

Sans Forgetica Font Does Not Improve Cognitive Reflection Test Performance

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Abstract

Many studies have failed to replicate the disfluency effect (i.e. disfluent font better than fluent font) on Cognitive Reflection Test (CRT) performance shown in Alter et al. (2007). Those studies manipulated perceptual disfluency using color, style, size, and/or typefaces. The new Sans Forgetica (SF) typeface, designed to promote desirable difficulty, creates perceptual disfluency through fragmented letters, which make it difficult for readers to use good continuation and perceptual completion to identify letters. Here, we compare CRT performance and font legibility ratings when CRT problems are presented in SF or in Arial. After solving CRT problems, participants who solved the problems in SF rated Arial to be harder to read than participants who solved the problems in Arial, suggesting that after prolonged use of SF, participants viewed Arial as being closer in legibility to SF.

Keywords: disfluent font, perceptual disfluency, cognitive reflection test, numeracy

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). Disfluent font, if shown to be a desirable difficulty, would be an easily adaptable and ready educational solution. (e.g., Diemand-Yauman et al., 2011; Geller et al., 2018). With disfluent font, perceptual disfluency is manipulated through changing the characteristics of the font used, such as clarity (blurry words: Rosner et al., 2015), color saturation (e.g., 15% and 25% grey scale: Seufert et al., 2017), size (e.g., 5 point font: Halamish, 2018), and typeface (e.g., Diemand-Yauman et al., 2011), or making fluent fonts harder to read (e.g., inverted words: Sungkhasettee et al., 2011) or harder to process (e.g., perceptual interference using backward-masked words: Besken & Mulligan, 2013).

Due to mixed findings across studies, whether perceptual disfluency can (reliably) improve educational outcomes is still debated. Recent meta-analyses are discouraging. Xie et al. (2018) gathered 25 empirical articles (totaling 3,135 participants), that measured recall and had a fluent font comparison group and found no effect of perceptual disfluency on recall ($d = -0.01$). Some researchers (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 et al., 2015). Especially 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 et al., 1994).

What Makes SF Special

Typefaces used in previous studies include: Haettenschweiler (Diemand-Yauman et al., 2011, Experiment 2; grey scale: Eitel et al., 2014; Lehmann et al., 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 et al., 2016), and Comic Sans (grey scale: Rummer et al., 2016). See Weisserber & Reinhard (2017) for a detailed table of manipulations and effects from recent literature.

SF was specifically designed with the concept of desirable difficulties in mind. The design team at RMIT University created this typeface, characterized by fragmented letters and digits (see Figure 1 for examples), to produce an optimal level of disfluency (Telford, 2018). One of the 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).

A B C D E F G H I J K L M N
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
o p q r s t u v w x y z
1 2 3 4 5 6 7 8 9 0

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

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 perceptual disfluency through being an unfamiliar reading font or making individual letters hard to parse out (either through narrow spacing or conjoined lettering as in cursive typefaces). In addition, SF uses fragmented letters, where the same slashes of omission are used for the same letter but there is no regular pattern across letters. Also, SF's letters are back-slanted while letters are front-slanted in italicizations and in most disfluent typefaces.

From the perspective of visual perception, these other typefaces produce a full signal for unfamiliar instances of known objects, whereas SF produces an impoverished signal for (unfamiliar instances of) known objects. Due to this impoverished signal, readers would need to rely on their perceptual systems to fill in the "gaps." However, due to how SF is designed, readers cannot easily use perceptual grouping to recognize a letter. For example, SF uses a gap to break up a segment in a letter. Much like Bregman's B's (Bregman, 1981) when letter B's are fragmented by gaps that disable recognition, such SF design makes it harder to recognize a letter. In addition, SF often makes oblique a vertical segment that, when a gap breaks it up into two pieces, would be perceived as parallel rather than colinear due to the Poggendorff illusion (Zöllner, 1860). This makes it harder for the two pieces to be perceptually completed into a single segment.

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. Additionally, due to its novelty and impracticality of public use (e.g., presentations, posters), many participants would not have encountered the font before, maximizing the produced perceptual disfluency.

Existing Research on SF

To our knowledge, there have only been five studies that investigated whether SF can be a desirable difficulty. SF seems to benefit recognition (greater sensitivity d') of studied words (Geller & Peterson, preprint: Experiment 1 – with no test expectancy) but not the recall of them (Casumbal et al., preprint). Eskenazi and Nix (2020) found that with learning new words, there was a SF effect for high-skill spellers but not for low-skill spellers. There are mixed findings as to whether SF improves recall of word-pairs: worse performance (Taylor et al., 2020; highly-associated word-pairs using 500ms presentation) and equivalent performance (Geller et al., 2020; weakly-associated word-pairs) compared to Arial. SF did not benefit memory for read information (Taylor et al., 2020; Experiment 3), recall of missing words in read passages over highlighted text (Geller et al., 2020; Experiment 2), or comprehension of passages (Taylor et al., 2020; Experiment 4). However, no studies have been done comparing Sans Forgetica and a fluent font on performance on the Cognitive Reflection Test.

Cognitive Reflection Test

The Cognitive Reflection Test (CRT; Frederick, 2005) consists of math word problems that have tempting wrong answers and require careful reflection to reach the correct answer. Alter et al. (2007) found that participants who received the test in a disfluent font (10% gray italicized Myriad Web 10-point font) outscored those who received it in a fluent font (black Myriad Web

12-point font). They believed that the degraded font encouraged the activation of system 2 (slower, more deliberative, and more logical thinking; Kahneman, 2011) processes, which helped them overcome incorrect “gut” answers. A meta-analysis of conceptual replications failed to find the same effect (Meyer et al., 2015). These conceptual replications utilized a wide range of perceptual disfluency manipulations: grey-scale, teal-colored, italicizing, small font sizes, disfluent typefaces like Mistral, Haettenschweiler, Curlz MT.

While previous research suggests that a disfluency effect with SF may be unlikely, we thought SF was worth exploring because it is a stronger manipulation of disfluency. Word recognition with fragmented letters may be more difficult, requiring the activation of words with similar spellings in long-term memory, and this may encourage more higher-level (lexical) processing. This is relevant because getting these CRT problems correct requires special attention to the words and the phrasing of the problems and seeing the correct relationships between items (e.g., A bat AND a ball cost \$1.10 in TOTAL. The bat costs \$1.00 MORE THAN the ball) in the problem. In fact, Eskenazi and Nix (2020) found, using eye-tracking, that participants skipped significantly more words when reading fluent font (Courier) than SF. This finding suggests that participants could skip over the important words in the CRT problems printed in a fluent font and less likely to skip over them in SF font. Given the unique characteristics of SF, we (optimistically) hypothesized that participants would perform better on the CRT problems when they were presented in SF than in Arial.

Present Study

The present study is a conceptual replication of Sirota, Theodoropoulou and Juanchich (2020b) with different disfluent/fluent font choices. Arial is used instead of black Myriad Web 12-point font for the fluent font and Sans Forgetica is used instead of 10% grey italicized Myriad Web 10-

point font for disfluent font. Participants either completed the CRT problems, which consisted of the Numerical CRT (Toplak, West & Stanovich, 2014) and the Verbal CRT (Sirota, Dewberry, Juanchich & Marshall., 2020a), in Sans Forgetica or in Arial. They also completed a numeracy scale (Lipkus, Samsa & Rimer, 2001), which allows us to consider numeracy skills as a boundary condition of the disfluency effect. Unlike Sirota et al. (2020b), we also asked all participants to rate how difficult it is to read Sans Forgetica and Arial.

We anticipated finding a disfluency effect with SF. We hypothesized that the fragmented letters in SF would encourage slower reading and an engagement of system 2 processes (Kahneman, 2011), which would result in better solution rates and longer response times. Thus, we expected participants in the Sans Forgetica condition to solve more CRT problems and take longer to come up with solutions than participants in the Arial condition. In the case that we do not find a disfluency effect with SF for the numerical CRT problems, we expected numeracy skills to be a boundary condition, such that SF only improves performance for participants with high numeracy skills. Finally, we expected legibility ratings of SF to differ between the Sans Forgetica and Arial conditions. Having to solve CRT problems, many of which are difficult questions, in SF font (as opposed to just reading a sample sentence used in the rating question) may create an impression that the font was harder to read. Thus, we expected participants who solved CRT problems in SF to rate SF to be harder to read than participants who solved them in Arial.

Methods

Participants and design

There were 374 undergraduates from University of California, Los Angeles who completed the experiment for partial course credit. Twenty-seven were excluded because of technical

difficulties. The resulting 347 (67 male, $M_{\text{age}} = 20.25$, $SD_{\text{age}} = 2.46$) completed the entire experiment, excluded 1 for not completing the questions (copied the problem text), and 5 for not having completed 80%+ of the problems, resulting in 340 in our analyses. The experiment had a 2 (font: fluent font – Arial vs. disfluent font – Sans Forgetica; between-subjects factor) x 2 (CRT: Numerical vs. Verbal; within-subjects factor) mixed-subjects design.

Materials

The experiment was created using PsychoPy and was run on a computer. Two CRT problem sets were used: the extended 7-item version of the Numerical CRT (Toplak et al., 2014) and the 10-item version of the Verbal CRT (Sirota et al., 2020a). The Numerical CRT (Toplak et al., 2014) consisted of the original three CRT items (Frederick, 2005) and four additional items (Toplak et al., 2014). This extended version of the CRT has better statistical and psychometric properties (Toplak et al., 2014). The Verbal CRT consists of questions that require cognitive reflection but does not involve mathematical calculations (e.g., “Mary’s father has 5 daughters but no sons – Nana, Nene, Nini, Nono. What is the fifth daughter’s name probably?”). Numerical ability was assessed using Lipkus et al.’s Numeracy Scale (Lipkus et al., 2001), which consisted of 11 simple mathematical word problems that tested on basic probability concepts, conversion of percentages to proportions and risk magnitude comparisons.

Procedure

Participants were randomly assigned into either the fluent font (Arial) or the disfluent font (Sans Forgetica) condition. At the beginning of the experiment, participants were acquainted with the font that will be used for their questions. They then completed the Numerical CRT and Verbal CRT problem sets by typing their responses onto the computer screen. The order of problems within problem sets was randomized and the order of problem sets was counterbalanced across

participants. After completing both problem sets, participants rated “how easy/difficult it was to read” each font on a scale from 1 (extremely easy) to 7 (extremely hard) [with 4 labeled “neither”] and “how familiar were you to the questions asked” on a scale of 1 (not at all) to 5 (with most/all) with the midpoint (with some). For the former question, the question “how hard/easy was it to read this text?” was presented in Arial and in SF, the order of which was counterbalanced across participants. Afterwards, they completed the Numeracy Scale. Finally, they reported their age, gender, whether English is their first language and whether they have completed a similar experiment before.

Results

Performance was assessed using solution rate, or the proportion of problems correct, and response time, or the time it took a participant to arrive at a solution.

Overall Performance

First, we assessed performance on all problems, combining the numerical problem set and verbal problem sets, using independent-samples t-tests. There was no significant difference in solution rate between Arial ($M = 0.42$, $SD = 0.23$) and Sans Forgetica ($M = 0.40$, $SD = 0.24$), $t(340) = 0.86$, $p = .39$. For each participant, we calculated an average response time using all problems. There was no significant difference in average response time between Arial ($M = 29.87$ seconds, $SD = 11.27$) and Sans Forgetica ($M = 30.17$, $SD = 9.92$), $t(340) = -0.26$, $p = .79$.

Next, we factored in the different problem sets. A 2 (font: Sans Forgetica vs. Arial; between-subjects factor) x 2 (problem set: numerical vs. verbal; within-subjects factor) mixed ANOVA was performed on solution rates. There was no main effect of font [$F(1, 340) = 0.69$, $p = .41$], no main effect of problem set [$F(1, 340) = 1.12$, $p = .29$], and no interaction between font and problem set [$F(1, 340) = 0.34$, $p = .56$].

A 2 (font: Sans Forgetica vs. Arial; between-subjects factor) x 2 (problem set: numerical vs. verbal; within-subjects factor) mixed ANOVA was performed on response times. There was no significant main effect of problem set: participants took no longer to respond to numerical problems ($M = 38.70$ seconds, $SD = 16.05$) than verbal problems ($M = 23.95$, $SD = 8.90$), $F(1, 340) = 2.57$, $p = 0.11$. However, there was no main effect of font [$F(1, 340) = 0.04$, $p = .84$] and no interaction between font and problem set [$F(1, 340) = 0.51$, $p = .48$]. See Figure 2.

To consider numeracy skills as a possible boundary condition for a disfluency effect, we used numeracy score as a covariate and performed 2 (font: Sans Forgetica vs. Arial; between-subjects factor) x 2 (problem set: numerical vs. verbal; within-subjects factor) mixed ANCOVAs on solution rates and response times. After numeracy scores were introduced as a covariate into the ANOVA on solution rates, there was also no significant main effect of problem set: participants did not have higher solution rates for the numerical problems ($M = 0.42$, $SD = 0.29$) than the verbal problems ($M = 0.40$, $SD = 0.27$) [$F(1, 340) = 1.31$, $p = 0.25$], but still no main effect of font [$F(1, 340) = 0.81$, $p = .37$]. There was a significant main effect of numeracy score [$F(1, 340) = 58.30$, $p < .001$] but no significant interaction between numeracy scores and problem set [$F(1, 340) = 0.42$, $p = 0.52$] and no interaction between problem set and font [$F(1, 340) = 0.85$, $p = 0.36$].

When numeracy score was introduced as a covariate into the ANOVA on response times, there was no significant main effect of problem type, such that participants did not take longer to respond to numerical problems ($M = 38.70$ seconds, $SD = 16.05$) than verbal problems ($M = 23.95$, $SD = 8.91$) [$F(1, 340) = 2.56$, $p = .11$] and still no main effect of font, $F(1, 340) = 0.04$, $p = .84$]. There was also no main effect of numeracy score [$F(1, 340) = 0.22$, $p = .64$], no

interaction between numeracy score and problem set [$F(1, 340) = 0.66, p = .42$], and no interaction between problem set and font [$F(1, 340) = 0.48, p = .49$].

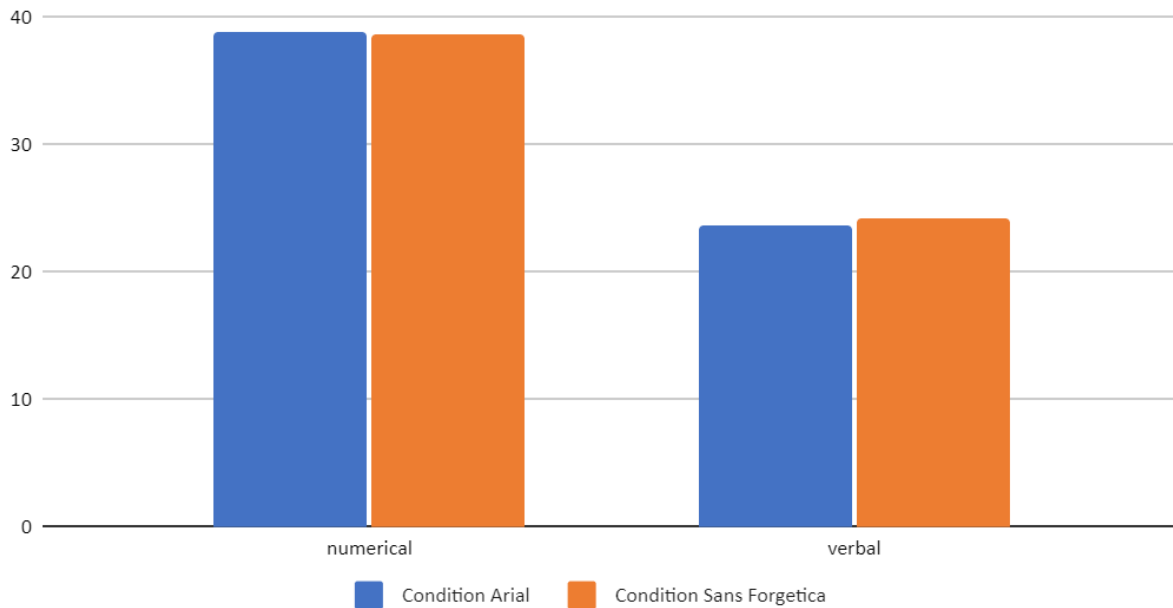


Figure 2. Response times of the font conditions (x-axis) with the problem sets represented by colored bars. Error bars represent standard error.

Numerical Problem Set

Independent-samples t-tests were performed on solution rates and response times for numerical problems only. There was no difference in solution rates between Arial ($M = 0.43, SD = 0.29$) and Sans Forgetica ($M = 0.42, SD = 0.29$), $t(340) = 0.18, p = .86$. There was also no reliable difference in response times between Arial ($M = 38.76$ seconds, $SD = 16.67$) and Sans Forgetica ($M = 38.64$ seconds, $SD = 15.46$), $t(340) = 0.07, p = .94$.

To consider numeracy skills as a possible boundary condition for a disfluency effect, we also performed a multiple linear regression on solution rates with font, numeracy scores and interaction between font and numeracy scores as predictors. While the overall model was significant, $F(3, 336) = 20.17$, $SE_{\text{residual}} = 0.21$, $p < .001$, $R_{\text{adj}}^2 = 0.15$, only numeracy score was a significant predictor, $\beta = 0.054$, $t(340) = 4.69$, $p < .001$.

Verbal Problem Set

Independent-samples t-tests were performed on solution rates and response times for verbal problems only. There was no reliable difference in solution rates between Arial ($M = 0.42$, $SD = 0.27$) and Sans Forgetica ($M = 0.39$, $SD = 0.27$), $t(340) = 0.97$, $p = .33$. There was also no reliable difference in response times between Arial ($M = 23.65$ seconds, $SD = 9.47$) and Sans Forgetica ($M = 24.24$, $SD = 8.32$), $t(340) = -0.61$, $p = .54$.

Legibility Ratings

A 2 (font condition: Arial vs. Sans Forgetica, between-subjects) x 2 (rated font: Arial vs. Sans Forgetica, within-subjects) mixed ANOVA was conducted on legibility ratings. There was a significant main effect of font condition, such that participants in the Sans Forgetica condition ($M = 2.96$, $SD = 1.45$) rated the two fonts as more difficult to read than participants in the Arial condition ($M = 2.63$, $SD = 1.13$), $F(1, 340) = 5.38$, $p = .02$. There was also a significant main effect of rated font, such that Sans Forgetica ($M = 3.51$, $SD = 1.64$) was rated more difficult to read than Arial ($M = 2.08$, $SD = 1.52$), $F(1, 340) = 5.56$, $p = .02$. There was also no significant interaction between font and rated font, $F(1, 340) = 1.06$, $p = 0.30$. See Figure 3.

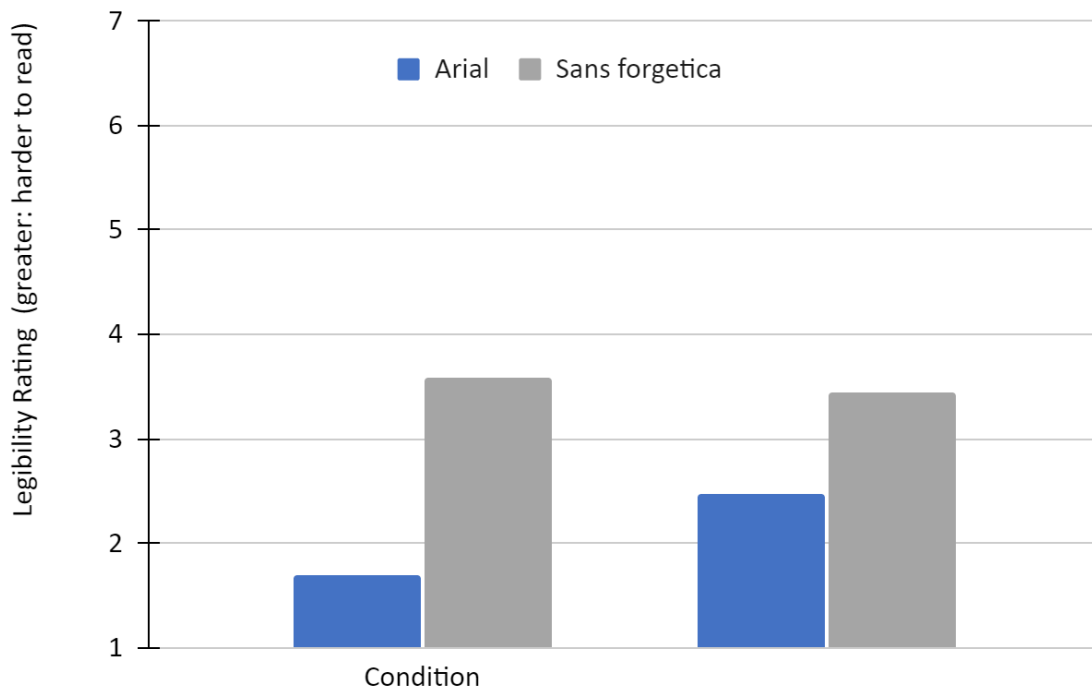


Figure 3: Legibility ratings of the font conditions (x-axis) with the fonts being rated represented by colored bars. Error bars represent standard error.

Post-hocs were performed with a Bonferroni correction. While participants in the Sans Forgetica condition ($M = 2.47$, $SD = 1.64$) rated Arial to be harder to read than participants in the Arial condition ($M = 1.69$, $SD = 1.28$), $t(340) = -4.94$, $p < .001$, there was no difference between conditions on their ratings of Sans Forgetica, $t(340) = 0.73$, $p = .47$. Sans Forgetica was rated significantly more difficult to read than Arial in both the Arial condition, $t(340) = 11.75$, $p < .001$, and in the Sans Forgetica condition, $t(340) = 5.54$, $p < .001$. In addition, the difference in font ratings in the Arial condition ($M = 1.89$, $SD = 1.93$) was significantly greater than that in the Sans Forgetica condition ($M = 0.98$, $SD = 1.51$), $t(340) = -4.88$, $p < .001$.

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., low contrast, small font) or by using hard-to-read typeface (e.g., narrow spacing 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. The added difficulty of recognizing words may be helpful in getting participants to notice the crucial words/phrasing in CRT problems needed to realize the correct solution. Because of these reasons, we anticipated a disfluency effect with SF on CRT performance.

We expected participants in the Sans Forgetica condition to solve more CRT problems than participants in the Arial condition. Unfortunately, across all our analyses, we did not find an effect of font. This null effect could be explained by a lack of a difference in response times between the two fonts across the problems/problem sets (i.e., participants did not spend more time reading and coming up with solutions for CRT problems presented in SF). Thus, SF does not seem to encourage the use of System 2 processes.

We considered numeracy skills as a boundary condition for a disfluency effect. However, in our multiple linear regression on numerical CRT solution rates, we did not find an interaction between font and numeracy score. We did however find that numeracy score was a significant predictor of solution rates for numerical CRT problems. These results are consistent with what

Sirota et al. (2020b) found with 10% grey italicized Myriad Web 10-point font as the disfluent font.

Finally, we anticipated participants in the SF condition to rate SF to be harder to read than participants in the Arial condition. Our reasoning was that having to solve CRT problems in SF may create an impression that the font was harder to read. Instead, we found that they rated Arial to be harder after solving CRT problems in SF. Surprisingly, there was no reliable difference in legibility ratings for SF between the two conditions, meaning solving CRT problems in SF changed how participants perceived the legibility of Arial (a fluent font). For context, legibility was rated on a 7-point Likert scale and participants, on average, rated SF as being in the middle of the scale. In other words, participants who solved CRT problems in Arial were willing to use the lowest end of the scale to rate the legibility of Arial but participants who solved CRT problems viewed Arial as being closer in legibility to SF.

A limitation is our between-subjects (on font) design since participants cannot serve as their own controls. However, a within-subjects design did not seem feasible because we would need to split in half the already small problem sets. An additional obstacle is that there is an odd number (7) of numerical CRT problems, which means either one problem would need to be left out completely or the omitted problem needs to be counterbalanced. Second, the problems in the numerical CRT and verbal CRT problem sets have very different reported solution rates making creating equivalent sets difficult. We tried to offset the downsides of using a between-subjects design by collecting a large sample.

A meta-analysis on the effect of disfluent fonts on CRT performance (Meyer et al., 2015) did suggest that a disfluency effect with SF would be unlikely. We were just hopeful that the unique characteristics of perceptual disfluency in SF would make a difference. Given our large

sample size, it is likely that there is no disfluency effect with SF. We, thus, caution against further work on this topic, unless it adds (novel) manipulations or boundary conditions that are convincing.

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