Is there emotional interference in a Stroop-like paradigm? Electrophysiologic evidence from temporal PCA applied to current source density (CSD) waveforms

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Abstract

Behavioral interference of emotional content has been reported for Stroop-like paradigms, but rarely studied using ERPs. Using the ANEW norms, word content (emotional, neutral) and valence (positive, negative) were systematically matched for valence, arousal, length, and frequency. Ignoring content, subjects indicated the color (blue, green, red, yellow) of foveally presented words via 4-button press using both hands. Positive/neutral and negative/neutral blocks were counterbalanced within subjects. Mean response latencies (671 ±98 ms) did not reveal emotional interference. Using 67-channel ERP recordings of 29 right-handed healthy adults, temporal principal components (unrestricted Varimax) were derived from stimulus- and response-locked reference-free CSD waveforms (common prestimulus baseline) to characterize neuronal generator patterns underlying emotional interference driven by stimulus (attentional/emotional bias) and/or response (selection/monitoring) processes. Stimulus-locked CSD factors were unambiguously related to ERP components known to reflect visual word processing. An inferior temporoparietal N2 sink (207 ms peak latency) showed a marked left-larger-than-right hemispheric asymmetry that was reduced for emotional compared to neutral words, suggesting differential categorization of emotional content. In contrast, a midparietal P3 source (359 ms) revealed no content or valence effects but was asymmetrically modulated by response hand. Response-locked analysis revealed an ERN-like midfrontal sink accompanied by a bilateral centroparietal source (39 ms) also asymmetrically affected by response hand. Although this source was greater for negative than positive blocks, it is unclear whether this reflects emotional interference (i.e., negative priming of neutral words) or random stimulus effects. The absence of content by valence effects and lack of behavioral interference questions the validity of the reported "emotional Stroop" phenomenon in healthy adults.

Introduction

- Weak behavioral effects related to the paradigm or differences in experimental methodology may mask or mimic emotional interference in Stroop-like paradigms (e.g., Whalen et al., 1998; Compton et al., 2003; McKenna and Sharma, 1995).
- Few studies have investigated ERP correlates of emotional interference of sensory- and/or response-related processing using a Stroop-like paradigm (e.g., Metzger et al., 1997; Perez-Edger & Fox, 2003).
- Enhanced ERP components related to processing emotional stimuli (e.g., N2/P3 complex) have been reported in studies exploiting the implicit emotional quality of a stimulus without requiring overt responses (Kayser et al., 1997, 2000) and those that blend cognitive and emotional processes (Cuthbert et al., 2000; Delplanque et al., 2005; Dietrich et al., 2001; Schupp et al., 2003a, 2003b).

Objective:

1. Develop a paradigm that controls for (i.e., limits) unrelated cognitive processes (e.g., word recognition or stimulus habituation) that may confound emotional effects of interest.
2. Investigate the time course and the contribution of regional cortical activity related to different stages of stimulus-locked information processing and cognitive interference locked to responses within an emotional Stroop paradigm by using a PCA approach to reference-free CSD waveforms.

Hypotheses:

1. Emotional words would produce longer RTs than neutral words due to a greater amount of attentional load.
2. Emotional compared to neutral words would result in N2-P3 augmentations seen as:
   a) Greater activity over ventroposterior and left temporal regions (N2)
   b) Greater midparietal activity (P3b)
3. Emotional words would produce an enhancement in cognitive interference resulting in an enhancement of ERN-like response-locked activity.

Participants

Healthy Adults (n = 29)	
Gender (male/female)	15 / 14
Age (years)	27.8 ± 6.6 (20 – 41)
Education (years)	16.7 ± 1.8 (14 – 21)
Handedness (EHI)	83.3 ± 17.5 (42.9 – 100.0)

- no history of psychopathology or neurological disorder
- Normal color vision
- Normal or corrected-to-normal visual acuity

Stimuli and Procedure

- 192 words rated for affective valence, arousal, and dominance (selected from the Affective Norms for English Words [ANEW; Bradley & Lang, 1999])
- 48 Positive-Emotional words - upper ANEW quartile (positive valence)
- 48 Negative-Neutral words - lower ANEW quartile (negative valence)
- 96 Neutral words - second and third ANEW quartiles (intermediate valence), systematically matched to positive and negative words for word length (labeled positive-neutral and negative-neutral, respectively)
- Participants self-rated ANEW words on the Semantic Apperception Scale following EEG recording session

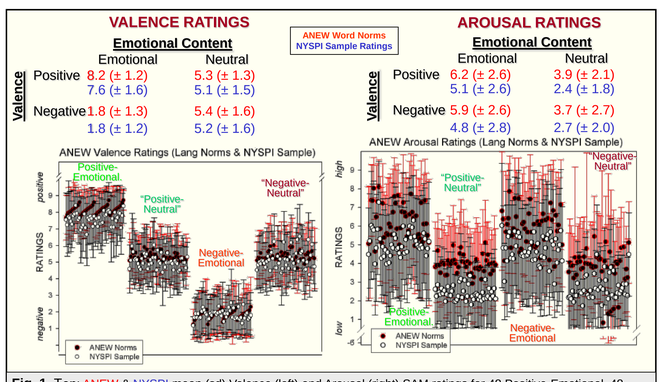


Fig. 1. Top: ANEW & NYSPI mean (sd) Valence (left) and Arousal (right) SAM ratings for 48 Positive-Emotional, 48 Positive-Neutral, 48 Negative-Emotional, and 48 Negative-Neutral words. **Bottom:** Scatter-plot of 192 mean SAM ratings for Valence (left) and Arousal (right) across ANEW (black/red error bars) & NYSPI samples (white/black error bars)

- Pseudorandomized (across participants) stimulus sequences (8 blocks of 12 word pairs):
  - emotional content (i.e., emotional or neutral) did not occur more than twice consecutively
  - participants exposed to each word only once
- Matched word pairs were in the same color (**blue**, **green**, **red**, **yellow**) under the following restrictions:
  1) the frequency of each color was equally presented to every participant
  2) the frequency of each color presentation was equal in every block
  3) no color was presented more than twice consecutively
- Color was indicated by a 4-choice button press (two buttons assigned to the left hand and two buttons assigned to the right hand, color assignment counterbalanced across participants)
- pseudorandomized across four SOAs (1.700, 1.825,1.950, 2.075 ms); 150 ms exposure
- Instructions: 1) indicate stimulus color as quickly and accurately as possible ; 2) ignore meaning of words

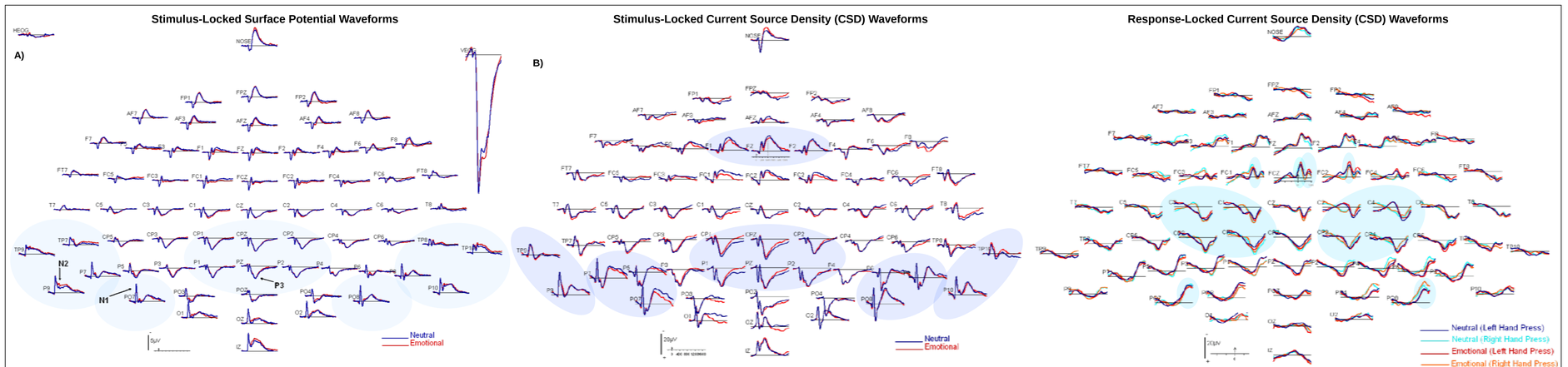


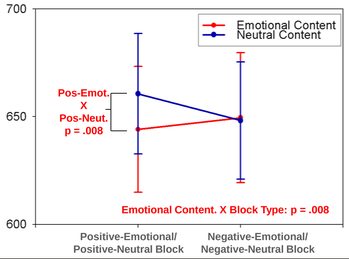
Fig. 2. **A) Mean average-referenced, stimulus-locked ERP waveforms for all emotional (red) and neutral (blue) words.** ERPs are comparable to waveforms reported by studies investigating the traditional Stroop (Liotti et al., 2000; West & Alain, 1999) and emotional Stroop (Perez-Edgar & Fox, 2003) paradigms

B) Grand mean stimulus-locked, reference-free CSD waveforms. A clear, stimulus-specific (i.e., visual-verbal) component structure with a ventroposterior N1 sink (141ms), an inferior temporoparietal N2 sink (207 ms), and a midparietal P3 source (359 ms) is present across conditions.

C) Grand mean response-locked, reference-free CSD waveforms. A prominent midfrontal sink (FCz maximum at approximately 40 ms) was shown for both emotional and neutral words. An expected response-related asymmetry at central sites (e.g., C3/4) was observed as right-greater-than-left sink for Emotional left-hand and Neutral left-hand presses, and a left-greater-than-right sink for Emotional right-hand and Neutral right-hand presses.

Behavioral Results

Condition	RT(ms)	(SEM)	% Correct	(SD)
Positive-Emotional	644.1	(29.2)	94.8	(5.8)
Positive-Neutral	660.6	(28.0)	94.2	(6.4)
Negative-Emotional	649.5	(30.1)	93.4	(7.9)
Negative-Neutral	648.2	(27.2)	92.8	(7.2)



Mean Log Transformed Response Latencies (SD) and Percentage Correct (SD) for Each Experimental Condition.

ERP Recording and Data Analysis

- Continuous DC (24-bit A/D) EEGs using an electrode cap, 67 scalp sites (extended 10-20 system), active recording reference (BioSemi), 256 samples/s. Continuous data exported to NeuroScan format using PolyRex (Kayser, 2003). Highpass causal filter (0.05 Hz) applied offline to remove DC drift/offsets. Rereferenced to average reference offline.
- Bipolar horizontal and vertical EOGs; blink reduction (continuous EEG) using spatial SVD; horizontal eye artifact correction (epoched EEG) using linear regressions of lateral EEG differences (Fp2-Fp1, etc.) then removing correlated activity (±beta weight / 2) of each lateral channel (Kayser et al. 2006).
- 2,000 ms epochs, 250 ms pre-stimulus baseline, ERP averages (artifact-free trials, correct responses) low pass filtered at 12.5 Hz (-24dB/oct.), 250 ms baseline correction
- Current Source Density (CSD) waveforms were derived from average-reference surface-potential waveforms. CSDs were submitted to ***unrestricted* temporal principal components analysis (PCA)** derived from the covariance matrix followed by *unscaled* Varimax rotation (Kayser & Tenke, 2003), to identify and measure the temporal pattern and spatial distribution of underlying cortical activity
- Factor scores of meaningful PCA factors were submitted to repeated measures ANOVA with Valence (Positive, Negative), Emotional Content (Emotional, Neutral), and Response Hand as within-subjects factors. A conventional significance level ($p < .05$) was applied for all effects.
- Subsets of recording sites at which PCA factor scores are largest and most representative of the associated component structure were included as a within-subjects factor
- ***Behavioral data***: The percentage of correct responses and mean response time for each condition were submitted to repeated-measures analysis of variance (ANOVA) with emotional Valence (positive and negative), Emotional Content (emotional and neutral), and Response Hand (right and left) as within-subjects factors, and Gender as a between-subjects factor.

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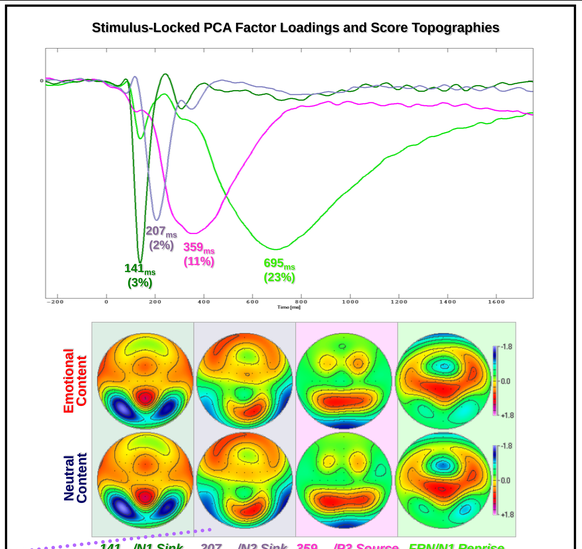

Figure 3. **Stimulus-Locked CSD-PCA Factor Loadings & Topographies.** **Top:** The first five extracted factors account for 88% of explained variance (1st factor representing slow-wave activity not shown). **Bottom:** Factors of interest included: A bilateral occipitoparietal sink (***N1 sink***, 141 ms); bilateral, inferior temporoparietal sink (***N2 sink***, 207 ms); midparietal source (***P3 source***, 359 ms); and a late (695 ms) midfrontal, response-related sink (***FRN***) accompanied by bilateral occipitoparietal sinks (***N1 reprise***). A marked left-greater-than-right asymmetry [$F(1,27) = 22.24$, $p = 0.0001$] was seen for *N207* over inferior temporoparietal sites (e.g., TP9/10). While *N2 sink* amplitude varied with emotional content (Figure 5), *P3 source* revealed no content or valence effects, but was asymmetrically modulated by response-hand (i.e.., greater over ipsilateral hemisphere).

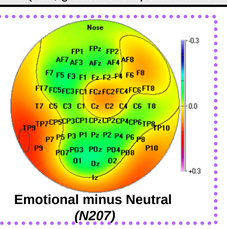

Figure 4. **Emotional net effect of *N2 Sink*.** Sinks over inferior temporoparietal sites were significantly reduced for emotional words compared to neutral words [$F(1,27) = 4.45$, $p=0.04$].

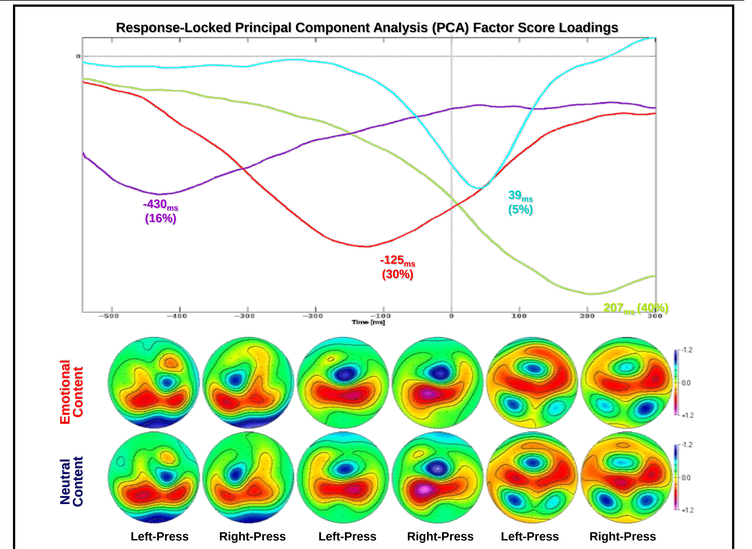

Figure 5. **Response-Locked CSD-PCA Factor Loadings & Topographies**. **Top:** The 1st four factors account for 91% of explained variance. **Bottom:** An ***FRN midfrontal sink*** (39 ms) is accompanied by asymmetric centroparietal bilateral sources. While the ERN-like sink did not systematically vary or interact with emotional content or valence, an enhancement of the accompanying posterior sources were observed contralateral to response-hands. This source amplitude was also greater in negative-emotional/negative-neutral than positive-emotional/positive-neutral blocks. Other response-related factors correspond highly with a subset of stimulus-locked factors including: B parietal sources accompanied by asymmetrical bilateral sinks (***P3 source***, -125 ms); and a late (207 ms) midfrontal sink (***FRN***) with bilateral occipitoparietal sinks (***N1 reprise***).

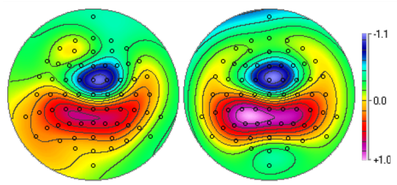

Figure 6. **Response-locked *FRN* Factor Score Topographies for Negative and Positive Blocks**. Greater parietal source activity was observed for Negative-Emotional/Negative-Neutral blocks (Right) than Positive/Postive (Left) blocks [$F(1,27) = 5.72$, $p=0.02$]. However, no differences in amplitude were observed between emotional and neutral trials within either block for this factor.

Summary and Conclusions

Behavioral Findings:

- Behavioral interference (e.g., longer RT) for emotional compared to neutral words was not observed.

Stimulus-Related CSD Findings:

- Significantly left-larger-than-right hemispheric N2 (207 ms) asymmetry was reduced for emotional compared to neutral words, suggesting differential categorization of emotional content.
- A midparietal P3 source (359 ms) revealed no content or valence effects but was asymmetrically modulated by response hand (enhanced for ipsilateral hemisphere).

Response-Related CSD Findings:

- No differences in emotional content were observed in any response-related factor.
- Greater amplitude in parietal sources accompanying the ERN sink were found for Negative-Emotional/Negative-Neutral blocks; however, it is unclear whether this reflects emotional interference (i.e., negative priming of neutral words) or random stimulus effects.

General Conclusion

- Whereas the difference between emotional and neutral words indexed by *N207* may reflect physiological processes (e.g., differential categorization) preceding overt behavioral interference, the lack of clear behavioral and/or electrophysiological effects resulting from a stringently controlled paradigm provide weak support for emotional-Stroop interference.