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Effects of Perceptual Fluency on Reasoning and Pupil Dilation

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Effects of Perceptual Fluency on Reasoning and Pupil Dilation

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Abstract

Research on perceptual disfluency has examined the effects of perceptually demanding stimuli on information processing and reasoning, suggesting that disfluent stimuli elicit slower and more effortful processing. Recent criticism of perceptual disfluency, however, suggests that the effects disfluent stimuli have on processing are marginal, and that they are mediated by individual differences. Participants completed a computerized reasoning task presented in either a fluent (i.e., easy-to-read font) or disfluent format (i.e., hard-to-read font) while pupil diameter was measured by an eye-tracker system. Pupillometry is an established reliable measure of mental activity that reflects differences in cognitive load. Results showed no performance differences between the two groups, as well as no difference in pupil dilation between the groups. Similar to the recent critiques of perceptual disfluency, these results call into question if perceptual disfluency is a valid prime of attentive and deeper processing as has been theorized.

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Effects of Perceptual Fluency on Reasoning and Pupil Dilation

In our everyday lives, we are constantly making decisions. Some decisions are small, like choosing what to wear on a given morning, while some are a big deal, like which presidential candidate to vote for or where to attend graduate school. Regardless of the importance of the choice, people engage in different strategies to make these decisions, by either following their gut feelings or intuition, or by weighting all the pros and cons to formulate a careful and systematic choice. From the dual-process approach of reasoning, Type 1 processing is consider to be fast, intuitive and effortless, while Type 2 processing is consider to be slow, deliberative and effortful (Evans, 2010; Tversky & Kahneman, 1974). Most scholars concur that each mode serves a particular function and that both possess a set of beneficial characteristics and a set of potential flaws (Kahneman, 2011). Still, it is important to understand and know in which situations it would be more beneficial to depend on one specific type of reasoning.

It is also important to know what other factors affect the type of reasoning with which we operate in a given situation. Many psychologists agree that the format in which information is presented impacts how we process the information, and subsequently the decisions we make with such information (Kahneman, 2011; Yue, Castel, & Bjork, 2012). A format may be in terms of gains or losses, numerical representations, or it can be something as simple as how easily, or fluently, the information is understood. Fluency has been defined as the subjective ease with which information comes to mind (Alter & Oppenheimer, 2009), while perceptual fluency has more specifically been defined as the subjective ease with which we process perceptual information. By contrast, perceptual disfluency is defined as the level of difficulty with which we process perceptual information. A few examples of the different levels of fluency include repetition (i.e., the more something it is repeated, the easier it is to remember it), prose (i.e., statements that rhyme are also remembered easier), or font type (i.e., easy-to-read font is read faster).

Research on processing disfluency has focused on adjusting the ease with which we process information with the intent of prompting slower, deeper and systematic processing (i.e., Type 2). In particular, perceptual disfluency deals with the ease of processing stimuli on the basis of manipulations to the perceptual quality of such stimuli (Alter & Oppenheimer, 2009). This stream of research suggests that by using perceptually demanding stimuli individuals enter a state of cognitive strain, in which more effortful, attentive, and exhaustive thinking is required to successfully process information (Kahneman, 2011). As a result of this state of cognitive strain, our mind allocates mental resources to properly perceive the low-quality, or disfluent, stimuli, increasing attention and resulting in a slower, deeper processing as a byproduct of the additional mental resources (Alter, Oppenheimer, Epley, & Eyre, 2007; Kahneman 2011). This effect has been observed across several studies and in different fields including reasoning and problem-solving (Alter et al., 2007, Study 1 and 4), sematic illusions (Song & Schwarz, 2008), High School learning (Diedmand-Yauman, Oppenheimer, and Vaughan, 2010) and cognitive biases (Hernandez & Preston, 2013). Song and Schwarz (2009) also showed that perceptual disfluency sensitizes individuals to risk and threats while reducing their self-confidence at the same time.

Despite these findings, the fluency hypothesis has been the subject of recent criticism, and some suggest that the effects of disfluent stimuli are marginal, at best, and are mediated by individual differences (Thompson et al., 2012). More importantly, several failures to replicate the results reported by Alter and colleagues (2007) have initiated a scholarly debate which calls into reconsideration the theoretical basis of disfluency (Thompson et al., 2012, 2013). As a result of this debate, it was proposed that perceptual dislfuency does elicit thorough and analytic thinking, though this does not guarantee greater accuracy on cognitive tasks (Alter, Oppenheimer & Epley, 2013). The current study aims to contribute to the ongoing discussion on perceptual disfluency by examining this claim.

Pupillometry and Disfluency

It has extensively been noted that changes in pupil diameter, and specifically dilation of the pupil, can serve as a reflection of cognitive load when an individual completes a cognitive task (Hess & Polt, 1960, 1964; Kahneman & Beatty, 1966; Laeng, Sirois, & Gredebäck, 2012). Simply stated, when mentally solving a difficult problem (e.g., 13 x 14 = ___), one's pupils dilate more, relative to when solving an easier problem (e.g., 3 x 4 = ___). This measurement has also proven to be reliable across different subject populations (Piquado, Isaacowitz & Wingfield, 2010). The physiological reason for this phenomenon is not well understood, though evidence suggesting the role of parasympathetic pathways and prefrontal cortex activation are prominent (Granholm & Steinhauer, 2004). Nonetheless, researchers around the world use pupillometry to study cognitive processes across multiple fields of study (Laeng et al., 2012), which include areas of research that have substantial overlap with disfluency research. For example, on average, individuals' pupils tend to increase in diameter when tested on the comprehension of syntactically ambiguous sentences (Engelhardt, Ferreira &Patsenko, 2010). Hyönä, Tommola, and Alaja (2007) measured pupil dilations as a reflection of effortful comprehension of spoken non-native language. These processes seem to access similar cognitive systems as disfluency, however, no one, to our knowledge, has used pupillometry measures to specifically study the effects of perceptual disfluency on cognition.

The Present Study

As mentioned above, perceptual disfluency augments the perceived difficulty of stimuli used in cognitive tasks. When used in combination with an already demanding task, such as the Cognitive Reflection Test (Frederick, 2005) which includes priming questions that can mislead participants to the wrong choice, the additional load will create a highly draining state of cognitive strain. The purpose of the present study is to clarify the effects that disfluency has on information processing and reasoning. Consistent with previous findings in the perceptual disfluency literature, disfluent stimuli should slow down individuals in order for them to engage in systematic and thorough reasoning, compared to fluent stimuli, which are hypothesized to contribute to more frugal and shallow information processing. Importantly, if perceptual disfluency truly stimulates effortful, deliberative, and exhaustive thinking, then participants' pupils should dilate in response to the additional demands of a cognitive task presented in a disfluent format relative to the same task presented in a fluent format.

Method

Participants

Fifty-eight undergraduate students (56% female) from Georgia Southern University participated to fulfill course credit requirements or for extra credit, as approved by the university's Institutional Review Board. Each participant was tested individually, after providing informed consent to be involved with the research.

Materials, procedure and design

In line with the methodology used by Alter and colleagues (2007) and previous disfluency research, this study used a between-groups experimental design, randomly assigning participants to one of two conditions. In the fluent condition, participants completed a computerized seven-item reasoning questionnaire presented in an easy-to-read font (i.e., Myriad Web16-point font), while those in the disfluent condition completed the questionnaire in a hard-to-read font (i.e., 10% gray italicized Myriad Web 8-point font). The questionnaire consisted of the three items in the Cognitive Reflection Test (see Frederick, 2005), two semantic illusions (see Song & Schwarz, 2008), and two items form the Wonderlic Personnel Test. These items were selected because they all elicit an initial, intuitive response regardless of the thinking system (e.g., Type 1 or Type 2) with which the individual processes information. Moreover, this initial response is wrong in regard to the problem. In layman terms, the problem itself suggests to the reader a particular incorrect answer (see Appendix for the complete questionnaire). To successfully solve each of these items, one has to override the initial (Type 1) response with a slow and systematic approach to the problem. These test items were interleaved with non-demanding demographic questions (e.g., year in college, academic major, etc.) as a measure of an individual's pupil diameter in the absence of cognitive strain (i.e., baseline).

The stimuli were presented on a TX300 Tobii Eye-Tracking system. This is a non-invasive, remote, corneal reflection system that looks like an ordinary flat screen computer monitor, but which allows us to track the binocular point of gaze of participants while they view stimuli presented on the screen. The screen size was 23 inches diagonal and stimuli were presented with a 1920 x 1080 pixels screen resolution. Sampling rate (binocular) was 300 Hz. E-Prime 2.0 was used in conjunction with Tobii Studio to record behavioral (i.e., accuracy and reaction times) and pupillometric data.

The study was conducted in a private lab room. After participants consented to participate in the experiment, the experimenter proceeded to calibrate the eye-tracking system to their eyes. Participants followed an expanding and contracting red circle with their eyes (without moving their heads) across nine locations on the screen. From the data collected during this process the software built a computer model of the characteristics of the participant's eyes, which maximized the capability of the eye-tracking system to track occulomotor behavior. The calibration routine was repeated until the system indicated that it had sufficient data to proceed. Participants were then instructed both orally by the experimenter and visually through text presented by the computer program (see Appendinx for the instruction set). A trial consisted of a non-demanding question presented individually followed by a test item presented individually. Between trials there was a short pause (6 seconds) consisting of a full blank screen to allow for the pupils to return to baseline size. Participants completed 7 trials total.

Results

Participants' accuracy on the task was measured by number of correct responses provided for the seven test items. A preliminary analysis of the data showed no gender differences in accuracy on the task across conditions. An independent samples *t*-test was used to analyze the data between the fluent and disfluent conditions. There was no significant difference between the number of correct responses of the participants in the fluent condition (*M* = 1.28, *SD* = 1.53) and the number of correct responses of those in the disfluent condition (*M* = 1.03, *SD* = 1.18), *t*(56) = .67, *p* = .50 , Cohen's *d* = .18. (see Figure 1). As suggested by Thompson and colleagues (2012), reaction times were measured as well to study the impact of perceptual difluency on reasoning. An independent samples *t*-test showed a difference between the mean time participants in the fluent condition spent per test item (*M* = 16.52 seconds, *SD* = 5.53) and the mean time participants in the dislfuent condtion spent per test item (*M* = 24.38, *SD* = 13.93), though this difference is marginally significant, *t*(56)= -2.86, *p* = .07, Cohen's *d* = -.74 (see Figure 2). Across condtions, however, there was no signigicant correlation bewteen the mean time spent per question and the number of correct responses, *r*(56) = .20, *p* = .13.

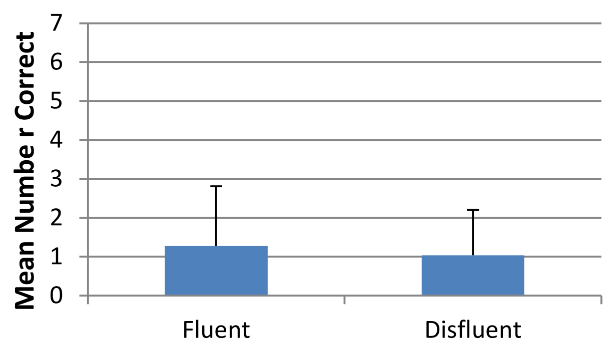

Figure 1. Average correct responses for the fluent and disfluent conditions. Error bars represent the group's standard deviation above the mean.

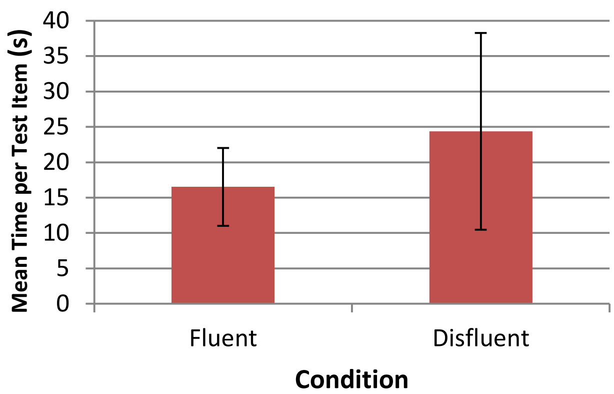

Figure 2. Mean time spent per test item for the fluent and disfluent conditions. Error bars represent the group's standard deviation above and below the mean.

Due to missing or irregular data (due primarily to inaccurate calibration, and difficulty tracking some individuals' eyes), six participants were removed from the pupilometry analyses. A mean relative pupil change score was computed for each participant by subtracting the mean pupil size (mm) at baseline from the maximum size during test trials and dividing the result by the mean size at baseline. This score was calculated to account for individual differences in pupil size. An independent samples *t*-test showed no significant difference between the relative change scores of participants in the fluent condition (M = .28 mm, SD = .14) and the scores of participants in the disfluent condition (M = .31, SD = .12), $t(52) = -.74$, $p = .46$, Cohen's d = -.23.

In line with traditional pupillometric research, analyses were also conducted on participants' pupillary reflexes during a narrow time window (4 seconds) before they input their response, since it is during this period when the greatest pupillary dilation is observed. An independent samples *t*-test showed no significant difference of the mean relative pupil change scores between participants in the fluent condition (M = .24, SD = .13) and those in the disfluent condition (M = .21, SD = .13) , $t(52) = .64$, $p = .52$, Cohen's d = -.23. Nonetheless, differences of the mean pupil size were observed between the two conditions during both baseline and test questions. For test questions, participants in the fluent condition exhibited significantly larger pupils (M = 3.21 mm, *SD* = .33) than those in the dislfuent condition (*M* = 3.03, *SD* = .26), *t*(52) = 2.13, *p* = .04, Cohen's *d* = .61. For baseline questions participants in the fluent condition exhibited larger pupils (*M* = 3.26, *SD* = .36) than those in the disfluent condition (*M* = 3.11, *SD* = .32), though the difference was non-significant, *t*(52) = 1.60, *p* = 0.11, Cohen's *d* = .44 (see Figure 3). These results contradict the idea that perceptual disfluency elicits deeper and more effortful processing.

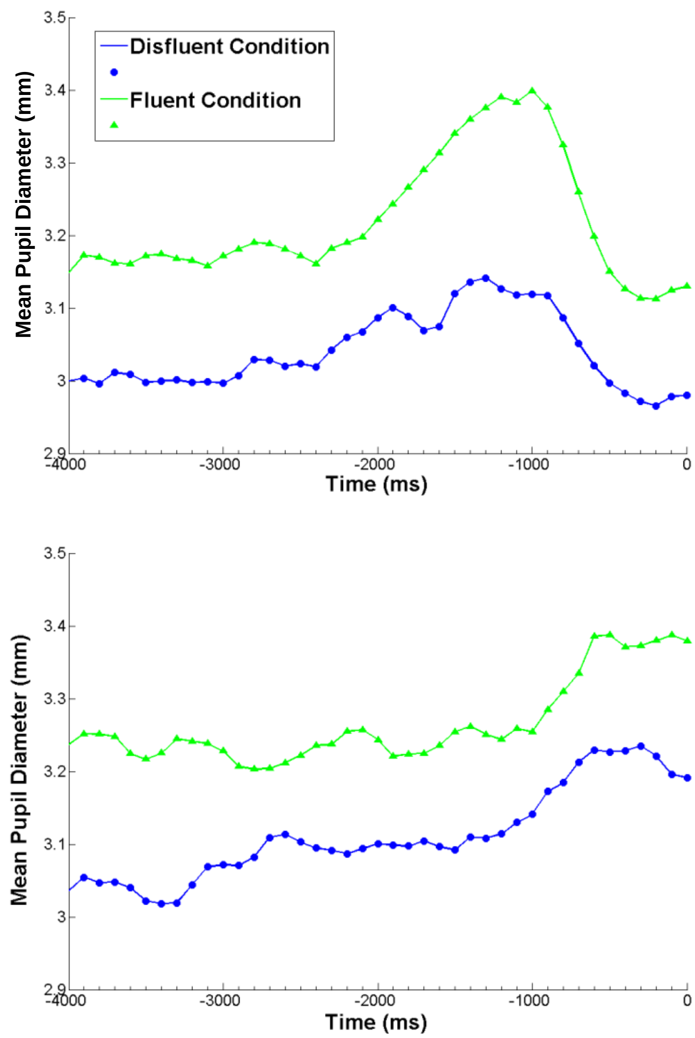

Figure 3. Mean pupil diameter for the fluent and disfluent conditions during a 4 second time period before they input their answers across both test (top) and baseline (bottom) questions.

In order to further examine the impact of perceptual fluency on pupillary reflexes, secondary analyses were conducted assessing a possible interaction between performance on the reasoning task and the two conditions. Assuming that those participants who obtained the highest scores on the task engaged in a slower and more systematic processing than those who score the lowest, it was predicted they would consequently show the greater change in pupil dilation, and that this difference would be mediated by the two fluency conditions.

To test this hypothesis a secondary analysis was conducted on the pupillary data after participants were divided into three groups according to their accuracy on the reasoning questionnaire (i.e., Low, Medium, and High Accuracy). Participants with scores = 0 were classified in the Low Accuracy group; subsequently, those with scores ≤ 2 (but ≠ 0) were classified in the Medium Accuracy group and those with scores ≥ 3 were classified in the High Accuracy group. A 2 (Fluent and Dislfuent) x 3 (Low, Medium, and High Accuracy) factorial Analysis of Variance (ANOVA) was conducted on the relative pupil change scores. Results show no effects for either Fluency condition, $F(1, 53) = 1.15$, $p = .30$, or Accuracy group, $F(2, 53) = .06$, $p = .94$, on the participants' relative pupil change scores. However, a trend was observed between Fluency condition and Accuracy group, though not statistically significant either, $F(2, 53) = 1.3$, $p = .28$. This interaction seems to be driven by the High Accuracy group in the disfluent condition, which was the group with the highest relative pupil change score ($M = .42$, $SD = .60$), followed by the Low Accuracy group in the fluent condition ($M = .35$, $SD = .15$) (see Figure 4).

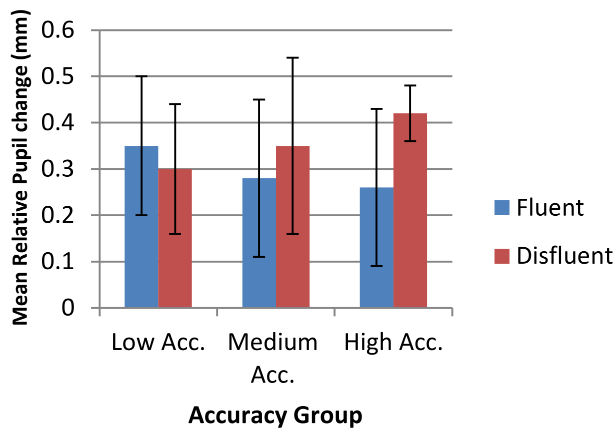

Figure 4. Avg. relative pupil change for the Low, Medium, and High Accuracy groups between the fluent and disfluent conditions. Error bars represent the group's standarddeviation above and below the mean.

It was also of interest to study the tendency of participants to rely on the initial, intuitive response evoked by each item of the questionnaire across conditions. Alter and colleagues (2007) showed that when performing this task, participants in the fluent condition provide the incorrect, intuitive response more often than those in the disfluent condition. In addition to intuitive responses, atypical and idiosyncratic responses were also analyzed, as they may indicate effortful and deliberate, though erroneous, processing. Overall, participants in both conditions relied more on the intuitive response (75% of the responses) than correct (17%) and atypical responses (8%). The number of both intuitive and atypical responses provided by the participants in the fluent condition did not differ from the number of intuitive and atypical responses provided by participants in the dislfuent condition, $\chi^2(2, 406) = 1.72$, $p = .63$. A one-way ANOVA showed no significant difference between the relative change in pupil dilation for the trials in which participants provided an intuitive response ($M = .29$, $SD = .19$), for trials in which participants provided an atypical response ($M = .31$, $SD = .18$), or for trials in which participants provided the correct response ($M = .31$, $SD = .22$), $F(2, 362) = .31$, $p = .73$.

Discussion

The results obtained in the present study support the recent criticisms of the perceptual disfluency approach. While the only difference in methodology between this study and previous studies on perceptual disfluency was the inclusion of a physiological correlate, this study still failed to replicate the previous results found in the research literature (e.g., Alter et al., 2007). Participants in both the fluent and disfluent conditions performed at the same level during the reasoning task, though those in the disfluent condition took more time to answer each question. There was no apparent difference in pupil dilation between the two groups as an effect of a hard-to-read font. These results suggest that the traditional manipulation used in disfluency research has a null impact on reasoning. However, the most unexpected finding was that participants randomly assigned to the fluent condition exhibited larger pupils than those assigned to the disfluent condition when answering baseline questions, and that this was compounded when answering test questions. This outcome may suggest that participants in the fluent condition were actually the ones processing the information deeply and explicitly, though there is no *a priori* theoretical position from which to predict such a finding.

Two possible explanations can account for the inability to reproduce results obtained in previous disfluency research, despite the finding that those in the disfluent condition took longer to respond than those in the fluent condition. The first implies that instead of engaging in systematic and deep processing, participants who take longer to respond are using the time to rehearse the initial, intuitive answer. This idea was originally proposed by Thompson and colleagues (2012), and it would explain the supremacy of intuitive responses over correct and atypical responses. They proposed that participants who do not already have enough mental resources (e.g., high working memory capacity) would lock on the intuitive response and rehearse it long enough to make it fit their "mental construct" of the problem. This might account for the participants in the disfluent condition taking longer to input their answers, though it would have been expected that they would have given a higher number of intuitive responses in comparison with those in the fluent condition. It is also plausible that they were indeed processing the information at a deeper level but still were unable to come up with the right answer, since thorough processing does not ensure precise accuracy on cognitive tasks. The second, perhaps slightly more subjective, explanation, suggests that the task itself is too difficult. Frederick (2005) recognized that the Cognitive Reflection Test was indeed a highly difficult task and only a small subset of participants excel in it. Alter and colleagues (2013) supported this argument and advised that the effects of disfluency might not be observed due to the inability of individuals to perform well in this task. However, this explanation falls short since in a single study Alter and colleagues (2007) demonstrate statistically significant better performance in the Cognitive Reflection Test when it was presented in a hard-to-read font.

The more plausible explanation suggested by the current study, however, is that information presented with a disfluent format does not prompt deeper processing than information presented with a fluent format. Pupillometric techniques have been extensively used in the last five decades of psychophysiological research, proving to be a reliable measure of cognitive load and effortful processing. Yet this type of processing was not reflected in the pupils of participants processing disfluent information. The present results suggest that, as a perceptual cue, disfluency slows the processing time of the information presented, but it does not prime a more thorough and systematic understanding.

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Appendix

Cognitive Reflection Test

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?

2) If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets?

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?

Wonderlic Personel Test

1) Some months have 30 days, others have 31 days. How many months have 28 days in them?

2) A boy is 17 years old and his sister is twice as old. When the boy is 23 years old, what will be the age of his sister?

Semantic Illusions

1) How many animals of each kind did Moses take on the ark?

2) If a plane departs Los Angeles for Mexico City and crashes on the US-Mexico border, where should the survivors be buried?

Instruction Set

You will see a series of demographic questions and reasoning questions. These questions will be presented in pairs (one first followed by the other). Please read the questions carefully and type in a response. Press ENTER after you have typed in your response. A brief pause will follow each pair of questions (please maintain your focus on the screen during the pause).