equally
likely to be the same or different. The main effect of the length of the preceding run was not significant, $F < 1$. However, there was a significant interaction between the length of the preceding run and serial position, $F(3, 75) = 7.96, \text{MSE} = 7.9, \eta^2_p = .24, p < .001$. Whereas there was no effect of serial position after a preceding run of length 4, $F < 1$, there was a significant effect of serial position after a preceding run of length 3, $F(3, 75) = 13.87, \text{MSE} = 10.6, \eta^2_p = .3, p < .001$. Inspection of Figure 8 makes clear that this effect of serial position arose from the relatively slow RTs at serial position 1. Indeed, RTs across serial positions 2 to 4 did not differ significantly, $F(2, 50) = 1.92, \text{MSE} = 17, \eta^2_p = .07, p = .16$. Finally, analysis of accuracy failed to find a significant main effect of either serial position or the length of the preceding run, $F < 1$ in both cases. Though the interaction between these two factors was significant, $F(3, 75) = 11.50, \text{MSE} = 0.17, \eta^2_p = .31, p < .001$, inspection of the results in Figure 8 confirms that this involved the later serial positions only (i.e., they appeared within runs of trials involving the same typeface).

**Discussion**

The results confirm that readers have some control over the retention of font-specific translation rules for re-implementation across successive portions of text. The constraints imposed on the stimulus sequencing in this experiment (i.e., the same typeface was used for runs of 3 or 4 successive stimuli) provided additional incentive for participants to retain the translation rules currently in working memory for use with the next stimulus. Specifically, the overall probability with which successive stimuli appeared in the same typeface, rather than in alternative typefaces, was increased from 0.5 (Experiment 2) to 0.7 (Experiment 3). This resulted in an effect of font-switching surviving the longer ISI of 0.75 s. It seems, therefore, that when it appears useful to do so, readers can retain the current font-specific translation rules in working memory for at least 0.75 s.
Initial predictions regarding how the constrained sequencing would moderate the effects of font-switching focused on overall levels of performance, and how these might differ according to whether an immediately preceding stimulus appeared in the same typeface as the current stimulus, or in the alternative typeface. Because of the particular constraints that were introduced, however, it was possible to assess participants’ sensitivity to item-by-item fluctuations in the utility of re-implementing the same font-specific translation rules across successive stimuli. This assessment involved taking account of the serial position of each item within a run of trials involving the same typeface (i.e. within runs of 3 and 4 stimuli). Whereas serial position 1 related to occasions where the current and immediately preceding stimulus appeared in different typefaces, all other serial positions related to occasions where these stimuli appeared in the same typeface. Contrasting performance at serial position 1 against performance at all other serial positions confirmed the deleterious effect of font-switching. Crucially, however, this effect emerged only when the switch was preceded by a run of just three same-typeface trials, it did not emerge when the switch was preceded by a run of four same-typeface trials. The effect of the length of the immediately preceding run on responses at serial position 1 confirmed that participants were sensitive to two consequences of the sequencing constraints. First, that after the third item in a run, the probability that the same typeface would be repeated dropped from 1.0 to 0.5 (i.e., each typeface became equally likely to be used). And second, that the typeface would always change after the fourth item in a run.

Following the third item in a run, the probability that the next item would appear in the same typeface (i.e., .5) was the same probability that applied following every item in Experiment 2. The fact that only in the present experiment did font-switching have a significant effect at the longer ISI, confirms that participants did not respond solely on the
basis of the specific probability value associated with each serial position. They were also sensitive to the overall probability with which successive items appeared in the same typeface.

Following the fourth item in a run, the next item always appeared in the alternative typeface. Despite the switch in typeface, performance was not impeded relative to performance on subsequent items in the run, suggesting that participants placed the appropriate translation rules in working memory in anticipation of the upcoming item. Had they waited until the item appeared before accommodating the change in typeface, some slowing of the responses would have been expected, embracing the time needed to retrieve the appropriate translation rules from long-term memory.

The serial position effect following a run of three same-typeface trials confirmed two additional things. First, because the impact of font-switching was confined to serial position 1, it does seem that only one set of translation rules is held in working memory. When the rules are removed from working memory, they lose any special status relative to all other sets of rules preserved in long-term memory, with the effect that the impact of font-switching is confined to 1-back transitions. Second, by isolating the specific conditions under which typeface switching will impact on performance, the level of impact was confirmed to be more pronounced than had hitherto appeared. Thus, before serial position and the length of the preceding run of same-typeface trials were taken into account, font-switching appeared to add approximately 16 ms to response times (cf. Table 4). However, it now appears to add at least 45 ms to response times (see Figure 8).

**General Discussion**

Evidence was reviewed in the first section of the present paper to support the concept of font tuning, that is, the derivation and implementation of font-specific rules mapping
visual features onto letters’ structural descriptions. Structural descriptions are seen as a major basis for accessing abstract letter identities, which in turn are seen as an important means of accessing the orthographic codes linked to lexical information (e.g., Miozzo & Caramazza, 1998; Rapp, Folk, & Tainturier, 2001). This route to word identification was contrasted with an alternative route in which the 2D visual patterns (images) created by letters and letter strings are matched to patterns in long-term memory, that in turn are linked to the orthographic codes associated with lexical information. The different conditions under which these two routes to word identification might be expected to yield font-repetition effects were explored.

In a series of three experiments, the time course of font tuning was examined, especially its sensitivity to the potential utility of retaining translation rules across successive portions of text. Factors that were explored included the overall probability with which successive portions of text appear in the same typeface, and the item-by-item fluctuations in this probability. By increasing the overall probability from .5 to .7, the font-repetition effect survived an ISI of 0.75 s. Thus, participants seem to have some control over the time course of font tuning, and the increase in the probability of font-repetition seemed to provide them with extra incentive to retain translation rules for re-implementation with successive portions of text. Without this extra incentive, retention for re-implementation was restricted to the shorter ISI of 0.1 s.

The analysis of serial position effects in Experiment 3 provided more detailed information about font tuning. For example, the absence of any performance cost arising from a switch in typeface when this was certain to occur (i.e., after the fourth item in a run of same-typeface trials), confirmed participants’ sensitivity to item-by-item fluctuations in the probability of font repetition. In addition, it confirmed that participants were able to prepare
in advance for the new typeface, and did not have to wait until the new text appeared before accommodating the change. It is proposed that this preparation involved retrieving the translation rules appropriate for the impending typeface from long-term memory, and making them available in working memory for implementation. In this way, participants were as well prepared for the next portion of text as they were within a run of same-typeface trials, when the upcoming text was sure to appear in the same typeface as the immediately preceding text. Of course, it was only because there were just two alternative typefaces being mixed in the present experiments that participants were able to prepare in this way for text that was to appear in a different typeface.

When only two typefaces are mixed in a sequence of stimuli, it is difficult to dissociate the impact of knowing that the same typeface will not be re-used (so that, for example, its translation rules could be removed from working memory), from the impact of knowing which particular typeface this will be. If the account offered here is correct, regarding how participants prepared for an inevitable change in typeface, then font-switching should induce performance costs in circumstances in which participants know that a different typeface will be used, but do not know which typeface this will be. In these circumstances, participants have no option but to wait until the next portion of text appears to fully accommodate the change in typeface. It would be interesting, therefore, to extend the present study to embrace situations in which several typefaces are mixed, and in which sequencing constraints ensure that the typeface will change after every n\textsuperscript{th} item in a run, but with every other typeface then being equally likely to be used. The only preparation that could be initiated by participants ahead of the new item would involve the removal of the translation rules currently in working memory.
The analysis of serial position in Experiment 3 also confirmed that the effects of font-switching were confined to immediately successive stimuli. This was predicted from the proposal that only one set of font-specific translation rules can be accommodated in working memory. When a set of rules is removed from working memory, their status becomes no different from the status of other translation rules in long-term memory, and this explains why the effects of font-switching are confined to 1-back transitions.

Though the present proposals concerning font tuning make reference to working memory for the temporary retention of font-specific translation rules, the nature of this resource has not been elaborated (except for reference to its capacity to hold only one set of translation rules). On the one hand, the memory concerned could be a dedicated resource, the sole purpose of which is to allow a set of font-specific translation rules to be made available for implementation. On the other hand, it could reflect a specific way of utilising a more general resource. To address this issue, the present studies could be extended to embrace dual-task analysis. What types of concurrent tasks, and what types of associated stimuli presented in each ISI, would not interfere with the font-repetition effect? For example, if requiring participants to encode and remember any visual stimulus in each ISI was found to remove the repetition effect, then the working memory supporting the temporary retention of font-specific translation rules would begin to look like a general resource. Alternatively, if the only concurrent tasks to interfere with the font-repetition effect are those requiring participants to deal with text in a different typeface, then this working memory would begin to look like a resource dedicated to dealing with text.

Participants’ sensitivity to the overall probability with which successive items appear in the same typeface, rather than in alternative typefaces, and to the item-by-item fluctuations in this probability, contrasts with their apparent lack of awareness of the sequencing
constraints put in place. All participants believed the sequencing, including the typefaces selected for successive stimuli, was completely random. It would seem, therefore, that variability in the time course of font tuning need not reflect conscious decision processes on the part of the reader, but can be an unconscious consequence of their implicit knowledge of the sequencing constraints currently in place. This result deserves to be confirmed and investigated further. It would be useful to have converging evidence that participants’ knowledge of the sequencing constraints is implicit. One possibility would be to change the constraints in various ways after they have been learned, and to examine both the extent to which participants are aware of the change, and the way in which performance is disrupted by the change. Identifying which changes are disruptive, and which are not, would help to confirm what has been learned implicitly about the original constraints. Participants’ implicit knowledge of the sequencing constraints could also be assessed by presenting them with two possible runs of new stimuli, with one run conforming to the constraints present in the experiment, and the other run deviating from these constraints. They could be asked to indicate which run seems to be the most pleasant. Implicit knowledge of the sequencing constraints might be expected to increase participants’ liking for runs that conform to the sequencing constraints present in the experiment trials (see, for example, Kunst-Wilson & Zajonc, 1980; Seamon, Brody, & Kauff, 1983; Bornstein & D’Agostino, 1992).

In all three experiments, the font-switching effect was insensitive to the lexical status of the current test item (i.e., by whether it was a word or pseudoword). Such insensitivity would normally be taken as evidence for the pre-lexical locus of an effect and, in the present context, this is consistent with a role for font tuning in initial letter identification. A potential role for the lexical guidance of font tuning is not to be denied, however. For example, Norris, Butterfield, McQueen, and Cutler (2006) assembled mixed lists of words and nonwords in
which one particular letter of the alphabet was always replaced by an ambiguous letter form. This letter form was created by morphing the feature distinguishing the uppercase versions of the letters H and N (i.e., the stroke connecting the two vertical strokes) until it was at the midpoint on the H-N continuum. In the context of the lexical decision task, Norris et al. gave readers experience with words and nonwords in which either the letter H, or the letter N, was always replaced by the ambiguous letter form. It was observed that identification of the words containing this letter form facilitated participants’ re-calibration of the H-N dimension. For example, after encountering text in which the letter form replaced the letter H, participants shifted the categorical boundary between H and N, towards the N end of the H-N continuum, so that forms in the midrange of this continuum would be categorised as an H. Though it is unclear if this re-calibration involved changing the font-specific translation rules and/or the stored structural description for the substituted letter, these results encourage exploration of the potential for lexical guidance in the acquisition of font-specific translation rules.

The concept of font tuning being promoted here embraces the assumption that, regardless of the typeface in which a particular case version of a letter appears, the same structural description will be derived and accessed in long-term memory. In an investigation of visual memory for letter-color conjunctions, Walker and Hinkley (2003) provide evidence that it is a record of the structural description for a letter, rather than a record of the font-specific visual pattern it created, that is linked to a memory representation of the color in which the letter appeared. Their investigation extended previous work on memory for visual feature conjunctions, some of which had examined shape-color associations using geometric shapes rather than letters. The theoretical context in which Walker and Hinkley situate their work deliberately blurs the distinction between letters and visual objects. Instead, they
suggest that letters can be encoded as if they were pictures of objects. They point out that the structural descriptions derived for letters could be equivalent to those derived for objects (e.g., the geon structural descriptions proposed by Biederman, 1987, with letter strokes serving as geons). Examples were presented in the review section of the present paper of typefaces which depict letters as 3D forms, and in everyday life we encounter signage incorporating objects doubling up as letters. Indeed, the parallel between these two categories of visual stimuli can be extended by suggesting that the font-specific 2D visual patterns created by letters are the equivalent of the viewpoint-specific images of individual objects proposed by Tarr (e.g., Tarr, 1995). Perhaps, therefore, letter/word and object identification are both supported by equivalent pattern-based and structure-based visual encoding processes.

Viewpoint-specific object images preserved in long-term memory can be networked to represent object categories (see, for example, Tarr & Gauthier, 1998). Initially, viewpoint-specific images pertaining to the same individual object (e.g., my chair) would be networked, and this network would then represent the individual object in an effectively viewpoint-independent manner (provided the object had been encountered from a sufficiently comprehensive range of viewpoints). Next, all of the object-specific networks pertaining to objects from the same category (e.g., all the networks for all chairs I have encountered) could themselves be networked, to create a supernetwork representing the object category. If this principle of establishing category representations by the layered networking of images is extended to letters, some interesting possibilities arise regarding different types of category that could be represented. For example, if all the images pertaining to a case-specific letter of the alphabet, regardless of typeface, were to be pooled, the emerging network would represent the same concept as a structural description. Similarly, if all the images pertaining
to a particular typeface, regardless of letter and case, were to be pooled, the emerging
network would represent all possible outcomes from the implementation of a set of font-
specific translation rules.

The existence of such category representations, based on pooling images of letters,
could provide an alternative explanation for some of the observations attributed to font
tuning. For example, instead of a set of font-specific translation rules being retrieved from
long-term memory for implementation with a new portion of text, the reader could take steps
to make the pool of images representing the typeface more accessible, thereby facilitating the
search for an image that matches current input. The benefits associated with font-repetition
would then reflect the continuing heightened accessibility of the relevant pool of images, and
the costs associated with font-switching would reflect the demands associated with making a
different pool more accessible. Given that the creation of Tarr-like images is dependent on
encountering individual objects from specific viewpoints, we see again the theoretical
significance of utilising novel typefaces in studies of font tuning, and of assessing the extent
to which experience with a subset of letters in a novel typeface generalises to letters that have
yet to be seen in that typeface. Future studies of the time course of font tuning, and of its
strategic control, will benefit from incorporating novel typefaces, and from exploring how
participants’ experience with a subset of letters in a novel typeface generalises to other
letters, and especially to letters that are visually dissimilar to those that have been seen.

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Figure 9 about here

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Returning to the issue of the extent to which letters and pictures of objects are
encoded in fundamentally similar ways, it is of interest to contemplate the object equivalent
of a typeface, and to rehearse how evidence might be obtained for the object equivalent of
font tuning. For this purpose, we need to locate sets of artefacts, from the same superordinate category, that have distinctive, yet coherent, designs. Candidate categories include furniture, jewellery, and tableware. Figure 9 illustrates a knife, fork, and spoon manufactured by David Mellor Design of Sheffield, England, according to two different designs, City and Chinese Black (cf. davidmellordesign.com). As with letters and typefaces, each item has the essential category-defining structure (in this case determined by the object’s intended function), but in different designs this is realised in different ways that are consistent across all items in a set. For example, the handles within a design have consistent features embracing shape, color, and other details (e.g., whether pins securing the handles are visible). The equivalent of font tuning would be in evidence if experience with a subset of items from a design allowed a person to appreciate the themes inherent in the design. The equivalent of a font-repetition effect would occur if, as a result of such experience, new exemplars from a set were identified more easily when they appeared in the same design, than when they appeared in a different design. The equivalent of font-mixing would occur if people were to find it more difficult to identify an item within a group of other exemplars from the same category (e.g., the knife in Figure 10) when these exemplars were realised in a different design (Figure 10a), than when they were realised in the same design (Figure 10b). Extending studies of font tuning to embrace the domain of artefacts, though very significant theoretically, would be relatively straightforward.

Figure 10 about here
References


Appendix

Pattern-based word identification: Typeface familiarity and reading fluency

Images of the visual patterns created by previously encountered letters and multi-letter strings are thought to be preserved in long-term visual memory, together with the abstract letter identities and orthographic codes with which they were previously linked and through which phonological and semantic representations can be accessed. As a result, words can be identified directly from their surface form, provided they have been seen in the same, or similar, surface form in a previous reading episode.

Studies designed to demonstrate that reading fluency can be enhanced as a result of having previously encountered text in the same visual format have often adopted an experimental paradigm in which text is presented in two phases. In the first phase, participants are presented with text in one of a number of visual formats. In the second phase, the same or related text is presented either in the same format as previously, or in one of the alternative formats. When reading fluency is enhanced to a greater extent when text reappears in the same format, it is concluded that aspects of the original text were preserved in memory in a format-specific manner. Determining whether and how this enhancement generalises to elements of text not included in the study phase (i.e., to other individual letters and multi-letter strings), helps identify which types of element are having their visual patterns preserved in memory.

*Familiar typefaces.* When text appears in a familiar typeface, the visual patterns created by the letters and multi-letter strings it contains will have been encountered before. Therefore, corresponding patterns will already be available in long-term visual memory to support reading. Because of this, giving readers additional experience with the typeface in the first phase of a study is unlikely to add new records to visual memory and is, therefore,
unlikely to enhance reading fluency when text in the same typeface is encountered in the
second phase. In general, therefore, font-specific facilitation of reading through repetition is
not expected to occur with familiar typefaces. However, there are two factors that might
create conditions in which reading fluency is enhanced through repetition when a familiar
typeface is involved. These factors concern the familiarity of the patterns created by multi-
letter strings. They do not concern the patterns created by individual letters because these will
always be familiar. The first factor is word frequency. Though readers will have read
uncommon words in familiar typefaces before, they will, by definition, have encountered
them infrequently. The second factor is the frequency of the multi-letter sequences (e.g., their
summed n-gram frequency). Though readers rarely encounter non-words, in any typeface,
they are likely to have encountered the multi-letter sequences they contain, especially where
the non-words are pseudowords rather than random sequences of letters, because the former
inevitably involve familiar letter sequences. Putting these two factors together, therefore,
suggests that the font-specific facilitation of reading through repetition, though not normally
expected when text appears in a familiar typeface, might be expected in the case of infrequent
words (compared with frequent words), pseudowords (compared with words), and random
letters strings (compared with pseudowords). Furthermore, because some letters of the
alphabet normally create a different visual pattern in their uppercase and lowercase form, any
factors encouraging font-specific repetition effects on reading fluency would also be expected
to encourage case-specific effects. Several studies provide support for all of these suggestions

_unfamiliar typefaces_. When text appears in an unfamiliar typeface, the visual patterns
created by the letters and multi-letter strings are unlikely to have been encountered before,
and so records of the patterns are unlikely to be available in long-term visual memory to
support reading. By giving participants some experience reading text in an unfamiliar
typeface, such records will be added to long-term visual memory, thereby enhancing reading
fluency when text in the same typeface is encountered later. In other words, a pattern-based
account of word identification can accommodate the font-specific facilitation of reading
through repetition when unfamiliar typefaces are involved (and the category of unfamiliar
typefaces might be assumed to include handwriting and text that has been spatially
transformed, such as when all the individual lines of text are inverted). As in the case of
familiar typefaces, facilitation through repetition would be expected to be more pronounced
in the case of infrequent words, pseudowords, and random letter strings, and to be
accompanied by case-specific effects. Several studies provide evidence in line with all of
these expectations (Brooks, 1977; Brown & Carr, 1993; Horton & McKenzie, 1995;
Kinoshita & Wayland, 1993; Kolers, 1979; Masson, 1986; Roediger & Blaxton, 1987;
Vaidya et al., 1998). Indeed, Brooks, Masson, and Roediger and Blaxton present evidence
confirming that whole words can qualify as multi-letter strings having their visual patterns
preserved in long-term visual memory.

Brooks (1977) asked participants to read through lists of 16 words as quickly as
possible, making a note of how many names of people and places each list contained. Some
lists were presented entirely in uppercase, others were presented with successive letters
alternating in case. Sufficient practice on these was given to ensure that participants became
equally fluent (quick) with either format. In a second phase, word lists were again presented,
and these included words that had originally appeared in alternating case. Some of these
words reappeared in the same pattern of alternating case (e.g., lInDa – lInDa), others in the
complementary case pattern (e.g., lInDa – LiNdA). Brooks observed reading fluency to be
enhanced when words reappeared in the same pattern of alternating case. Because there were
no constraints on the case in which individual letters and multi-letter sequences appeared in the first phase of the study, this result was interpreted as evidence for the preservation of visual patterns created by whole words.

In a carefully designed study, Masson (1986) confirmed that the visual patterns created by whole words can be preserved in memory and can enhance reading fluency. In one experiment (Experiment 3), he arranged for all the letters to be inverted, and for successive letters of each word to appear in alternating case, with the case of a word’s initial letter being determined on a random basis. With these constraints on format, Masson ensured that each letter of the alphabet, and each sub-lexical letter sequence, appeared equally often in each case, whereas whole words appeared in only one of the two possible case versions. In the first phase of his study, he gave participants practice at reading word triplets presented in this unusual format. In the second phase, participants re-read the same words, again with the letters inverted. Half of the words were presented in the same case pattern in which they had been seen in the first phase, half were presented in the alternative case pattern. Masson observed reading in the second phase to be enhanced when the words were re-presented in the same case pattern, rather than in the complementary case pattern. In a replication of Masson’s experiment, Horton and McKenzie (1995) used both a familiar and an unfamiliar typeface, and observed a combined word- and case-specific facilitation effect only with the unfamiliar typeface.

To conclude, in line with more recent studies of the effects of case mixing on reading (cf. the Introduction), evidence exists for format-specific repetition effects involving both familiar and unfamiliar formats, including familiar and unfamiliar typefaces. This evidence reveals a number of factors determining when pattern-based font-repetition effects are to be
expected. These factors, which include word and n-gram frequency, reflect a reader’s unfamiliarity with the visual patterns created by multi-letter strings.
Author Note

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Table 1
Experiment 1: Mean correct RT and mean percentage error rate (in italics) according to the spatial location of the current word/pseudoword, and the spatial location of the immediately preceding word/pseudoword.

<table>
<thead>
<tr>
<th>Location of preceding word/pseudoword</th>
<th>Upper</th>
<th>Lower</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location of current word/pseudoword</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td>927</td>
<td>984</td>
</tr>
<tr>
<td>Lower</td>
<td>990</td>
<td>1008</td>
</tr>
</tbody>
</table>


Table 2

Experiment 1: Mean correct RT and mean percentage error rate (in italics) according to whether the word/pseudoword appeared in the same typeface as the consonant string, or in a different typeface, and according to the lexical category of the test stimulus.

<table>
<thead>
<tr>
<th>Lexical category</th>
<th>Word</th>
<th>Pseudoword</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typeface correspondence between word/pseudoword and consonant string</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Same typeface</td>
<td>870</td>
<td>1067</td>
</tr>
<tr>
<td></td>
<td>4.6</td>
<td>11.9</td>
</tr>
<tr>
<td>Different typeface</td>
<td>901</td>
<td>1094</td>
</tr>
<tr>
<td></td>
<td>5.1</td>
<td>9.6</td>
</tr>
</tbody>
</table>
Table 3
Experiment 2: Mean correct RT and mean percentage error rate (in italics) according to typeface transition, ISI, and lexical category transition.

<table>
<thead>
<tr>
<th>A</th>
<th>ISI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.1 s</td>
</tr>
<tr>
<td>Typeface transition</td>
<td></td>
</tr>
<tr>
<td>Same typeface</td>
<td>661</td>
</tr>
<tr>
<td>Different typeface</td>
<td>678</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B</th>
<th>Lexical category transition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Same category</td>
</tr>
<tr>
<td>Typeface transition</td>
<td></td>
</tr>
<tr>
<td>Same typeface</td>
<td>660</td>
</tr>
<tr>
<td>Different typeface</td>
<td>683</td>
</tr>
</tbody>
</table>
Table 4
Experiment 3: Mean correct RT and mean percentage error rate (in italics) according to typeface transition and ISI.

<table>
<thead>
<tr>
<th>ISI</th>
<th>Same typeface</th>
<th>Different typeface</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 s</td>
<td>691 5.0</td>
<td>708 4.7</td>
</tr>
<tr>
<td>0.75 s</td>
<td>719 3.9</td>
<td>733 2.9</td>
</tr>
</tbody>
</table>
Figure Legends

Figure 1. Some of the cognitive components involved in the pattern-based and structure-based identification of letters and words.

Figure 2. Examples of typefaces possessing decorative visual features that are not diagnostic of underlying letter structure, but have been added to make the typefaces appropriate for use in a particular context.

Figure 3. A selection of typefaces illustrating how individual letters strokes can be realised in surface form in many different ways.

Figure 4. Examples of typefaces illustrating how VERTICAL and HORIZONTAL in a letter’s structural description need not be translated into vertical and horizontal according to the spatial frame of reference provided by the page and the virtual lines on which the text is placed.

Figure 5. Examples of typefaces in which not all elements of a letter’s prototypical structural description are apparent in its surface form, encouraging readers to rely more heavily on other structural features for letter identification (cf. text for an explanation).

Figure 6. Letters are more easily identified when they are presented alongside other letters appearing in the same typeface.

Figure 7. The two typefaces used in the present experiments.

Figure 8. Mean correct RTs and error percentages for each serial position within a run of same-typeface trials, distinguished according to the length of the immediately preceding run of same-typeface trials.

Figure 9. City and Chinese Black cutlery from the David Mellor range illustrating how designs for sets of artefacts serve as the equivalent of a typeface for sets of letters.
Figure 10. Is there an object equivalent of font tuning, with objects (e.g., the knife) being more easily identified when other objects from the same category appear in the same design, rather than in a different design?
"text"

images of multi-letter strings

images of individual letters

previously assembled font-specific translation rules in LTM

font-specific translation rules for current text in working memory

structural descriptions of letters

images of multi-letter strings in LTM

textual representations of whole words in LTM

orthographic representations of multi-letter strings in LTM

orthographic representations of multi-letter strings in LTM

abstract letter representations in LTM

LETTER IDENTIFICATION

WORD IDENTIFICATION

Figure 1
Figure 2
Figure 3

Bayer Shadow
Calypso
Croissant
Gayjin Shadow
Hounslow
Piccadilly
Shatter
Figure 4
Figure 5
Figure 6
Cooper Black

Palatino Italic

Figure 7
Figure 8
Figure 9
Figure 10