Sans Forgetica font may help memory for words but not for numbers, nor does it help analytical thinking

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Abstract

Recently, the new Sans Forgetica (SF) typeface, designed to promote desirable difficulty, has captured the attention of many researchers. Here, we investigate whether SF improves memory for words, memory for numbers, and analytical thinking. In Experiment 1A, participants studied words in Arial and SF and then completed an old-new recognition test where words retained their study fonts. While participants correctly identified significantly more words as ‘old’ in SF than in Arial condition, this difference can be explained by a higher tendency to respond ‘old’ for words in SF than Arial. In Experiment 1B, participants studied words in Arial and SF and then completed an old-new recognition test on those words in either Arial or SF. Participants had significantly higher sensitivity indexes (d') when words were tested in SF than in Arial, but no other effect was found for d' or correct identifications. Experiment 2 had a 2 (font: Arial vs. SF) x 2 (trial type: study vs. generate – estimate answer) within-subjects factorial design. Participants were to learn decimal equivalents of square roots and completed trials three times before a cued-recall test. There were no effects on accuracy, absolute deviation from correct answer, or response time. In Experiment 3, participants completed a cognitive reflection test where half the problems were presented in Arial and the other half in SF. There were no differences in accuracy or response time. We cannot strongly recommend the use of SF in these areas.

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Introduction

Desirable difficulty refers to a situation during learning when encoding of information is deliberately made difficult, but the encoded information becomes better retained and retrieved later (Bjork, 1994). Researchers have studied the potential for disfluent font to be a desirable difficulty, mostly because using a disfluent font is an easily adaptable and ready educational solution, if shown to be beneficial (e.g., Diemand-Yauman, Oppenheimer, & Vaughan, 2011; Geller, Still, Dark, & Carpenter, 2018). Perceptual disfluency is manipulated through changing the characteristics of the font used, such as clarity (blurry words: Rosner, Davis & Milliken, 2015), color saturation (e.g., 15% and 25% grey scale: Seufert, Wagner, & Westpal, 2017), size (e.g., 5 point font: Halamish, 2018), and typeface (e.g., Diemand-Yauman, Oppenheimer, & Vaughan, 2011). Other manipulations include making what would otherwise be a fluent font (standard size, color, typeface) harder to read (e.g., inverted words: Sungkhasettee, Friedman & Castel, 2011) or harder to process (e.g., perceptual interference using backward-masked words: Besken & Mulligan, 2013).

However, research in this area remains controversial due to mixed findings across studies – whether perceptual disfluency can (reliably) improve educational outcomes is still debated. Recent meta-analyses are discouraging. Xie, Zhou, & Liu (2018) gathered 25 empirical articles (totaling 3,135 participants) that used text-based learning, manipulated font-related attributes (i.e., font type, size, grayscale, bolding) of visual texts or audio-related attributes of spoken texts, measured recall performance after learning, and compared a group with disfluent material to one with fluent material. They found no effect of perceptual disfluency on recall ($d =$

-0.01) or transfer ($d=0.03$) and no evidence of moderators (participant characteristics, learning material, experimental design) for an effect. However, their meta-analysis is under some recent scrutiny - Weissgerber, Brunmair, & Rummel (2021) find combining covariate-corrected results and uncorrected results in moderator analyses problematic and suggest obtaining raw values from primary studies. Another meta-analysis examined the effect of disfluent font on people's abilities to solve Cognitive Reflection Test (CRT) problems, where the most intuitive solution to problems is incorrect and deeper processing is needed to reach the correct solution. For example, given the problem: "A bat and a ball cost \$1.10 in total. The bat costs \$1.00 more than the ball. How much does the ball cost?", one may automatically subtract the two costs and say the ball costs 10 cents, which is incorrect. Meyer et al. (2015) pooled data from the original study that found a disfluency effect on CRT problems (Alter, Oppenheimer, Epley, & Eyre, 2007: black 12-point font vs. 10% gray italicized 10-point font) and 16 conceptual replications (a range of different manipulations: grey-scale, teal-colored, italicizing, font sizes, disfluent typefaces like *Mistral*, *Haettenschweiler*, **Impact**, *Carlz MT*), but found no evidence of an effect. Furthermore, Sirota, Theodoropoulou, and Juanchich (2020) updated the meta-analysis from Meyer et al. (2015) with their experiment, which took into account participants' numeracy skills, and found no evidence of a disfluency effect either.

Researchers have proposed different explanations for the mixed findings in the literature. Some (e.g., Halamish, 2018; Weissgerber & Reinhard, 2017) blame null effects on a mismatch between the encoding processes evoked during learning and the retrieval processes required for the test and stress the importance of transfer-appropriate processing. Others (e.g., Geller et al., 2018) attribute the differences in results to the type of experimental manipulation – those that evoke increased top-down, higher-level processing (e.g., inverted words: Sungkhasettee, et al.,

2011) find significant results but not low-level processing (e.g., blurry words: Rosner, Davis & Milliken, 2015). Specially for studies using words, Eskenazi and Nix (2020) believe that blurring causes readers to focus too much on the visual aspects of the stimuli, preventing them from engaging in deeper processing to encode orthography, phonology, and semantics (Hirshman, Trembath & Mulligan, 1994).

What makes Sans Forgetica (SF) special

Typefaces used in previous studies include: **Haettenschweiler** (Diemand-Yauman et al., 2011, Experiment 2; grey scale: Eitel, Kuhl, Scheiter, & Gerjets, 2014; Lehmann, Goussios, & Seufert, 2016), *Monotype Corsiva* (Diemand-Yauman et al., 2011, Experiment 2; French et al., 2013; Experiment 1; Seufert et al., 2017, Experiment 2), *Brush Script* (Eitel & Kuhl, 2016, Experiment 1), *Mistral* (Pieger, Mengelkamp, & Bannert, 2016), and **Comic Sans** (grey scale: Rummer, Schweppe, & Schwede, 2016). See Weisserber & Reinhard (2017) for a detailed table of manipulations and effects from recent literature. SF stands out in many regards.

SF was specifically designed with the concept of desirable difficulty in mind. The team of psychology and design researchers at RMIT University created this new typeface, characterized by fragmented letters and digits (see *Figure 1* for examples), to produce an optimal level of disfluency (Telford, 2018). One of the team's researchers explained that SF works because people have an automatic tendency to complete the broken font and this "slows down the process of reading inside your brain. And then it can actually trigger memory" (Simon, 2018).

Due to its specific visual/perceptual characteristics, **Sans Forgetica** brings the ultimate test of disfluent font as a desirable difficulty in a way that previously studied typefaces (**Haettenschweiler**, *Monotype Corsiva*, *Brush Script*, *Mistral*) cannot. These other typefaces create

1 perceptual disfluency through being an unfamiliar reading font or making individual letters hard
2 to parse out (either through narrow spacing or conjoined lettering as in cursive typefaces). While
3 SF still encompasses some of these characteristics, it also uses fragmented letters, where the
4 same slashes of omission are used for the same letter but there is no regular pattern of which part
5 of a letter is missing. SF's letters are also back-slanted while letters are front-slanted in
6 italicizations and in most disfluent typefaces.

7 From the perspective of visual perception, these other typefaces produce a full signal for
8 unfamiliar instances of known objects, whereas SF produces a noisy signal for (unfamiliar
9 instances of) known objects. Due to this noisy signal, readers would need to rely on their
10 perceptual systems to fill in the "gaps". However, because of how SF is designed, readers cannot
11 easily use perceptual grouping to recognize a letter. According to the Gestalt law of good
12 continuation, if a straight line has a gap in the middle, the line is still perceived as a single line,
13 but "good continuation" only works if the straight line is vertical or horizontal. If the line is
14 oblique/slanted, then the two pieces of the line are perceived to be parallel with each other
15 instead, namely, the Poggendorff illusion (Zöllner, 1860). Since SF uses back-slanted letters,
16 vertical strokes in letters are tilted and the perceptual continuation weakened. The gaps, sharing
17 the same color as the background, make perceptual completion more difficult. When an object is
18 occluding another object, we do not perceive the object underneath as being two separate objects.
19 We perceive the two "fragmented" pieces to be one object and are able to perceive the missing
20 contours of the object underneath (Kanizsa, 1979). Let's say we have a gray capital letter B that
21 is partially occluded by a white bar on a black background. The B can still be easily recognized,
22 but if that black background was changed to white to match the occlusion, the resulting visual
23 being how SF appears, completion becomes more difficult (Bregman, 1981). And without the

perceived occlusion, completion becomes impossible. Recognizing the letter B may then rely on context clues, which engages higher-level processing.

These are the many ways that SF produces perceptual disfluency. In comparison to the manipulations of perceptual disfluency in previous literature, it can be argued that SF utilizes perceptual degradation, perceptual distortion, and perceptual interference. As an added bonus, due to its novelty and impracticality of public use (e.g., powerpoint presentations, posters), it is safe to assume that many participants would not have encountered the font before, maximizing the produced perceptual disfluency.

Existing Research on SF

To our knowledge, there has only been five studies that investigated whether SF can be a desirable difficulty. We have split them into three categories based on stimuli: words, word-pairs, and sentences or passages and provided details for each study below.

Words. SF seems to benefit recognition of studied words (in certain cases) but not the recall of them. Geller, Davis, and Peterson (2020; Experiment 3) used an old-new recognition test and found that participants had greater sensitivity (d') to words (single-word nouns) studied (self-paced) and tested in SF than words studied and tested in Arial. Geller and Peterson (preprint; Experiment 1) replicated this finding but found that the SF effect existed only when participants were not told about a memory test and disappeared when participants knew about the test. As for recall of studied words, Casumbal, Chan, de Guzman, Fernandez, Ng, & So (preprint) had participants study 15 words (printed in SF or Arial) from flashcards for 30 seconds while listening to low-fidelity (lo-fi) music (or soft music typically used to relax or study) with or without lyrics, or no background music. While they found a main effect of music, SF did not benefit recall of studied words.

1 The above studies used high frequency (familiar) words for stimuli, but what about learning
2 new words (what students want to improve)? Eskenazi and Nix (2020) investigated whether SF
3 improves the lexical acquisition process during word learning. Participants read sentences that
4 contained very low frequency words, in either SF or Courier font. They then completed (A) a test
5 on those words (orthographic acquisition: multiple-choice spelling test, semantic acquisition:
6 free-response vocabulary test) and (B) a spelling skills test (spelling recognition and spelling-to-
7 dictation task). There was a SF effect for high-skill spellers (positive z scores) but not for low-
8 skill spellers (negative z scores). Eye-tracking data showed that high-skill spellers spent more
9 time processing words in SF, but low-skill spellers spent the same for both fonts.

10 **Word-pairs.** There are mixed findings as to whether SF improves memory for word-pairs:
11 worse performance (Taylor, Sanson, Burnell, Wade & Garry, 2020), equivalent performance
12 (Geller et al., 2020), and better performance (Geller & Peterson, preprint) compared to Arial.
13 Taylor et al. (2020; Experiment 2) modeled their experiment after the SF team's methods
14 (materials, exposure time, test format) using details from a published interview with Teacher
15 Magazine and personal communication with the team (J. Blijlevens, 12 December, 2018; Earp,
16 2018). Participants studied (highly associated) word-pairs for 100 ms each, half in SF and half in
17 Arial. Using half of the word-pair as a cue (in Times New Roman) for recall, participants
18 recalled fewer word-pairs that they studied in SF than in Arial, and the same disadvantage was
19 found for different lengths of delay between exposure and test: 10 s, 20 s, and 30 s. Because
20 weakly related word-pairs may produce more elaborative processing than highly related word-
21 pairs (e.g., Carpenter, 2009), Geller et al. (2020; Experiment 1) decided to use the former. They
22 found that the use of SF, for one half of weakly related word-pairs, i.e., (word in Arial)-(word in
23 SF) that were studied for 5 seconds each, did not improve cued-recall (expected test) over that of

word-pairs printed completely in Arial. Geller and Peterson (preprint) revisited highly associated word-pairs but thought the exposure time in Taylor et al. (2020) was too short and used self-paced trials instead in their Experiment 2. Participants studied (highly associated) word-pairs in Arial and SF at their own pace, completed a cued-recall test where the cues were presented in a different font: Open Sans (debatably identical to Arial besides greater spacing between letters), and accurately recalled more words studied in SF than in Arial.

Sentences or Passages. Multiple studies failed to find a benefit of SF on memory for read information. Taylor et al. (2020; Experiment 3) had participants read passages where one of the four paragraphs was printed entirely in SF with the remainder in Arial and complete a (fact-based) multiple-choice test on the information they read – one question per paragraph. They performed equally well on questions based on information read in SF as questions on information read in Arial. There was no benefit of SF on memory even when SF was used sparingly. Geller et al. (2020; Experiment 2) had participants read a passage with select sentences printed in SF or highlighted in yellow. The participants were then cued to recall a missing word from each of the previously mentioned sentences where the rest of the sentence was provided verbatim. While cued recall was better for sentences read with pre-highlighting than without it, there was no difference between sentences read in SF and those read in the passage's regular font.

SF also did not benefit conceptual understanding. Taylor et al. (2020; Experiment 4) had participants read passages (some paragraphs in SF and the rest in Arial) and answered conceptual questions, defined as those that require integrating information across different sentences in order to be correct, in free-response form. Two raters scored written responses to be incorrect (0 points), partially correct (1 point), or correct (2 points) with an 86% interrater reliability.

1 Performance in the SF and Arial conditions was deemed equivalent using an equivalent-testing
2 approach (Lakens, 2017).

3 **Present study**

4 In the present study, we surveyed a range of cognition (recognition of studied words, recall of
5 studied numbers, analytical thinking) to narrow down where the use of SF may be beneficial.

6 The present study contributes to existing literature on SF by expanding on research on memory
7 for words and adding two novel domains: recall of numbers and analytical thinking. Arial was
8 used as a control font because of its common usage in everyday life and in studies from this
9 research area. In Experiment 1A, using the principle of transfer-appropriate processing, we had
10 participants study and test in the same font and compared word recognition between using Arial
11 and SF. In Experiment 1B, we varied the font (Arial vs. SF) used for the study phase and test
12 phase in a within-subjects design. In Experiment 2, we compared the recall of math facts that
13 were studied in either Arial or SF and in addition, introduced another type of desirable difficulty
14 (generating an estimate instead of just studying the answer) as a second variable. In Experiment
15 3, we compared participants' performance on a Cognitive Reflection Test when problems were
16 displayed in Arial and SF. Specific research questions and hypotheses are discussed in each
17 experiment's corresponding section.

18

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z
a b c d e f g h i j k l m n o p q r s t u v w x y z

1 2 3 4 5 6 7 8 9

How difficult was it for you to read this sentence?

bureau

avenue

Figure 1. Sample of SF typeface. (SF is licensed under the Creative Commons Attribution-NonCommercial License (CC BY-NC; <https://creativecommons.org/licenses/by-nc/3.0/>)

Experiment 1A: Memory for words using transfer-appropriate processing

To assess improved memory, recognition was chosen over word recall for two main reasons: (1) the experimental set up would be analogous to vision experiments and allows for the interpretation of selectivity indexes and (2) some disfluency effects are found in recognition but not recall. It has even been proposed that recall tests are simply not sensitive to beneficial effects of small font size (Halamish, 2018). In addition, many manipulations of disfluent font are done through perceptual degradation (e.g., 10% grey-toned text: Seufert et al., 2017; blurry words: Rosner et al., 2015), perceptual distortion (e.g., inverted words: Sungkhasettee et al., 2011), and perceptual interference (e.g., backward-masked words: Besken & Mulligan, 2013). There exists extensive research showing that perceptual degradation and perceptual interference benefit recognition more than recall (Hirshman & Mulligan, 1991; Mulligan, 1996; Narine, 1988, Rosner et al., 2015).

The transfer-appropriate (TAP) framework has been used to explain when difficulties are desirable (McDaniel & Butler, 2010) and why some studies have not found a disfluency effect -

1 the type of processing used during learning is incompatible with the type of retrieval required at
2 test (Halamish, 2018; Weissgerber & Reinhard, 2017). For example, a generation task that
3 required participants to complete word fragments within text improved verbatim recall because
4 the task required processing the word cue and word surroundings in order to identify the missing
5 word fragment, but this task did not improve performance on relational test questions (McDaniel,
6 Hines, Waddill, & Einstein, 1994).

7 With the above in mind, we first tackled the question of whether SF can improve
8 recognition of studied words by applying the principle of transfer-appropriate processing to
9 maximize our chances of detecting an effect. Since we are simply presenting words to
10 participants (with no additional task), we tested their memory by presenting those words and
11 administering an old-new recognition test. Words were presented briefly (one second) to prevent
12 a ceiling effect and because brief presentations of words have been shown to improve
13 recognition due to participants' need to fill in details of what they may have missed during the
14 brief presentation (what Nairn (1988) considered a generation effect). Because we perceived SF
15 to be more perceptual degradation than small font size, we had presentation a little longer than
16 Halamish (2018), which used 0.5 second.

17 SF may illicit deeper processing of words at study and greater consideration of "oldness"
18 at test, thereby increasing performance on a recognition test, compared to the automatic
19 processing of words presented in legible and familiar font. The fragmented letters in SF may
20 make word recognition more effortful, either by increasing the amount of processing at the letter
21 level or increasing the number of attempts until the word is read correctly. The increased
22 attention to letters (e.g., identifying (ambiguous) letters one-by-one) and the activation of more
23 vocabulary in order to correctly identify the word may create additional memory traces for the

1 studied word that can be used later on the recognition test. The more effortful (and slow) reading
2 of words in SF may translate into more careful consideration of “oldness” at test since reading
3 words is less automatic than with familiar, legible fonts.

4 Alternatively, SF may hurt performance on a recognition test - the brief presentation may
5 not be enough time for word recognition or extraction of enough features for regenerating words.
6 Consequently, participants may need to depend on memory for the visual image of the word,
7 which would be less reliable than memory for the actual word. Likewise, SF may have high
8 working memory demands – the “defragmentation” of letters may be similar to the descrambling
9 of words in Weissgerber & Reinhard (2017), who believed that descrambling words requires
10 retrieval of many words from long term memory and keeping those words active in working
11 memory while trying to identify the intended word. While “defragmented” letters may have less
12 and different working memory demands (e.g., inhibiting the initially-read-but-incorrect letter,
13 like reading h instead of b in bureau shown in *Figure 1*, and holding the correct letter, b, in
14 working memory), reading words in SF introduces additional demands over reading words in
15 Arial. The word could be misread the first time and need to be reread for the correct word
16 recognition. Nonetheless, the discussion of working memory demands is nontrivial - in some
17 cases, the disfluency effect can only be found for participants with high working memory
18 capacities (Lehman et al., 2016).

19 **Methods**

20 **Participants.** Sixty-six undergraduates from the University of California, Los Angeles
21 (UCLA) participated.

22 **Materials.** The stimuli for this experiment consisted of 120 words generated from the
23 English Lexicon Project database (<http://ellexicon.wustl.edu>). While the chosen words could be

nouns, adjectives and/or verbs depending on context (e.g., “red” is a noun and adjective, “work” is a noun and verb), they all have noun as their primary part of speech. Words were 4 to 6 letters long and had 1 to 3 syllables. Their appearance frequency was between 42 and 50.

Procedure. Participants were told to remember the presented words. The experiment consisted of three blocks. In each block, participants studied 10 words in SF and 10 words in Arial, presented in random order for 1 second each, and then completed an old-new recognition task that consisted of 40 words: the 20 studied words in their studied fonts plus 10 new words presented in SF and 10 new words in Arial, presented one at a time. Participants had unlimited time to identify the test word as ‘having seen it before’ or ‘not having seen it’. Participants completed the next block with a new set of study words and a new set of test words, with their fonts assigned randomly but evenly.

Results

Performance was assessed via true positive rate, or proportion of studied words correctly recognized as ‘old’ or studied; and the sensitivity index (d'), which takes into account false positive rates. A paired-samples t-test on d' s revealed no difference between SF condition ($M = 2.32, SD = 0.66$) and Arial ($M = 2.26, SD = 0.77$), $t(65) = 0.71, p = .48$.

A paired-samples t-test on true positive rates revealed a just-barely significant difference between SF and Arial, $t(65) = 2.01, p = .048$, Cohen’s $d = 0.23$. Participants had a higher true positive rate with SF ($M = 0.78, SD = 0.12$) than with Arial ($M = 0.75, SD = 0.14$). A significant difference in true positive rates but no difference in d' s suggests that there may be a (greater) response bias in one condition over the other. We assessed response bias by computing the decision criterion: $C = -[Z(\text{true positive rate}) + Z(\text{false positive rate})]/2$, where Z representing Z transformation. A negative C value means that the participant had a liberal decision criterion

1 whereas a positive C value means a conservative decision criterion, with zero representing no
2 bias. A paired-samples t -test on C values revealed a marginally significant difference between
3 the two font conditions, $t(65) = 1.94, p = .057$, Cohen's $d = 0.23$. Participants had a more liberal
4 criterion with SF ($M = -0.44, SD = 0.09$) than with Arial ($M = -0.42, SD = 0.08$). This analysis
5 reveals that participants had a higher true positive rate for SF because they were more biased
6 towards identifying test words as 'old' or 'studied'. See *Figure 2*.

7 Participants' stronger bias to identify words printed in SF as "old" could be a result of
8 either misremembering a studied word (or having a false memory of another word) or being
9 uncertain whether the word was studied but leaning enough towards "old" to select it. It is
10 possible that more words were activated in working memory during the studying of words
11 printed in SF (either words that were lexically or semantically similar or words that the
12 participant "regenerated" in attempts to read the presented word) and these activated words
13 formed a false memory of having studied said words. Participants may have had a more liberal
14 criterion for SF because of the perceived disfluency – participants believe their memory for
15 studied words is weaker and compensate (for anticipated weaker performance) by saying a word
16 was studied when unsure. Whatever the reason may be, SF seems unideal in situations where
17 false positives matter, like standardized tests that have guessing penalties – losing points for
18 wrong answers instead of just not receiving points, but debatably better in situations where only
19 true positives matter.

20 **Experiment 1B: Memory for words when varying study and test fonts**

21 While Experiment 1A controlled for many variables by keeping study font and test font constant,
22 this set up is not realistic and cannot be applied to students' academics – exams are usually
23 printed in standard legible fonts like Arial. To mitigate this issue, in Experiment 1B, we

1 investigated whether SF could benefit encoding and/or retrieval by varying the font used in the
2 study phase (encoding) and the font used in the test phase (retrieval). The resulting design was a
3 2 (study font: Arial vs. SF) x 2 (test font: Arial vs. SF) within-subjects design. Here, the most
4 realistic condition is studying in SF and testing in Arial.

5 The desirable difficulty argument for disfluent font emphasizes deeper and more
6 elaborate processing, or the encoding stage. Typically, disfluent font is manipulated during the
7 encoding stage and a legible font is used for testing. We expected a main effect of study font,
8 such that studying words in SF would lead to better performance on a recognition test regardless
9 of which font was used for the test. We were not anticipating test font to make a significant
10 difference in recognition test performance because we did not have reason to believe that the font
11 of the test words would differentially help participants retrieve studied words.

12 While there are many possible patterns of interaction, one possible pattern of interaction
13 is finding an advantage of testing in a different font than the font used to study. One may
14 naturally ask about match (when study font and test font match) and mismatch conditions, which
15 we analyzed as a secondary research question. There are arguments for either match conditions
16 or mismatch conditions doing better. While the principle of transfer-appropriate processing may
17 suggest that match conditions would outperform mismatch conditions, the change in font in
18 mismatch conditions may help participants make old-new decisions during the recognition test –
19 seeing words studied in Arial tested in SF may promote more careful consideration of “oldness”
20 and seeing words studied in SF tested in Arial may alleviate some working memory demands of
21 reading SF.

22 **Methods**

23 **Participants.** Fifty-eight UCLA undergraduates participated.

1 **Materials.** Words used here were from the same database as Experiment 1A.

2 **Procedure.** Participants were told to remember the presented words. The experiment
3 consisted of two blocks: (1) study in the two fonts (SF, Arial) and test in SF, and (2) study in two
4 fonts and test in Arial, the order of which was counterbalanced. For each block, participants first
5 studied 30 words, 15 of which were randomly assigned to be displayed in SF and the other 15 in
6 Arial. Each word was presented for 1 second and one at a time. After the study phase,
7 participants completed an old-new recognition task. This test consisted of 60 words: 30 studied
8 words and 30 new words, all displayed in one font (SF or Arial). The test items were presented
9 one at a time, in a random order, with no time limit for a response. Participants completed the
10 next block with a new set of words, with the test font different than that of the first block.

11 **Results**

12 Performance was similarly assessed via true positive rate, and the sensitivity index (d').

13 **Correct identifications.** We conducted a 2 (study fonts) $\times$ 2 (test fonts) repeated-
14 measures ANOVA on participants' true positive rates. Participants made more correct
15 recognitions of words studied in Arial ($M = 0.79$, $SD = 0.13$) than words studied in SF ($M =$
16 0.77 , $SD = 0.13$), but this difference was not significant, $F(1, 57) = 1.22$, $p = .27$. Whether test
17 words were displayed in SF ($M = 0.78$, $SD = 0.12$) or Arial ($M = 0.78$, $SD = 0.14$) made no
18 difference, $F(1, 57) = .001$, $p = .97$. There was also no interaction, $F(1, 57) = 0.84$, $p = .36$.

19 **Sensitivity index.** D' was calculated separately for the two independent variables: study
20 font and test font. D' of study font would be $Z(H \text{ of words studied in Arial from both blocks}) -$
21 $Z(F \text{ of words studied in Arial from both blocks})$. A concern for the d' calculation is false positive
22 rates of zero. Among the 58 total participants, 15 had zero false positives when the test font was
23 SF. Six of the 15 also had zero false positives when the test font was Arial. We used a typical

correction method for zero false positives (Wickens, 2002) and adjusted the false positive rate to be $1/(2n)$, where $n = 30$ was the number of signal trials in that block. After these corrections, we calculated d 's for each study font and each test font.

While a paired-samples t -test of d 's for study font showed no difference (SF: $M = 2.23$, $SD = 0.88$, Arial: $M = 2.29$, $SD = 0.91$), $t(54) = 1.28$, $p = .21$; a paired-samples t -test of d 's for test font revealed a significant difference, $t(57) = 2.42$, $p = .02$. Participants had significantly higher d ' when studied words were tested in SF ($M = 2.71$, $SD = 1.35$) than when studied words were tested in Arial ($M = 2.31$, $SD = 1.04$; see *Figure 2*). Degrees of freedom differ because three participants had infinity as d 's for study font – a result of (close to) perfect true positive rates and close to zero (after correction) false positive rates. However, the statistical significance persisted even after these three participants were excluded, $t(54) = 2.21$, $p = .032$. Nevertheless, the effect size with and without the three participants removed from analysis was weak (Cohen's $d = 0.32$ - 0.33).

Finding a main effect of test font but not study font suggests that SF does not necessarily strengthen the encoding of studied words but possibly supports successful retrieval. This result further supports that SF changes the nature of one's consideration of whether tested words were previously studied, much like in Experiment 1A. No difference in true positive rates and a greater d ' for SF as a test font suggests that bias was no longer an issue in Experiment 1B. The variation of test font with respect to study font may have led participants to be more conservative in their judgments of whether a tested word was previously studied, perhaps because the font of the tested words could no longer serve as a cue for recognition.

Match-Mismatch comparisons. We collapsed conditions to form match (study and test font match) and mismatch groups. There was no difference between match conditions ($M = 0.79$,

$SD = 0.16$) and mismatch conditions ($M = 0.77$, $SD = 0.15$) on true positive rate, $t(115) = 0.89$, $p = .37$, or on d' (match: $M = 2.72$, $SD = 1.48$; mismatch: $M = 2.57$, $SD = 1.36$; $t(115) = 1.49$, $p = .14$). We also made comparisons within match conditions (i.e., study Arial test Arial vs. study SF test SF) and within mismatch conditions. D' for studying in Arial and testing in SF ($M = 2.79$, $SD = 1.52$) was higher than for studying in SF and testing in Arial ($M = 2.36$, $SD = 1.15$), $t(57) = 2.09$, $p = .04$. This difference supports our interpretation of the main effect of test font – SF supports careful consideration of old-new. All other comparisons for true positive rate and d' were not significant, $t(57)s < .94$, $ps > .35$. SF could be recommended for testing, especially in cases where study font and test font would differ. While impractical for administering exams, SF could be used as a study tool coupled with the benefits of testing effects – students could study in a fluent font and test/retest themselves in SF.

Figure 2. Key findings from Experiment 1.

Experiment 2: Recall of numbers or math facts

To our knowledge, the effect of disfluent font on memory for numbers or math facts has not been studied. Existing studies in the math domain (See meta-analyses: Meyer et al., 2015; Sirota et al., 2020) include solving “math problems”, which were questions from the Cognitive Reflection Test. Memory for numbers or math facts, however, is very practical for everyday situations and educational settings. Experiment 2 serves to fill the gap in the literature.

We chose decimal equivalents of square roots to be our to-be-learned material. These math facts (e.g., square root of 2 = 1.41) make good stimuli because they keep the range of answers small and manageable (as compared to, say, learning answers to squares) and are rarely known by students. We decided upon two different tasks for participants to do: studying the math fact and estimating/generating the answer to those math facts. This introduces a known desirable difficulty: the generation effect (Hirshman & Bjork, 1988; Slamecka & Graf, 1978). Geller, et al. (2020, Experiment 1) did something similar but for word-pairs, comparing SF to Arial, and comparing completed word-pairs to those with missing letters in the second word. Our study is a complete factorial design with font and task (study vs. generate) as within-subjects factors. We chose a recall test instead of a recognition test because the former adheres to the principle of transfer-appropriate processing by making the generation task and task at test similar. We also added legibility ratings that were not present in Experiment 1A/B.

Foremost, we expected a generation effect, such that learning the math facts through generate trials leads to better recall than study trials. Estimating the answer to the square roots requires participants to think more deeply about the magnitudes and develop more context (e.g., neighboring numbers) for the correct answer. The effect of SF on the study and generate conditions is more unpredictable. Some research has shown that working memory capacity plays a role in whether the disfluency effect is found or not (Lehmann et al., 2016). SF may demand more working memory resources, both in the study and generate conditions. If the numbers presented in SF are not immediately recognizable, participants may need to store the numbers (problem and answer) they decoded in working memory while trying to store the fact in long term memory. For generate trials, participants need generate and study. Just the generating task

itself demands more working memory, but participants still need to do the same “studying” as the study trials, just with less time, since time on study trials and generate trials was equated.

Methods

Participants. Eighty-one undergraduates from UCLA participated.

Design. The experiment has a 2 (font: Arial vs. SF) x 2 (trial type: study vs. generate) within-subjects factorial design. Participants learned the answers to square roots of whole numbers from 2 to 46 up to two decimal places, for a total of 40 items after removing perfect squares (e.g., 4, 9).

For the “study” trials, participants studied the square root fact (e.g., “sqrt of 2 = 1.41”). For the “generate” trials, participants generated (estimated) an answer to the square root problem, before the correct answer was given to study from. Besides using perfect squares to determine the range of whole numbers (e.g., between 4 and 5 for the sqrt of 20) the answer falls in, participants needed to rely on memorization because the last digit of the answer cannot be quickly determined by a simple multiplication or division. Essentially, the participants just needed to memorize 2 of the 3 displayed digits in the answer.

Materials.

Demo. Participants were then given one practice trial for each font and trial type combination. Participants studied the answer to $\sqrt{50}$ in Arial and the answer to $\sqrt{70}$ in SF. Participants then estimated and studied the answer to $\sqrt{60}$ in Arial and $\sqrt{90}$ in SF. Time durations for “study trials” and the estimate and study portions of “generate” trials were the same as the ones used in the learning phase. Participants reviewed the perfect-squares facts needed to make appropriate estimates for the learning phase via a recall test. Since the to-be-learned square

1 roots range from 2 to 46, participants were tested on the square roots of 4, 9, 16, 25, 36, and 49.
2 They had 2 seconds to respond and 0.5 seconds to review the correct answer.

3 ***Learning Phase.*** The range of square roots (2 – 46) were split into two lists: lower range
4 (2 – 24) and upper range (26 – 46). For each participant, the lists were randomly assigned to be
5 displayed in either Arial or SF. For each list, square roots were randomly assigned to be either a
6 “study” trial, during which the square root fact (e.g., “Study: sqrt of 2 = 1.41”) was displayed on
7 the screen for 13 seconds; or a “generate” trial, during which participants were prompted to
8 estimate the answer to the square root shown (e.g., “Estimate: sqrt of 3 = ”) within 8 seconds and
9 immediately after response entry, were shown the correct answer (e.g., “Study: sqrt of 3 = 1.73”) for 5 seconds, such that there is an equal number of “study” trials and “generate” trials for each
10 list. Participants completed the whole learning set before the set was repeated two more times.

11 ***Distractor Task.*** In between learning and testing, participants completed a distractor
12 task, where they answered word problems. The problem set consisted of all three of the original
13 cognitive reflection test (CRT) questions (Frederick, 2005), and three problems from the
14 alternate CRT questions (CRT-2, Thomson & Oppenheimer, 2016) (see Appendix A for exact
15 problems). Problems were randomly assigned to be displayed in Arial or SF, in equal proportion.
16 Participants had 20 seconds to type their answers onto the computer screen. These answers were
17 analyzed as part of the next experiment (Experiment 3).

18 ***Testing Phase.*** Participants were tested on the answers to the learned square root
19 problems in Arial. They were informed that they would have 20 seconds to give their responses.
20 For each trial, participants were prompted to give a response (e.g., “Recall: sqrt of 2 = ”) and
21 were not given feedback.
22

1 **Survey.** Participants were asked to report their age and gender, and to answer questions
2 about their attitudes towards numbers and prior knowledge and strategy used. Participants rated
3 the legibility of the SF typeface by answering “How difficult was this font to read?” with an
4 example of the typeface displayed underneath, on a 5-point Likert scale from 1-‘a little bit’ to 5-
5 ‘a lot’. They rated the confusability between numbers printed in the SF typeface on a 5-point
6 Likert scale from 1-‘a little bit’ to 5-‘a lot’. They then reported the numbers that they got
7 confused.

8 **Procedure.** Participants completed the experiment on a computer. At the beginning of
9 the experiment, participants were informed that they would be learning the answers, up to two
10 decimal places, for square roots. The two trial types were explained to them. They were
11 instructed to study the answer to the full square root fact for “study” trials. They were instructed
12 to give their best estimate of the answer, up to two decimal places, for the “generate” trials, to
13 study the answer when it is on the screen, to refrain from doing exact mental math (i.e., long
14 division), and to not worry about whether their estimate is far off from the correct answer. They
15 were informed of the time limit for estimates (8 seconds). Participants were also provided tips for
16 making estimates: they can rely on memorized answers to square roots to provide a range for
17 estimates (e.g., $\sqrt{55}$ would be between 7 and 8) and use how far away the number in a square
18 root is from a perfect square to gauge estimates (e.g., $\sqrt{50}$ would be slightly bigger than 7 and
19 $\sqrt{63}$ would be slightly smaller than 8). After reading these instructions, participants completed
20 the demo, learning phase, distractor task, testing phase and survey.

21 **Results**

22 While we hoped participants learned and remembered the answers to square roots from the
23 learning phase, participants can still use perfect squares to guide their responses for the posttest.

For example, square root of 53 should be more than the square root of 49 (or 7) and less than square root of 64 (or 8). As in this example, a response of 6 or 9 would be really off and call into question the participant's compliance to the task. Therefore, we excluded participants who too frequently gave questionable responses, as follows. We considered (at least) one whole number away from the correct answer to be questionable and considered more than 10% of trials to be too frequent to be from a compliant participant. Using these criteria, two participants were excluded from our data analyses.

Performance. We measured performance using accuracy, absolute deviation and response time. Accuracy is the proportion of problems answered correctly. A response is considered correct if it matches the correct answer presented during the learning phase – same exact number up to two decimal places. Using accuracy to measure performance may be too strict, as just one decimal place off (e.g., submitting 1.24 instead of the correct 1.23) would make a response incorrect. We used *absolute deviation* to capture this nuance, defined as how far away the participants' response is from the correct answer, in either direction (i.e., unsigned value). We conducted a 2 (task: study vs. generate) x 2 (font: Arial vs. SF) repeated-measures ANOVA for each dependent variable. There were no significant main effects or interactions for any of our dependent variables. For numerical details, see Appendix A. Given that we did not find a generation effect, there are two possible explanations for the null effects: (a) the task was too difficult and thus, neither of the fonts or tasks provided an advantage/disadvantage for the learning task, or (b) participants were not motivated. Performance in general was poor. Accuracy was at about 12%, which is getting about 5 of the 40 test problems correct. Absolute deviation was at about 0.12, which is not terrible – they are on the correct side of the midpoint (e.g., for

1 $\sqrt{38}$, they are not guessing 6.5+) by a good amount. In other words, participants were giving
2 reasonable responses but did not remember exact answers.

3 **Subjective measures.** Legibility ratings for the SF were moderate ($M = 2.86$ out of 5, SD
4 $= 1.20$, *Median* = 3.00) and confusability ratings for the font were also moderate ($M = 2.52$ out
5 of 5, $SD = 1.07$, *Median* = 3.00). These numbers are reassuring – some researchers have
6 proposed that the ideal manipulation of disfluency is moderate disfluency (e.g., Seufert et al.,
7 2017) and that the effect of disfluency on performance tends to follow an inverted-u shape
8 relationship (e.g., Diemand-Yauman et al., 2011; Seufert et al., 2017). With these ratings, SF does
9 not appear to be too illegible or not enough disfluent from typical fonts. We looked through
10 participants responses to the question of which numbers they confused for each other. The
11 following were the most common responses: 2 vs. 3, 3 vs. 8, but some participants reported
12 confusing 1 with 7, 3 with 5, 3 with 6, 3 with 9, or 5 with 6. Only 22 (of 81) participants did not
13 list any numbers for that question.

14 **Experiment 3: Analytical thinking / problem solving**

15 The Cognitive Reflection Test (CRT; Frederick, 2005) consists of math word problems that have
16 tempting wrong answers and require careful reflection to reach the correct answer. Perceptual
17 disfluency was theorized to improve people's performance on this test. Alter et al. (2007) found
18 that participants who received the test in a disfluent font (10% gray italicized Myriad Web 10-
19 point font; $M = 2.45$ out of 3) outscored those who received it in a fluent font (black Myriad Web
20 12-point font; $M = 1.90$). The authors believed that the degraded font encouraged the activation
21 of system 2 (Kahneman, 2011) processes, which helped them overcome incorrect “gut” answers.
22 A meta-analysis of conceptual replications failed to find the same effect (Meyer et al., 2015).
23 These conceptual replications utilized a wide range of perceptual disfluency manipulations: grey-

scale, teal-colored, italicizing, small font sizes, disfluent typefaces like *Mistral*, **Haettenschweiler**, **Impact**, *Curly M*. SF can be argued to be fundamentally different from all of these manipulations – fragmented letters, novel font, etc. The perceptual disfluency it produces may encourage more higher-level (lexical) processing. This is relevant because getting these CRT problems correct requires special attention to the words and wording in the problems and seeing the correct relationships between items (e.g., ball vs. bat) in the problem.

Unlike Alter et al. (2007), our Experiment 3 had a within-subjects design. Since the original Cognitive Reflection Test (Frederick, 2005) only had three problems, we also added three alternate CRT questions (CRT-2, Thomson & Oppenheimer, 2016) into our question pool. That way participants can complete an equal number of problems displayed in each font. We hypothesized that participants would have higher solution rates for problems presented in SF than those presented in Arial, and also spend more time to reach their solutions for problems presented in SF.

Methods

Experiment 3 is the distractor task from Experiment 2.

Results

General performance on the CRT questions was poor. The most common accuracy score for either of the two fonts was zero. A small portion of trials (15.84% or 77 out of 486) received no response from the participant. Twenty-five of these trials were due to hitting the 20 second limit (set to ensure that the experiment can be completed during the allotted time). The remaining trials were cut short by the participant pressing ‘enter’ with no response. We do not know whether these were accidental or intentional. Of the 77 that did not receive a response, 28 of them (36.36%) were for CRT problems displayed in Arial and 49 of them (63.64%) for CRT

1 problems displayed in SF. If the trials were skipped on purpose, it could mean that participants
2 are more likely to give up on problems printed in SF than those printed in Arial. For these no-
3 response trials, we do not know at what stage of problem solving the participant was in – almost
4 got an answer, had an answer but was not able to type it out in time, etc. In light of these
5 limitations, we only included participants that responded to at least two out of three problems for
6 both fonts in our analyses. There were 71 participants that met this criterion. Missed trials were
7 dropped in the calculation of accuracy scores and average response time.

8 Solution rate is the proportion of correct responses from problems the participants
9 answered. Participants answered numerically more problems correctly when the problems were
10 displayed in Arial ($M = 0.33$, $SD = 0.31$) than those displayed in SF ($M = 0.31$, $SD = 0.34$). A
11 paired-samples t-test showed that this difference was not statistically significant, $t(70) = 0.49$, p
12 $= .63$.

13 Response time was analyzed in two ways: for all submitted responses and for correct
14 responses only. For all submitted responses, participants took more time, but without statistical
15 significance, to reach an answer for problems displayed in SF ($M = 12.39$ seconds, $SD = 3.10$)
16 than those displayed in Arial ($M = 11.69$, $SD = 2.78$; $t(70) = -1.52$, $p = .13$). We also investigated
17 whether participants arrived at the correct answer faster in one font than the other. To do this, we
18 only included participants that responded to at least two out of the three problem for both fonts
19 and gotten at least one problem correct for both fonts. Only 27 participants (out of 81) matched
20 these criteria. While participants on average took longer to respond correctly to problems
21 displayed in SF ($M = 12.44$ seconds, $SD = 3.57$) than in Arial ($M = 11.33$ seconds, $SD = 4.43$),
22 this difference was not statistically significant, $t(26) = -1.00$, $p = .33$.

General Discussion

SF serves as an ultimate test of disfluent font because it creates perceptual disfluency of a different nature than previous manipulations. While the existing studies in this area create perceptual disfluency by lowering the quality of text (e.g., using low contrast, small font) or by using hard-to-read typeface (e.g., those that make letters harder to recognize because of limited space or conjoined letters as with cursive), SF creates perceptual disfluency by fragmentizing letters in an irregular way (i.e., pieces that are missing are not the same across letters) and back-slanting those letters. These characteristics make it difficult for viewers to use Gestalt principles such as good continuation and perceptual completion to identify letters. Reading words, in turn, may depend more on context clues when letters are ambiguous individually.

Given the novelty of SF, there are few existing studies. Of those studies, there are mixed results on whether SF can benefit memory, understanding, or education. We sought to contribute to this growing literature by surveying various levels of cognition. We conducted three studies: Experiment 1: recognition of studied words (1A: study font and test font are the same; 1B: study font and test font vary), Experiment 2: recall of math facts, and Experiment 3: analytical thinking or problem solving. We expected SF to encourage higher-level lexical processing thereby improving recognition of studied words (Exp 1) and to encourage reconsideration of intuitive (but wrong) answers to Cognitive Reflection Test questions, leading to higher solution rates (Exp 3). However, we expected SF to interfere with the learning of math facts, especially in combination with generating estimates before studying answers, because of higher working memory demands, leading to worse recall performance (Exp 2).

Our results were unexpected. When the study font and test font of studied words matched (Exp 1A), participants had significantly higher true positive rates for SF than for Arial, but also

1 higher biases to identify words as “old”, suggesting uncertainty or overcompensation for it. Their
2 sensitivity indexes were equivalent. When study font and test font varied (Exp 1B), we found
3 that participants had higher sensitivity indexes when SF was used as the test font, regardless of
4 the study font. Taken together, the results suggest that SF changes the consideration of words at
5 test, but the direction of the effect may depend on set up – for example, our variation in Exp 1B
6 served as a protection against bias. For Experiments 2 and 3, unfortunately, we found null
7 results, which we attribute to the difficulty of the tasks and the potential existence of a floor
8 effect. For Experiment 2, we chose math facts to test for the recall of numbers because it would
9 make generate trials more meaningful and we hoped that it would make participants more aware
10 of where the number would be in respect to other numbers on a number line. An alternative
11 approach would be to have participants remember more arbitrary numbers (either alone) or in
12 association to a word or image. An example with ecological practicality could be remembering
13 the extension code (e.g., 806) for service words (e.g., “plumbing”), but participants would be
14 randomly guessing during generate trials (e.g., “plumbing: ???”). Given this simpler task, For
15 Experiment 3, almost two-thirds of the no-response trials came from problems printed in SF.
16 Although the exact reason is unclear, one explanation is that problems printed in SF were more
17 discouraging to participants. A possible future direction is to compare metacognitive judgments
18 of difficulty between problems printed in SF and those printed in a fluent font.

19 Future studies on SF as a potential desirable difficulty may benefit from a better
20 understanding of how people process SF. This understanding can help us understand or explain
21 the existence of or lack of an effect and better anticipate which domains SF may benefit.
22 Eskenazi and Nix (2020) was a good starting point – through eye-tracking data, they found that
23 participants skipped significantly more words when reading text printed in Courier (fluent font)

1 than text printed in SF and that total reading time for SF text was significantly longer only for
2 participants with high spelling skills. Their data debunks the common assumption that all people
3 read SF slower than a fluent font.

4 SF was developed to be a study tool, so to pay tribute to the designers' efforts and to
5 protect students from fruitless efforts in incorporating SF into their studying, it is still worthwhile
6 to identify domains where SF could be used as a study tool. Research in this area may benefit
7 from out-of-the-box thinking – not simply asking which domains SF is beneficial but how SF
8 can be used in those domains. Given our results from Experiment 1, perhaps an application can
9 be using the font to test ourselves after we have already studied the material in a fluent font,
10 almost like using SF as a cued recall. The possibilities could be endless and we should not limit
11 ourselves to what has been done with other disfluent typefaces.

12 13 **Declarations**

14 No funding was received for conducting this study. The authors have no conflicts of interest to
15 declare. The data is available at <https://osf.io/nb8ce/> and none of the experiments were
16 preregistered.

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Appendix A – Experiment 2 analyses

	Mean (Standard deviation)		Statistics
Accuracy			
Main effect of Task	Study: 0.12 (0.11)	Generate: 0.13 (0.10)	$F(1, 78) = 1.46$ $p = .23$
Main effect of Font	Arial: 0.12 (0.11)	Sans Forgetica: 0.12 (0.12)	$F(1, 78) = 0.002$ $p = .97$
Interaction			$F(1, 78) = 0.03$ $p = .86$
Absolute deviation			
Main effect of Task	Study: 0.11 (0.06)	Generate: 0.12 (0.07)	$F(1, 78) = 0.31$ $p = .580$
Main effect of Font	Arial: 0.12 (0.06)	Sans Forgetica: 0.11 (0.06)	$F(1, 78) = 0.30$ $p = .583$
Interaction			$F(1, 78) = 0.66$ $p = .42$
Response time (s)			
Main effect of Task	Study: 8.19 (2.33)	Generate: 8.19 (2.37)	$F(1, 78) < 0.01$ $p = .99$
Main effect of Font	Arial: 8.25 (2.25)	Sans Forgetica: 8.13 (2.49)	$F(1, 78) = 1.11$ $p = .30$
Interaction			$F(1, 78) = 0.70$ $p = .41$

Appendix B**Distractor Questions / Cognitive Reflection Test questions**

1. A bat and a ball cost \$1.10 in total. The bat costs \$1.00 more than the ball. How much does the ball cost? In cents
2. If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets? In minutes
3. In a lake there is a patch of lily pads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of the lake? In days
4. If you're running a race and you pass the person in second place, what place are you in?
5. A farmer had 15 sheep and all but 8 died. How many are left
6. How many cubic feet of dirt are there in a hole that is 3' deep x 3' wide x 3' long?