

## Common or Distinct Attention Mechanisms for Contrast and Assimilation?

Hope K. Snyder<sup>1</sup>, Sean M. Rafferty<sup>1</sup>, Julia M. Haaf<sup>1</sup>, & Jeffery N. Rouder<sup>2,1</sup>

<sup>1</sup> University of Missouri

<sup>2</sup> University of California, Irvine

### Author Note

This document was written in R-Markdown with code for data analysis integrated into the text. The Markdown script is open and freely available at

<https://github.com/PerceptionAndCognitionLab/ctx-flanker/tree/public/papers/current>.

The data were *born open* (Rouder, 2016) and are freely available at

<https://github.com/PerceptionCognitionLab/data1/tree/master/ctxIndDif/flankerMorph4>

Correspondence concerning this article should be addressed to Hope K. Snyder, 205 McAlester Hall, University of Missouri, Columbia, MO 65211. E-mail:

[hks7w2@mail.missouri.edu](mailto:hks7w2@mail.missouri.edu)

## Abstract

The ability to inhibit distractors while focusing on specific targets is crucial. In most tasks, like Stroop or priming, the to-be-ignored distractors affect the response to be more like the distractors. We call that assimilation. Yet, in some tasks, contrast tasks, the opposite holds. Contrast and assimilation are opposing behavioral effects, but they both occur when to-be-ignored information affects judgments. We ask here whether inhibition across contrastive and assimilative tasks is common or distinct. Assimilation and contrast are often thought to have different underlying psychological mechanisms, and we use a correlational analysis with hierarchical Bayesian models as a test of this hypothesis. We designed tasks with large assimilation or contrast effects. The stimuli are morphed letters, and whether there is contrast or assimilation depends on whether the surround is a letter field (contrast) or a word field (assimilation). Critically, a positive correlation was found - individuals who better inhibited contrast-inducing contexts also better inhibited assimilation-inducing contexts. These results indicate inhibition is common, at least in part, across contrast and assimilation tasks.

*Keywords:* Inhibition, Selective Attention, Contrast Effects, Assimilation Effects

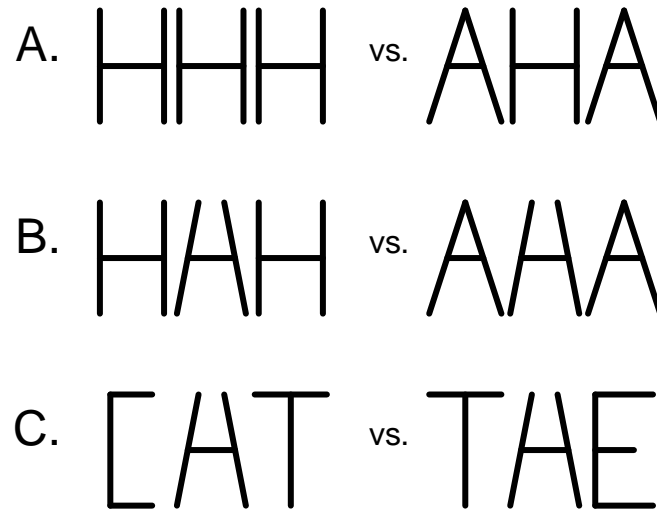
## Common or Distinct Attention Mechanisms for Contrast and Assimilation?

The concepts of *spatial selective attention* and *response inhibition* have been topical in the psychological literature since at least Helmholtz (1867) and James (1890). The ability to inhibit some elements in the environment while focusing on other target elements is crucial to proper functioning (e.g., Broadbent, 1958; Cowan, 1995). Failures to properly inhibit responses to inappropriate elements in the environment are used to describe and understand pathological development (Barkley, 1997; Hasher & Zacks, 1988). Inhibition is usually treated as a fairly unified or homogenous concept. It may be measured in tasks where the goal is to select or identify target items in the presence of to-be-ignored distractors. We provide a novel and, in our opinion, an exceedingly strong test of whether spatial inhibition is a unified phenomenon.

In many spatial interference tasks, such as Eriksen interference (B. A. Eriksen & Eriksen, 1974), the effect is usually in a specific direction that we term *assimilation*. Assimilation is displayed in Figure 1A where the goal is to identify the center letter as either an “A” or an “H.” People are more likely to misidentify the target *H* as an “A” when surrounded by *A*’s than surrounded by *H*’s. Because they are making responses seemingly driven by the identity of the flankers rather than the target, we say their inhibition failure leads to an *assimilation* of the background.

Assimilation, however, is not the only outcome. Rouder and King (2003) used a modified version of the flanker task and found the opposite effects, which are called here *contrast* effects. Rather than use well-formed letters, Rouder and King’s targets were morphed letters between *A* and *H* (see Figure 1B). Perhaps surprisingly, morphs surrounded by *H*’s were *less likely* to be identified as “H” than morphs surrounded by *A*’s. This effect is exactly opposite because inhibition failures lead to a response that is in contrast to the background.

The presence of two different attention effects, assimilation and contrast, provides a fruitful window for examining the unity of inhibition. Both contrast and assimilation here



*Figure 1.* Three flanker paradigms. The participants' task is to identify the center letter as either an A or an H. **A.** Conventional Eriksen & Eriksen (1974) flanker paradigm results in assimilation. **B.** Modified paradigm with morph-letter targets results in contrast (Rouder & King, 2003). **C.** Word contexts result in assimilation (Neisser, 1967).

reflect a failure to completely inhibit the background, but they lead to opposite behavioral patterns. The question then is whether the inhibition processes are the same in both tasks. We address this question by studying the correlation of inhibition abilities across people. Are people who are good at ignoring the surrounding information in a standard flanker task that promote assimilation also good at ignoring the surrounding information in a modified flanker task that promotes contrast?

Correlation studies across attention tasks are certainly popular in cognition. Indeed, far more expansive studies than ours which provide for far more correlations across tasks have been performed (Barrett, Tugade, & Engle, 2004; Miyake et al., 2000). To the best of our knowledge, these studies use assimilative inhibition tasks such as the flanker interference with well-formed letters and anti-saccade tasks. In fact, we are unaware of any individual-differences studies that use contrast tasks. Here, we compare the correlations among people with contrast and assimilation. Such a positive correlation, if found, provides stronger evidence for a unified concept than just assimilation tasks because the

correlation relates behaviorally opposing effects.

The current literature on whether there should be common inhibition mechanisms across assimilation and contrast tasks is mixed. Support for the common-mechanism view is as follows: Most proposed behavioral and neural mechanisms of selective attention rely on a narrowing of receptive fields. This narrowing process occurs whether the to-be-excluded information is contrastive or assimilative (e.g., Cowan, 1995; Desimone & Duncan, 1995; Eriksen & Schultz, 1979; Hedden & Gabrieli, 2010). Behavioral evidence comes from Miyake et al. (2000) who studied individual differences. When variability across a range of executive-function tasks is decomposed, one recovered latent factor is a unified concept of inhibition. Yet, there are strong arguments that contrast and assimilation are not the same process. Most theories of contrast rely on a center-surround organization of low-level, perceptual receptive field structures (Palmer, 1999). Most theories of assimilation flanker effects, however, are failures of response inhibition, which is conceptualized as a higher-level, top down process (B. A. Eriksen & Eriksen, 1974). Behavioral evidence for distinct processes comes from Rouder and King (2003) whose design is a bit complicated. These researchers associated the letters *c* and *A* with one response, denoted  $R_1$ , and *e* and *H* with another, denoted  $R_2$ . When well-formed letters were the target, assimilation to the response assignment of the background was observed. For well-formed *A* letters, backgrounds of *c* resulted in higher proportion of  $R_1$  response than did backgrounds of *e*. When morphed letters were targets, the effect varied. If morphs between *A* and *H* were surrounded by either *A* or *H*, the effect was contrastive. Yet, if these same morphs were surrounded by *c* or *e*, the effect was assimilative. Rouder and King (2003) interpreted the assimilative effect to be at the response level and the contrastive effect to be at a perceptual level.

We employ better stimulus control than Rouder and King (2003). We sought targets and backgrounds such that whether there was contrast or assimilation was a function of the background rather than the target. Our targets were morphed letters like those in Figure 1B. Our backgrounds came in two types, either a letter context such as in Figure 1B or a word

context such as in 1C. For the letter context, we expect large contrast effects as was observed by Rouder and King (2003). The rationale for the word context comes from Neisser (1967). We expect that a morph between *A* and *H* will be judged more “A” like in *C\_T* context than *T\_E* context. This effect is assimilative, and it has been repeatedly demonstrated that there is an assimilative effect of word contexts for both visually and orally presented letters (Baron & Thurston, 1973; Reicher, 1969). As an aside, this assimilation effect has been a motivating phenomenon in the development of connectionist models (e.g., Carpenter & Grossberg, 1987; Rumelhart & McClelland, 1982) where word nodes feed positive activation to corresponding letter nodes.

In the following experiment, each participant identified several *A*-to-*H* morphs (see the top row of Figure 2). These target morphs were embedded within four background contexts (see the bottom row of Figure 2). By comparing performance in the *A*-letter and *H*-letter contexts, we assess each participant’s ability to inhibit contrastive information. By comparing performance in the *C\_T*-word and *T\_E*-word contexts, we assess each participant’s ability to inhibit assimilative information. Note that for each target, there are assimilative and contrastive background contexts such that the critical comparisons may be made across backgrounds. To assess the question of whether inhibition across contrastive and assimilative contexts is common or distinct, we assess the correlation across individuals of their inhibition within the two context types.

## Method

### Sample Size Consideration

The following experiment is a massively repeated within-subjects design. Each participant observes 960 trials, a number that was as large as possible within an hour time frame. The critical question is how many participants to use, and the key consideration is whether the main source of variability is within-trial noise or across-participant noise. There is little guidance in the literature, and as a consequence we used a sequential approach where

the critical Bayes factor, to be discussed subsequently, reached a ratio of 5-to-1 (Rouder, 2014). In reality, we ran out even after reaching this goal to provide opportunities for participants to take part. We ended with 93 usable participants who made 65,541 usable responses, and our Bayes factor was 25-to-1. Although our protocol was not preregistered and did not follow a set sequential plan, we exercised good judgment. Readers wishing the check can do so. All of our data were made publicly available as they were collected and may be found at

<https://github.com/PerceptionCognitionLab/data1/tree/master/ctxIndDif/flankerMorph4>.

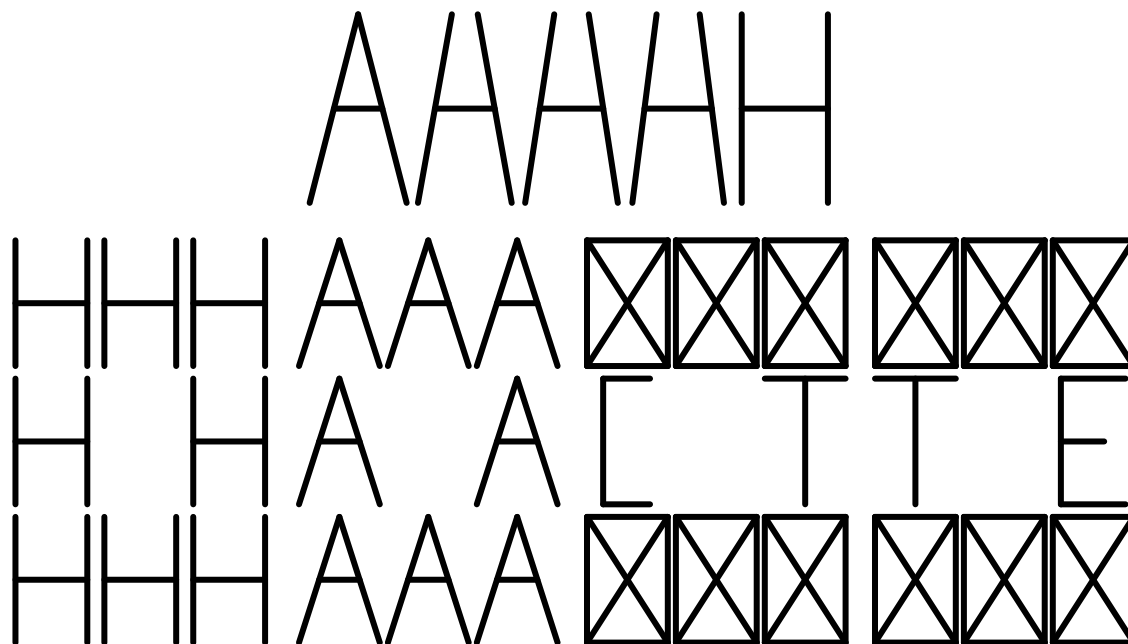
This mode of data collection is called Born Open Data (Rouder, 2016) and readers can see the effects of stopping at any point.

## Participants

Ninety-nine undergraduates from the University of Missouri served as participants as part of an introductory course requirement. Data from two participants were discarded due to a computer error and data from an additional four were discarded because twenty or more of their responses were shorter than a criterial 200 ms in duration. The data from the remaining 93 participants were used in analysis.

## Design

The experiment was a  $5 \times 2 \times 2$  within-subject factorial design. The first factor was the target, and it was manipulated through 5 levels from the letter *H* through the morphs to the letter *A*. The second factor was the context type, and the background was either a letter or a word. The final variable was context direction, a context that promotes “A” or “H” responses. We coded the *H* background and the *C\_T* background as promoting “A” responses based on prior literature. This coding does not determine the direction of results; it simply provides a clear language for discussing them.



## Material

## Procedure

An experimental trial proceeded as follows: The screen was blank during a 1.5 sec foreperiod. We warned participants that a target was about to appear as follows. Two brief tones were presented 500 ms and 250 ms before the stimulus. These tones allowed



participants to precisely time the stimulus. Next, the stimulus was presented for 100 ms, and thereafter, was replaced by a blank screen. This blank screen remained until participant pressed either the “A” or “H” key to indicate their judgment about the target. The response marked the end of the current trial and the beginning of the next one. Responses and the time taken to respond was recorded. A block consisted of 96 trials and the experimental session consisted of 10 blocks for a total of 960 trials. Participants were encouraged to take breaks between blocks. No feedback was given about participant responses during the course of the experimental session.

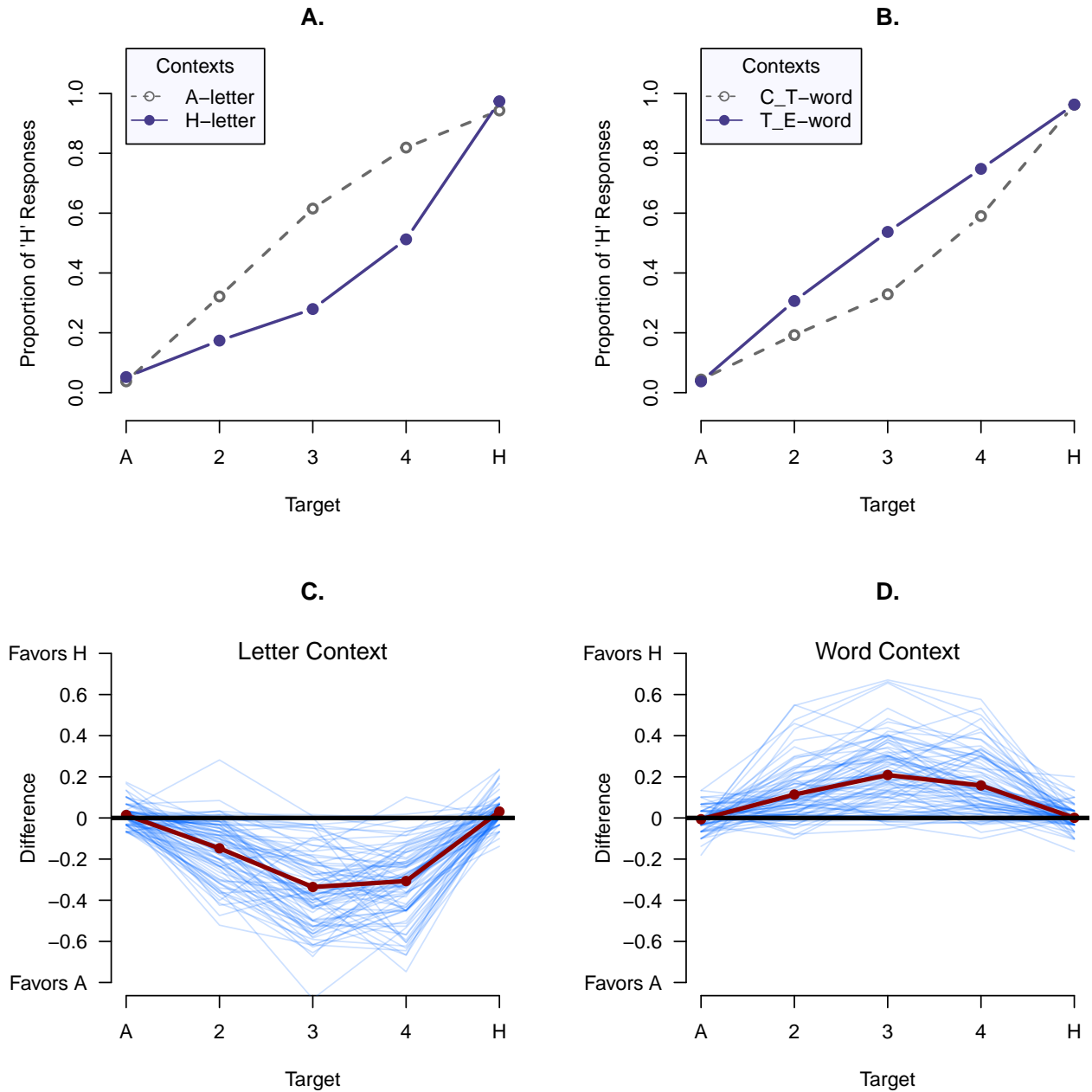
All experimental sessions were conducted on MacMini computers running the operating system MacOSX 10.6.2 with Octave version 3.2.3. This experimental procedure was approved by the Institutional Review Board at the University of Missouri.

## Results

Data were cleaned by discarding responses with latencies less than 200 ms and greater than 2 sec. These discards comprised about 1% of the total. Additionally, the first twenty trials of the session were considered practice and excluded. These criteria were chosen before data collection.

Figures 3A and B show the proportion of “H” responses as a function of target and context. As expected, the curves start low for *A* and *A*-like stimuli and increase as the targets become more *H*-like. Figure 3A displays the results for the letter contexts (*A*-letter and *H*-letter) and Figure 3B displays results for the word contexts (*C\_T*-word and *T\_E*-word). Solid and dashed lines differentiate in each graph differentiates the contexts in each graph from one another. A contrast effect may be seen for letter contexts. Here, the *A*-letter context promoted higher proportions of “H” responses than the *H*-letter context did. The opposed effect—assimilation—may be seen for the word contexts. The context *T\_E* promoted higher proportions of “H” responses than the *C\_T* context did.

Figures 3A and B show effects averaged across individuals. Effects for each individual



*Figure 3.* Empirical Results. **A.** Response proportions for letter contexts. Solid and dashed lines differentiate between A-letter and H-letter contexts. **B.** Response proportions for word contexts. Solid and dashed lines differentiate between C\_T-word and T\_E-word contexts. **C.** Individual effects in the letter contexts. The negative direction denotes a robust contrast effect. **D.** Individual effects in the word contexts. The positive direction denotes a robust assimilation effect.

are shown in Panels C and D. To observe individual effects in the letter-context condition, we subtracted the proportion of “H” responses for the *A*-letter context from that for the *H*-letter context. In this graph, positive values indicate an assimilation effect; zero indicates no effect of context direction; negative values indicate a contrast effect. The following three points are noted: 1) The contrast effects of letter contexts are robust across individuals. 2) The size of these effects is much larger than usual. The differences in proportions average as much as 0.34, which dwarfs the size of differences in most experiments. 3) The degree of individual variability is also quite large. This degree provides increased resolution in the following correlational analysis. Figure 3D shows the same plot for the word context; it is formed by subtracting the proportion of H responses in the *C\_T*-word context from that in the *T\_E*-word context. The story about individuals is largely the same: 1) seemingly every individual shows an assimilation effect, 2) the effect is large, averaging as much as 0.21, and 3) there is a suitable range of variation.

To assess the correlation among individual assimilation and contrast effects, we developed a Bayesian hierarchical mixed model with a probit link. The benefits of the modeling approach are two-fold: First, it provides a principled means of combining data across the different targets. Second, and more importantly, the hierarchical structure provides a form of regularization used to avoid overstating the range of individual variation (Davis-Stober, Dana, & Rouder, 2017; Efron & Morris, 1977; Lehmann & Casella, 1998). The model and corresponding analysis are described in an online supplement at <https://github.com/PerceptionAndCognitionLab/ctx-flanker/tree/public/papers/current>. The main outputs are individual estimates of assimilation and contrast effects and a posterior distribution of the correlation. The individual estimates are shown in the scatter plot in Figure 4A; more positive values indicate a stronger assimilation and stronger contrast effects in the respective background contexts.

As can be seen in Figure 4A, there is a fair degree of variation across individuals as well as an overall positive relationship. An issue, however, is the presence of an outlying

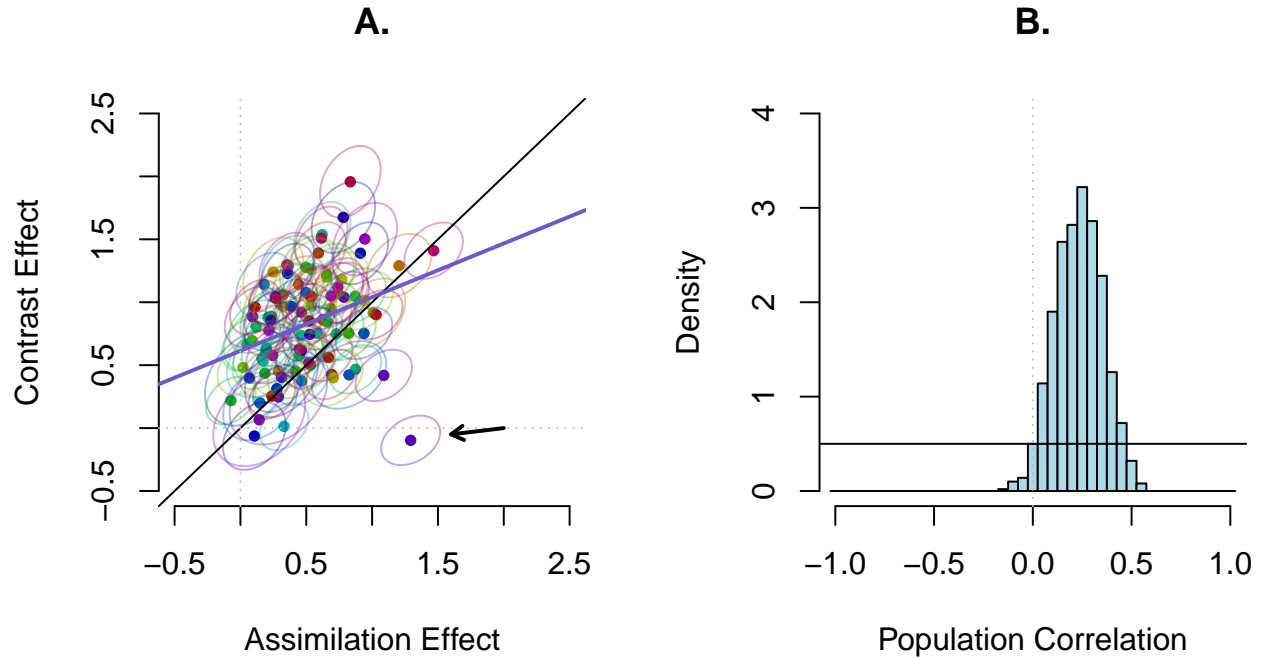


Figure 4. Model Results. **A.** Each participant’s estimated assimilation effect against their estimated contrast effect. An ellipse denotes the standard deviations of the estimate and the blue regression line is the line of best fit. **B.** The posterior distribution of the population correlation,  $\rho$ , between assimilation and contrast. The solid line denotes the prior distribution.

point, indicated with an arrow. This participant had the highest degree of assimilation and the lowest degree of contrast. Performance here stands apart from that of the other participants; if the points is included in analysis, then it would have great leverage. We decided in a *post-hoc* manner to exclude this participant, and the following analyses are based on this exclusion. Our results therefore pertain to the vast majority of individuals in the main cluster.

Assimilation and contrast estimates show a positive relationship as seen by the OLS regression line in Figure 4A. OLS regression, however, is inappropriate as an inferential tool because the estimates are correlated through the hierarchical structure. To perform inference, we plot the prior and posterior distributions of the population-level correlation coefficient. The prior distribution here was chosen to be flat, placing equal plausibility on all values of the correlation coefficient. The resulting posterior distribution is well localized for

positive values away from zero. The mean of this posterior distribution serves as a point estimate, and it is 0.23. One way of competitively assessing the null-correlation hypothesis vs. the alternative is to compute the change in plausibility at zero. The plausibility was greatly reduced by a factor of 1. This indicates the data are 1 times more plausible under the alternative than the null, and this computation is the Savage-Dickey approach to Bayes factors (Dickey, 1971; Gelfand & Smith, 1990).

To place this correlation in context, it is helpful to consider the reliability of individual estimates. We suspected high reliability because we had each participant perform a total of 960 trials, which is quite numerous. We split each individual's data into odd and even trials, and reran the Bayesian probit regression analysis separately for the odd and even trials. Each analysis provides an estimate of each individual's assimilation and contrast, and the assimilation estimates in the odd trials may be correlated with the assimilation in the even trials, and the same for the contrast estimates. The correlation among individuals' assimilation estimates was 0.76; the correlation among individuals' contrast estimates was 0.78. These values when extrapolated to the full sample imply reliabilities of 0.86 and 0.87, respectively. Hence, much of the variation in the scatter is not due to trial-by-trial noise, but reflect true latent variation across individuals.

## Discussion

Our goal here was to explore whether inhibition was mediate by a common or distinct mechanisms in assimilation and contrast contexts. On one hand, inhibition is often conceptualized as a well-integrated concept (e.g., Miyake et al., 2000). On the other hand, assimilation is often thought of as a response-level cognitive process (B. A. Eriksen & Eriksen, 1974) whereas contrast is thought of as a low-level perceptual process (e.g., Palmer, 1999). To explore this question, we assessed the correlation between individuals' ability to inhibit background assimilative information and their ability to inhibit background contrastive information. Our approach relied on morph-letter targets. Large assimilation

effects were found when the surrounding, to-be-ignored information could potentially be a word, replicating the often observed top-down effect of word contexts on letter identification. Contrast effects were found when the surrounding contexts were letters, replicating Rouder and King (2003). The key finding is a positive correlation across individuals. Individuals who were better able to inhibit the contrastive effects of surrounding letter contexts were better able to inhibit the assimilative effects of surrounding word contexts.

The findings are surprising inasmuch as contrast and assimilation effects are generally thought to have different loci. We think the correlation is of interest in itself. Perhaps the most parsimonious account is from Lachter, Forster, and Ruthruff (2004), who provide an updated version of Broadband's classic early-attention theory (Broadbent, 1958). Here attention acts fairly early but is imperfect and some irrelevant information is processed. When it is, the ensuing contrast and assimilation effects result. In this view, the common variation across these tasks indexes the individual's raw ability to control selective attention. Linking correlations with processing must be done tentatively. The next step forward in this line of research is exploring how the correlations across contrastive and assimilative tasks interact with manipulations designed to affect spatial attention.

***Author's Contributions.*** H.K.S. helped conceive the project, programed the experiment, performed the Bayesian data analysis, and contributed to the writing of the manuscript. S. M. R. led data collection and provided initial analysis of the data. J. M. H. contributed to the design and data analysis. J. N. R. contributed to all aspects of the project except for data collection. All authors take responsibility for the integrity of the data, analysis, and interpretation.

## References

- Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of adhd. *Psychological Bulletin*, 121(1), 65.
- Baron, J., & Thurston, I. (1973). An analysis of the word-superiority effect. *Cognitive Psychology*, 4(2), 207–228.
- Barrett, L. F., Tugade, M. M., & Engle, R. W. (2004). Individual differences in working memory capacity and dual-process theories of the mind. *Psychological Bulletin*, 130(4), 553–573.
- Broadbent, D. E. (1958). *Perception and communication*. New York: Oxford University Press.
- Carpenter, G. A., & Grossberg, S. (1987). A massively parallel architecture for a self-organizing neural pattern recognition machine. *Computer Vision, Graphics, and Image Processing*, 37(1), 54–115.
- Cowan, N. (1995). *Attention and memory: An integrated framework*. Oxford University Press.
- Davis-Stober, C., Dana, J., & Rouder, J. N. (2017). When are sample means meaningful? The role of modern estimation in psychological science. *Open Science Framework*. April, 12.
- Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, 18(1), 193–222.
- Dickey, J. M. (1971). The weighted likelihood ratio, linear hypotheses on normal location parameters. *The Annals of Mathematical Statistics*, 42(1), 204–223. Retrieved from <http://www.jstor.org/stable/2958475>
- Efron, B., & Morris, C. (1977). Stein's paradox in statistics. *Scientific American*, 236, 119–127.
- Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a

- target letter in a nonsearch task. *Perception & Psychophysics*, 16, 143–149.
- Eriksen, C. W., & Schultz, D. (1979). Information processing in visual search: A continuous flow conception and experimental results. *Perception & Psychophysics*, 25, 249–263.
- Gelfand, A., & Smith, A. F. M. (1990). Sampling based approaches to calculating marginal densities. *Journal of the American Statistical Association*, 85, 398–409.
- Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 22, pp. 193–225). Academic Press.
- Hedden, T., & Gabrieli, J. D. (2010). Shared and selective neural correlates of inhibition, facilitation, and shifting processes during executive control. *Neuroimage*, 51(1), 421–431.
- Helmholtz, H. von. (1867). *Treatise on physiological optics* vol. iii.
- James, W. (1890). *Principles of psychology (Volume I)*. New York: Holt. Retrieved from <http://psychclassics.yorku.ca/James/Principles/index.htm>
- Lachter, J., Forster, K. I., & Ruthruff, E. (2004). Forty-five years after broadbent (1958): Still no identification without attention. *Psychological Review*, 111(4), 880.
- Lehmann, E. L., & Casella, G. (1998). *Theory of point estimation, 2nd edition*. New York: Springer.
- Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology*, 41(1), 49–100.
- Neisser. (1967). *Cognitive psychology* (Classic Edition.). Psychology Press/Meredith Publishing Company.
- Palmer, S. E. (1999). *Vision science: Photons to phenomenology*. Cambridge, MA: MIT Press.
- Reicher, G. M. (1969). Perceptual recognition as a function of meaningfulness of stimulus



- material. *Journal of Experimental Psychology*, 81, 275–289.
- Rouder, J. N. (2014). Optional stopping: No problem for Bayesians. *Psychonomic Bulletin & Review*, 21, 301–308. Retrieved from <http://dx.doi.org/10.3758/s13423-014-0595-4>
- Rouder, J. N. (2016). The what, why, and how of born-open data. *Behavioral Research Methods*, 48, 1062–1069. Retrieved from [10.3758/s13428-015-0630-z](http://dx.doi.org/10.3758/s13428-015-0630-z)
- Rouder, J. N., & King, J. W. (2003). Flanker and negative flanker effects in letter identification. *Perception & Psychophysics*, 65(2), 287–297.
- Rumelhart, D. E., & McClelland, J. L. (1982). An interactive activation model of context effects in letter perception: II. The contextual enhancement effect and some tests and extensions of the model. *Psychological Review*, 89, 60–94.