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Neuromodulation of cursing in American English: A combined tDCS and pupillometry study

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ABSTRACT

Many neurological disorders are associated with excessive and/or uncontrolled cursing. The right prefrontal cortex has long been implicated in a diverse range of cognitive processes that underlie the propensity for cursing, including non-propositional language representation, emotion regulation, theory of mind, and affective arousal. Neurogenic cursing often poses significant negative social consequences, and there is no known behavioral intervention for this communicative disorder. We examined whether right vs. left lateralized prefrontal neurostimultion via tDCS could modulate taboo word production in neurotypical adults. We employed a pre/post design with a bilateral frontal electrode montage. Half the participants received left anodal and right cathodal stimulation; the remainder received the opposite polarity stimulation at the same anatomical loci. We employed physiological (pupillometry) and behavioral (reaction time) dependent measures as participants read aloud taboo and non-taboo words. Pupillary responses demonstrated a crossover reaction, suggestive of modulation of phasic arousal during cursing. Participants in the right anodal condition showed elevated pupil responses for taboo words post stimulation. In contrast, participants in the right cathodal condition showed relative dampening of pupil responses for taboo words post stimulation. We observed no effects of stimulation on response times. We interpret these findings as supporting modulation of right hemisphere affective arousal that disproportionately impacts taboo word processing. We discuss alternate accounts of the data and future applications to neurological disorders.

1. Introduction

Cursing represents a powerful and ubiquitous component of natural language. In American English, cursing serves beneficial functions such as pain alleviation, increased grip strength, and social bonding among peers (Bergen, 2016; Stephens, Atkins, & Kingston, 2009; Stephens, Spierer, & Katehis, 2018). These benefits are counterbalanced by a variety of negative social and/or legal consequences. For example, no other subset of our lexicon has the power to compel a parent to symbolically wash their child's mouth out with soap or to trigger a misdemeanor charge when taboo words are uttered on a public roadway. Cursing is *verboten* in some social contexts, yet entirely appropriate and indeed socially sanctioned in other situations. There exists no fixed set of rules that govern taboo word usage, and pragmatic decisions about taboo word usage typically rest with the speaker.

Most of us know friends or family members who struggle with the unwritten pragmatic rules that govern cursing. Occasional violations in the quantity, quality, and contextual appropriateness of taboo word usage are not necessarily a marker of neuropsychiatric pathology. The propensity to curse across different age ranges and social strata varies greatly among neurotypical speakers (Jay, 2009, 1992). In contrast, non-volitional or uncontrolled cursing is a hallmark of numerous neurological disorders that impact cognitive, linguistic, and/or emotional control. Hereafter, we refer to this phenomenon as *neurogenic cursing.*[1] Neurogenic cursing is characterized by excessive and/or non-volitional production of taboo words (Van Lancker & Cummings, 1999), a feature that is evident across a wide range of disorders, including stroke aphasia, Tourette syndrome, traumatic brain injury, schizophrenia, and the behavioral variant of frontotemporal degeneration (bvFTD) (Bergen, 2016; Freeman et al., 2009; Jay, 2000; Martino, Madhusudan,

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[1] An alternate term for neurogenic cursing is *coprophenomena.* This nomenclature does not, however, meet with universal agreement as an appropriate umbrella descriptor for any type of cursing that emerges in the context of a neurological disorder. Many sources link coprolalia exclusively with Tourette Syndrome.

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Zis, & Cavanna, 2013; Ringman et al., 2010; Van Lancker & Cummings, 1999). Neurogenic cursing is frequent fodder for humor in film and media. People affected by this condition anecdotally report distress. However, the impact of non-volitional cursing on psychosocial and/or occupational functioning has never been formally assessed. Morevero, there is no known behavioral treatment for this communication disorder.

1.1. A brief review of neurogenic cursing

Neurolinguistics was built upon a foundation of aphasiology and its tradition of linking brain structure to particular linguistic functions. Introductory language textbooks often highlight Paul Broca's seminal case study of Leborgne (Broca, 1863). Leborgne presented with a unique language profile; most of his expressive language was limited to the neologism, *tan.* Many subsequent case descriptions referred to Leborgne by the moniker "Tan". Upon autopsy, Broca discovered an extensive lesion encompassing the third inferior covolution of Leborgne's left frontal lobe, linking his nonfluent, neologistic production to what has since become known as Broca's Area (but see Dronkers, Plaisant, Iba-Zizen, & Cabanis, 2007). "Tan" is perhaps a misnomer, however, because in addition to this single neologism, Leborgne was also able to produce taboo the religious epithet "Sacre nom de Dieu!" (roughly translated, "God be damned!"), serving as early evidence for the uniqueness and modularity of taboo expressions in the lexicon.

Later in the 19th century, Hughlings-Jackson cultivated an interest in the etiology of neurogenic cursing, offering perhaps the first cogent theory of the representation of cursing in the human brain (Hughlings-Jackson, 1878). Hughlings-Jackson noted the relative preservation of non-propositional language in patients with aphasia secondary to left hemisphere brain injury, including lexicalized and overlearned phrases such as counting, reciting the alphabet or a prayer, or producing an idiom. Cursing, particularly automatic cursing where utterances are void of a specific semantic context, represents one form of non-propositional language mediated by the right cerebral hemisphere. When the left hemisphere is damaged, patients often lose access to propositional language (e.g., open class words) while retaining residual contribution (s) of the right hemisphere. Stated in an even stronger tenor, damage to the left hemisphere often results in predominence of the non-dominant hemisphere. This right hemisphere lateralization hypothesis remains one of the dominant approaches to characterizing neurogenic cursing to this day.

Gilles de la Tourette Syndrome (GTS) presents another contrastive case of neurogenic cursing. The core diagnostic features of GTS are tics involving partially involuntary motor movements of the face and extremities coupled with stochastic phonic productions often perceived as grunts or squeaks (Martino et al., 2013). A minority (10% to 50%) of people with GTS experience the co-morbid behavior of coprolalia (Bergen, 2016; Freeman et al., 2009), characterized by the semi-involuntary production of taboo words. People with GTS may also experience related phenomena such as copropraxia (i.e., obscene gestures). Whereas cursing in aphasia appears subjectively normal in terms of rate and volume, coprolalia in GTS has been described as pressured and staccato with abnormal prosodic contours, rapid rate, and excessive volume (Freeman et al., 2009).

It is difficult to reconcile coprolalia in GTS within a strict lateralization approach. The pathology of GTS is believed to involve dysfunction of cortico-striato-thalamo-cortical circuitry, specifically the basal ganglia and frontal lobes (Kushner, 2009; Peterson et al., 2001). People who experience GTS are not aphasic, nor is their expressive language limited to non-propositional words and phrases. Moreover, the phenomenology of cursing in GTS appears to fundamentally differ from that of aphasia. People with GTS have been known to premonitorily "sanitize" their output (e.g., swapping 'fake' for 'fuck'). In addition, people with GTS subjectively describe coprophenomena similar to that of sneezing: a progressive buildup of pressure until there is a sudden cursing release (Kushner, 2009; Peterson et al., 2001).

Dysexecutive disorders that emerge in the context of frontoparietal damage present yet another form of neurogenic cursing that qualitatively differs from both aphasia and GTS. Executive functioning is a broad cognitive construct encompassing attentional vigilence, theory of mind, cognitive estimation, emotion regulation, metacognition, and inhibitory control (and arguably others) (Alvarez & Emory, 2006; Banich, 2009; Fernandez-Duque, Baird, & Posner, 2000; Stuss & Knight, 2002; Zelazo, Craik, & Booth, 2004; Zelazo & Cunningham, 2007). Some subdomains of executive functioning are bilaterally represented, whereas others (e.g., attentional vigilance, spatial attention) appear to have right hemisphere specialization (Heilman & Van Den Abell, 1980). Two neurological disorders associated with executive dysfunction are often notable for the presence of neurogenic cursing, traumatic brain injury (TBI) and the behavioral variant of frontotemporal degeneration (bvFTD) (Gordon, Haddad, Brown, Hibbard, & Sliwinski, 2000; Ringman et al., 2010).

It has long been recognized that orbitofrontal cortex and adjacent frontal lobe structures play crucial roles in behavioral inhibition and emotion regulation. Phinneas Gage represents one of the best-known neuropsychological case studies of a dysexecutive disorder arising from prefrontal cortex damage. Gage was a railroad foreman who was the victim of a tamping iron that was propelled with explosive force on an upward trajectory entering through the left cheek, obliterating his left eye, and exiting from the top of his skull (Hughlings-Jackson, 1878). Gage's physical convalescence was reportedly swift. However, he experienced profound post-morbid personality, behavior, and judgment changes. His physician commented of Gage, "He is fitful, irreverent, indulging at times in the grossest profanity (which was not previously his custom)" (Harlow, 1868). Although no formal autopsy was performed, his skull was retained, more than a century later yielding clues to the trajectory of the tamping rod and the probable margins of the associated neurological damage. Modern reconstructive methods have linked Gage's executive dysfunction largely to left prefrontal cortex and its underlying white matter connectivity (Horn et al., 2012)

Each of the disorders we have discussed thus far (aphasia, GTS, TBI, bvFTD) are characterized by excessive and/or uncontrolled cursing. In contrast, right hemisphere frontal lobe damage is typically associated with diminished cursing. This relative dearth of cursing behavior in right hemisphere disorders has been attributed to unavailability of non-propositional language and a diminished capacity to experience extremes of negative valence that would evoke spontaneous and automatic cursing (Jay, 2000). Patients with right hemisphere damage also have difficulties with other forms of non-propositional language, including comprehension of idioms, metaphor, and jokes (Coulson & Van Petten, 2007; Coulson & Wu, 2005; Speedie, Wertman, Ta'ir, & Heilman, 1993; Van Lancker & Kempler, 1987). In addition to these high level linguistic deficits, damage to the right prefrontal cortex also produces apathy, hypoarousal, and neglect (Heilman & Valenstein, 1979; Heilman & Van Den Abell, 1980; Hillis, 2006). Eden et al. (2015) diffusion tensor imaging study illustrated the relationship between emotion regulation and the PFC establishing links between anxiety and structural connectivity between amygdala and right PFC.

1.2. Aims of the current study

We have identified numerous brain pathologies that can cause a person to curse either more or less. In the study to follow we focus on differences in hemispheric lateralization. More specifically, we evaluated whether transcranial direct current stimulation to the left or right frontal lobes could modulate either behavior (e.g., reaction times) or physiological responses (e.g., task-evoked and resting state pupillometry) as neurotypical adults read aloud or inhibited verbal response to taboo words. Here, the focus is on the impact of word tabooness in hemispheric recruitment. Tabooness in words is defined mostly by reduced emotional valence, and heightened physiological arousal, with an interaction between the two (Reilly et al., 2020). As such, we employed stimuli matching procedures controlling for these constituents of tabooness.

Our predictions regarding the effects of tDCS are predicated upon the mechanism of anodal-excitation and cathodal-inhibition (AeCi) effects (Jacobson, Koslowsky, & Lavidor, 2012). This assumption holds that anodal stimulation will produce subthreshold depolarization of the resting neuronal membrane potential proximal to the strongest locus of electrical field flow, in turn producing subtle upregulation of the stimulated areas. In contrast, cathodal stimulation will produce subthreshold hyperpolarization of colonies of neurons, resulting in subtle downregulation of stimulated areas (Bikson, Datta, Rahman, & Scaturro, 2010; Bikson, Rahman, & Datta, 2012; Brunoni et al., 2012; Jacobson et al., 2012; Price, McAdams, Grossman, & Hamilton, 2015).[2]

Given these assumptions about AeCi effects in tDCS, we hypothesized that a bilateral electrode montage that upregulates right prefrontal cortex (anodal) and downregulates left prefrontal cortex (cathodal) would grossly mimic neurogenic cursing behavior in aphasia. This stimulation montage would potentially amplify the degree of negative valence associated with a given word, consequently increasing phasic arousal for taboo words. This effect would be evident in greater dispersion between the peak pupillary amplitudes between taboo and non-taboo words along with reaction time slowing for taboo relative to non-taboo words. Previous work utilizing non-invasive brain stimulation tends to support this hypothesis. For example, Roesmann et al. (2019) modulated right versus left hemisphere prefrontal cortices using inhibitory continuous theta burst transcranial magnetic stimulation (cTMS) to investigate hemispheric differences in valence processing. Participants received stimulation followed by magnetoencephalographic recording of activation elicited by silent reading of emotionally valent words. A double dissociation was found such that left-lateralized cTBS evoked more cortical activation for negatively valenced words, whereas right hemisphere cTBS amplified responsivity to positively valenced words. The electrode montage we employed in the experiment to follow targeted prefrontal cortex with a between-subjects manipulation of electrical polarity.

2. Methods & materials

2.1. Overview

We conducted a pre/post neurostimulation design with two participant groups, each receiving opposite polarity stimulation with the same electrode montage placement. In the pre-stimulation condition, participants read aloud lists of taboo and non-taboo words as we continuously monitored pupil size and collected reading latencies. Participants were then subjected to a 20-minute intervening session of neurostimulation. In the post-stimulation session, participants read aloud lists of taboo and non-taboo words matched in form to the pre-stimulus list (see stimulus development). We contrasted reading latencies and pupillary response patterns both within and between subjects as functions of word type (taboo/non-taboo), polarity (cathodal/anodal), and time (pre/post stimulation).

2.2. Participants

Participants included young adults between the ages of 18-35 from the Temple University community. Participants were by self-report free of neurological disorders (including past seizure activity) and reading and visual disability. We used stratified random assignment to construct two groups roughly matched in the frequency of taboo word usage as determined by a self-report survey administered prior to stimulation (see Appendix A). For example, if a participant assigned to tDCS Condition A indicated a high propensity to curse, we assigned another participant with similar subjective ratings to tDCS Condition B. The goal of this procedure was to homogenize the groups as much as possible. The two experimental groups did not differ ($p > .05$ all) in terms of age (mean = 24.63 years), sex distribution (10 m/22f), subjectively reported taboo word usage (3.91 on a 7-pt Likert Scale), or religiosity (2.33 on a 7-pt Likert Scale).

2.3. Electrode montage & neurostimulation parameters

We administered stimulation using a 1×1 low intensity transcranial direct current stimulator (Soterix Medical Inc., Model 1300) with an intensity of 2 mA for a duration of 20 min. Both the anode and cathode electrodes were positioned within 5×3 cm rectangular saline soaked sponges fixed in place using caps pre-landmarked to the 10/20 EEG system (EASYCAP). One electrode was placed over the right dorsolateral prefrontal cortex, while the other was situated over the left hemisphere homologue. One group received left anodal and right cathodal stimulation. The other group received the opposite polarity stimulation at the same anatomical sites.

We derived estimates of local electrical field intensity and field flow directionality for this stimulation montage using Stim Preview Viewer on NIC2 software (Neuroelectrics, Inc.). Fig. 1 illustrates a simulation of the field flow, which was primarily localized to prefrontal cortex with peaks in bilateral dlPFC extending to high convexity and ventral frontal regions, including orbitofrontal cortex.

2.4. Pupillometry data collection procedures

We collected continuous measures of pupil size using a remote, table-mounted infrared eyetracker (Eyelink 1000 Plus). The participant's head was held in a fixed position using a chinrest at a distance of approximately 60 cm from a 24″ LED monitor. We sampled pupillary data continuously at an initial rate of 1000 Hz from both eyes. All data collection was completed in a sound and light insulated booth. Data were acquired after each participant successfully completed 9-point calibration and validation procedures at two successive timepoints during the experiment. All ambient lighting in the sound booth was turned off, and the only remaining light source was the computer monitor. Metered luminance at the chinrest was 47 lx.

2.5. Stimulus characteristics & matching procedures

This experiment was composed of two separate word lists, each containing 60 taboo words and 90 non-taboo words matched roughly between lists ($p > .05$) by word length (mean = 6.10 letters), physiological arousal (mean = 5.02 on 7-pt Likert Scale) per the Warriner et al. psycholinguistic norms (2013), word concreteness (mean = 3.48 on a 5pt Likert Scale) per the Brysbaert et al. norms (2013), and word frequency (mean = 36.08 per million words) per the SUBTLEX norms (Brysbaert & New, 2009). Half of the non-taboo words matched the taboo set in terms of negative emotional valence, whereas the remainder were neutrally valent based on the Warriner et al. norms (2013).

Thirty taboo words acted as targets to be read aloud in Experiment Version A, whereas the remaining thirty taboo words acted as fillers. In experiment Version B, the filler items from Version A acted as targets, and the targets from Version A acted as fillers in Version B. 30 non-taboo words appeared as additional targets in each version, with 60 non-taboo items used as fillers. Non-taboo words were not recycled between lists, and no target word was read aloud more than once. Items within word lists were presented in a fixed random order, and word lists

[2] It should be noted that AeCi effects are not always found, and some investigators have argued that single session effects of tDCS are largely unreliable (Horvath, Forte, & Carter, 2015a, 2015b). Cathodal stimulation has been observed to facilitate some behaviors (Binney, Ashaie, Zuckerman, Hung, & Reilly, 2018).

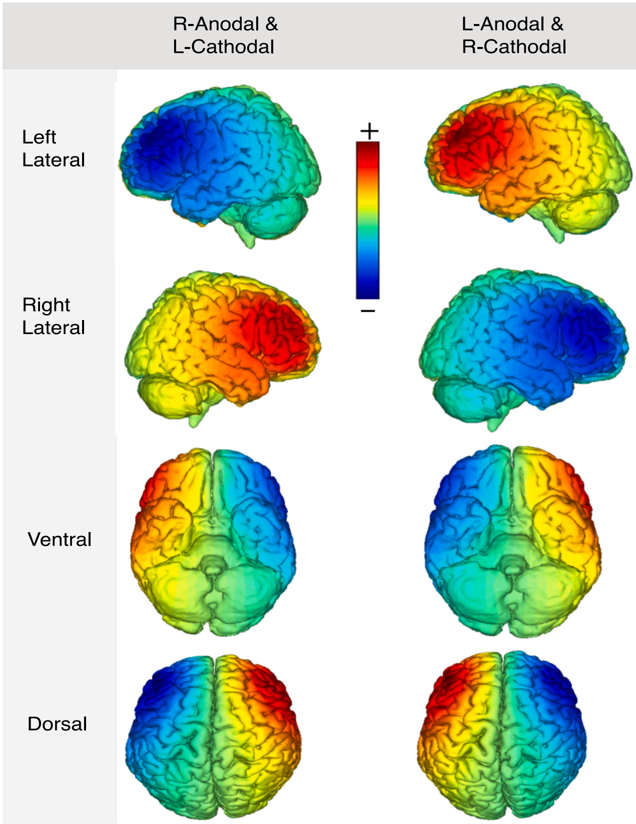

Fig. 1. Field flow estimates.

were counterbalanced. Stimuli were presented in Arial 28 point font using Experiment Builder software (SR Research, Inc).

2.6. Experimental procedures

Participants were positioned in an optical chinrest and after confirming their readiness, the experimenter initiated a sequence of instructions. The participant was instructed that they would view a series of words rapidly appearing and disappearing on their screen. When the font of the presented word was black, the participant was to ignore the word and do nothing. However, when the word appeared in a green font, the participant was instructed to read the word aloud as quickly and accurately as possible. Prior to initiating the true experiment, participants completed a brief familiarization sequence (16 words) with identical timing parameters. Once the participant expressed comfort with the task, the true experiment was initiated.

The experiment was composed of taboo words and non-taboo words. All trials initiated with a 900 ms central attention fixation cross (48 pt in black font) accompanied by a 150 ms 500 Hz pure tone at the onset. Filler and target trials then diverged in terms of task demands. Target (read aloud) trials appeared in a 28 point Arial green font, whereas non-target (do nothing) trials appeared in black. Across both versions of the experiment, all taboo items appeared as target trials (in green font) and non-target trials (in black font) once each, with additional non-target trials differing between versions. All words were presented for 3000 ms. A gray background was maintained throughout the experiment. Stimuli were presented continuously. We recorded all verbal responses for offline scoring using a Tascam digital recorder. Trials were presented in two blocks of 75 trials each.

2.7. Data analysis procedures

We measured naming latencies by marking the time elapsed between the tone indicating stimulus onset and the onset of each response by indexing its respective waveform in Audacity, avoiding filled pauses, coughs, or other vocal artifacts. When reviewing the audio recording, we discovered that the data of two participants was corrupted and/or of poor quality, and these participants were subsequently removed from further analysis. At the item level, one taboo word (i.e., cunnilingus) was discarded due to an excessively high rate of mispronunciation (43%). Incorrect responses occurred at similar rates across all conditions ($> 1\%$ of trials). We analyzed reading latencies exclusively for accurate responses and derived difference scores for each participant (i.e., Taboo minus Other) pre/post stimulation. These difference-in-difference scores allowed us to evaluate relative differences between taboo and non-taboo words as a function of stimulation that is independent of its baseline (Goodman-Bacon, 2018). The latency values were highly positively skewed and non-normally distributed. After trimming outliers, incorrect responses, and distortions, we conducted a Box-Cox transformation (Box & Cox, 1964) of the latencies with the goal of satisfying the normality assumption of ANOVA.

We processed pupillary data using the GazeR package in R (Geller, Winn, Mahr, & Mirman, 2019). Initial steps consisted of isolating data from the right eye only, converting measurements of pupil area from the arbitrary units recorded by the eyetracker to a metric scale (i.e., millimeters) (Hayes & Petrov, 2016) and removing both individual trials and participants with greater than 20% missing data. These cleaning procedures resulted in the removal of one participant from further analysis. Missing data caused by eyeblinks were treated by linear interpolation between a window of 100 ms extended on either side of the blink. The remaining pupil data were bandpass filtered for additional outliers (Mathôt, 2018), and further corrected for abnormally rapid pupil dilation (Kret & Sjak-Shie, 2019). GazeR was used to linearly interpolate across the trimmed timeseries, and smoothing was applied using a simple moving average with an eight item window. Finally, we performed subtractive baseline correction using the median value from a baseline period for each trial defined as the 500 ms preceding stimulus onset, and downsampled the baseline-corrected data to 250 Hz (see also Reilly, Kelly, Kim, Jett, & Zuckerman, 2018). Responses were modeled over a 3000 ms period based on the time course of the pupil response, whose onset can occur several hundred milliseconds after stimulus onset, but peak and degrade over several seconds (Beatty & Lucero-Wagoner, 2000).

3. Results

3.1. Pupil responses to tDCS & tabooness

Fig. 2 illustrates evoked pupil responses to taboo and non-taboo words pre/post stimulation. We contrasted maximum peak pupil amplitude by word type by deriving relative difference scores (in mm of evoked dilation) for the pre-stim condition (taboo – non-taboo) relative to the post-stim condition (taboo – non-taboo). We then contrasted the ‘difference of differences’ within and between-groups using Bayesian t-tests as implemented within Jasp statistical software (Team, 2017).

In stimulation Condition A (right anodal, left cathodal), participants showed relative homogenity of the pupillary response functions pre-stimulation with divergence in the response functions post stimulation. In the pre-stimulation condition, participants showed similar peak amplitudes between taboo (mean = 0.15 mm) and non-taboo words (mean = 0.12 mm) [$BF_{10} = 0.97$ (no evidence for H_1))] and similar sustained amplitudes over the 3000 ms sampling window for taboo [mean = 0.06 mm] and non-taboo words (mean = 0.03 mm)

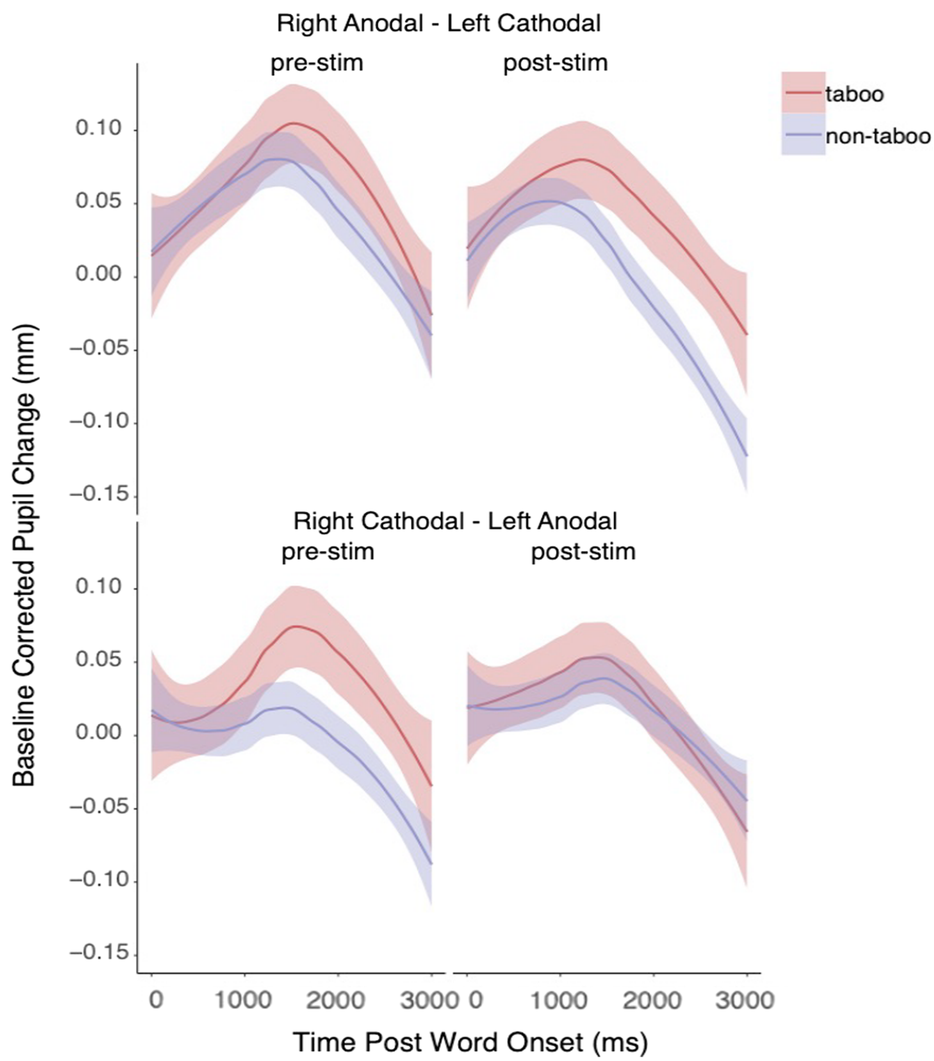

Fig. 2. Word-evoked pupillary responses.

[BF_{10} = 0.76 (no evidence for H_1))]. In the post-stimulation condition, participants showed divergence in the pupillary responses with an elevation in sustained amplitude for taboo (mean = 0.04 mm) relative to non-taboo words (mean = 0.01.mm) [BF_{10} = 1.96 (weak or anecdotal[3] evidence for H_1)] and marginal differences in peak amplitudes for taboo (mean = 0.10 mm) relative to non-taboo words (mean = 0.13 mm) [BF_{10} = 1.45 (weak or anecdotal evidence for H_1)].

In stimulation Condition B (right cathodal, left anodal), participants showed higher peak amplitude pupillary dilation at baseline in the pre-stimulation condition for taboo (mean = . 13 mm) relative to non-taboo (mean = . 08 mm) words [BF_{10} = 3.04 (moderate evidence for H_1)]] and also higher sustained pupil amplitudes for taboo (mean = 0.04 mm) relative to the non-taboo (mean = -0.01 mm) across the 3000 ms sampling window [BF_{10} = 2.70 (moderate evidence for H_1]. Post stimulation peak amplitudes for taboo (mean = 0.10 mm) and non-taboo (mean = 0.08 mm) words marginally differed [BF_{10} = 1.63 (weak evidence for H_1)]]; however, mean sustained pupil amplitudes between taboo (mean = 0.01 mm) vs. non-taboo (mean = 0.01 mm) words were virtually identical [BF_{10} = 0.26 (moderate evidence for H_0)]].

3.2. Reading latency differences as functions of polarity, time, & word type

Reading latencies of participants in both stimulation conditions remained consistant across both time points. In Condition A (right anodal, left cathodal) pre-stimulation condition, participants showed similar reaction times for taboo (mean = 809.78 ms) and non-taboo (mean = 802.49 ms) words. In the post-stimulation condition, participants maintained their speed for taboo (mean = 806.33 ms) relative to nontaboo words (mean = 792.69 ms). A similar pattern is found the stimulation Condition B (right cathodal, left anodal). In the pre-stimulation condition participants showed similar reaction times for taboo (mean = 806.34 ms) and non-taboo (mean = 802.20 ms) words. In the post-stimulation condition, participants maintained their speed for taboo (mean = 823.18 ms) relative to nontaboo words (mean = 814.52 ms).

Fig. 3 represents raw reading latency differences pre/post tDCS. We conducted a 2 × 2 mixed ANOVA on the derived difference scores using Box-Cox transformed latency data. The between-subjects factor was tDCS polarity. The within-subjects factor was time (pre/post stimulation). There were no significant main effects or interactions

[3] This effect size interpretation of weak/anecdotal may be unfamiliar to readers accustomed to frequentist effect size guidelines (e.g., small, medium, large). Anecdotal evidence is roughly equivalent to a very small difference between the null and alternative distributions. For a more comprehensive explanation see Team (2014)

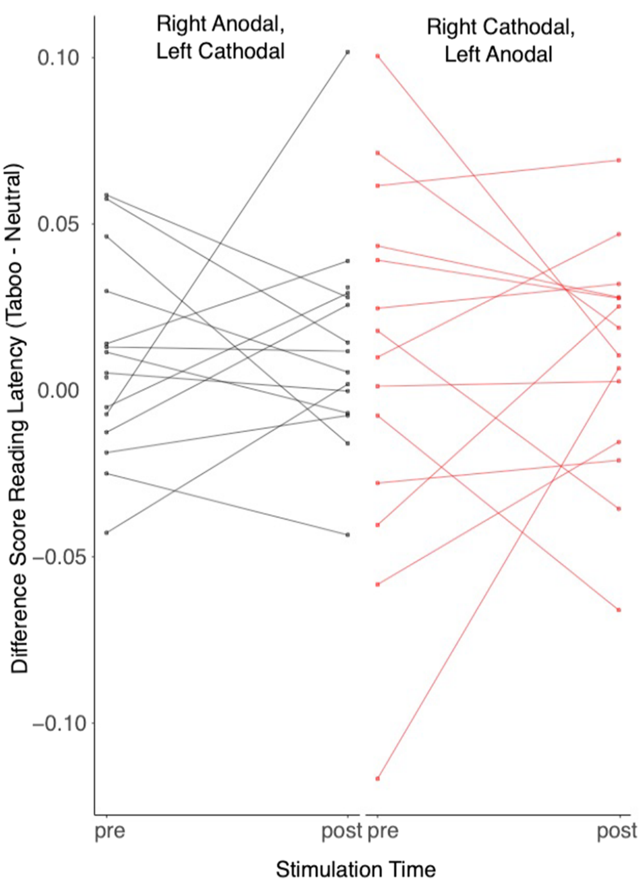

Fig. 3. Reading latencies pre/post stimulation.

between time or stimulation polarity ($p > .05$) on the latency difference.

4. General discussion

Our aim was to evaluate whether tDCS delivered over bilateral dlPFC could modulate cursing behaviors, either through latency differences while reading aloud taboo words or through pupillary responses as an index of physiological arousal. We did not observe modulation of reading latencies for taboo words. We did, however, observe crossover interaction/double dissociation in pupillary reponses as a function of stimulation polarity. An electrode montage that grossly mimicked the pattern of aphasia (left cathode, right anode) produced divergence between taboo and non-taboo words with higher peak and sustained pupil amplitudes post stimulation for taboo words. In contrast, an opposite polarity montage produced the opposite pattern of pupillary responses. Namely, a pre-stimulation baseline difference at baseline (taboo > non-taboo) was dampened post-stimulation (taboo ≈ non-taboo).

4.1. Interpreting Task-Evoked pupil responses

Pupillometry is a well-worn psychophysical measurement technique with an evidence base of over half a century (Hess & Polt, 1960, 1964; Kahneman & Beatty, 1966; Kahneman & Tversky, 1973; Mathôt, 2018; Mathôt, Melmi, Van der Linden, & Van der Stigchel, 2015; Zavagno, Tommasi, & Laeng, 2017; Zekveld, Heslenfeld, Johnsrude, Versfeld, & Kramer, 2014). The task-evoked pupillary response (TEPR) is a linear function thought to index sympathetic upregulation of phasic arousal associated with locus coeruleus norepinephrine (LC-NE) activation (Aston-Jones & Cohen, 2005; Einhauser, Stout, Koch, & Carter, 2008; Elman et al., 2017; Papesh & Goldinger, 2015). The physiological basis for cognitive pupillometry is that the pupil dilates in tandem with demands on cognitive load such that more difficult tasks evoke more dilation (Beatty, 1982). In addition to parametric dilation induced by information processing demands, the pupil dilates in response to numerous other factors, including surprisal, imagined light, pleasant tastes, caffeine, ocular accommodation, reward, sexual arousal, and psychosensory reflexes (Tryon, 1975). Pertinent to the current study are two specific causes of pupil dilation identified in past research. First, the pupil dilates parametrically in response to affective arousal for both negative and positively valenced stimuli (Bradley, Miccoli, Escrig, & Lang, 2008). Second, the pupil dilates as a function of inhibitory control in tasks that demand conscious suppression of a prepotent response (e.g., Stroop) (Laeng, Orbo, Holmlund, & Miozzo, 2011; Rondeel, Van Steenbergen, Holland, & van Knippenberg, 2015). Cursing behaviors likely load heavily on both affective arousal and inhibitory control. This is especially true for the participants in the current experiment, who were asked to curse in an unfamiliar laboratory setting. The relative contributions of valence and inhibitory control remain unclear.

Our working assumption is that anodal tDCS to the right prefrontal cortex would transiently amplify arousal, imbuing taboo words with more affective salience. This would in turn elicit a greater subjective 'jolt' of phasic arousal when reading and producing a taboo word. The pupil response functions we observed in the right anodal condition were consistent with this prediction. At baseline, participants showed roughly comparable pupil amplitudes for taboo and non-taboo words. After right anodal stimulation, taboo words elicited higher phasic arousal than non-taboo words. The opposite polarity montage was also consistent with this prediction but in the reverse direction. A baseline difference in phasic arousal for taboo relative to non-taboo words was dampened after right cathodal stimulation. It is important interpret these pupil amplitude findings based not only on the differences in magnitude between pre- and post-stimulation, but also on the direction of the effect.

4.2. Alternate explanations & limitations

There exist a range of alternative explanations for these results. Many cognitive processes that contribute to cursing behaviors are mediated by the right hemisphere, including non-propositional language, affective regulation, and physiological arousal.

We have advanced an affective arousal hypothesis consistent with neurological dissociations found in lateralized brain injuries, i.e., left hemisphere prefrontal damage in the context of aphasia (e.g. Leborgne) or TBI (e.g., Phinneas Gage) results in neurogenic cursing, whereas right prefrontal injuries tend to reduce cursing behaviors. It is nevertheless feasible that the modulatory effects we observed are the result of upregulation/downregulation of inhibitory control, lateralized attentional processes, or non-propositional language. It is important to note that our findings might only refer to a subset of non-propositional vocabulary weighted on negative valence, as our investigation was restricted to cursing language.

We know of very few past studies that have yoked tDCS with pupillometry as an outcome measure. In one recent study of affective picture viewing, Allaert, Sanchez-Lopez, De Raedt, Baeken, and Vanderhasselt (2019) found that anodal stimulation over right dlPFC diminished the amplitude of pupil dilation elicited by both negative and positively valenced pictures, whereas anodal stimulation to left dlPFC evoked higher pupil dilation for negative images only. These findings support lateralization differences in resource allocation for emotional processing as a function of valence. It has been argued that left and right prefrontal cortices have different biases for emotional processing. Hemispheric valence theory holds that the left hemisphere is more positively biased, whereas the right hemisphere is more negative at baseline (Adolphs, Jansari, & Tranel, 2001). The Allaert et al. (2019) finding that right prefrontal anodal stimulation reduced pupil dilation for negatively valent words is consistent with hemispheric valence theory. That is, a temporary amplification of negative affective bias induced by right anodal stimulation reduced the cognitive load for processing negatively valenced images, in turn resulting in lower phasic arousal. The Allaert et al. (2019) finding of reduced arousal after right anodal stimulation is not universal. Keuper, Terrighena, Chan, Junghoefer, and Lee (2018) administered continuous theta burst stimulation via TMS (inhibitory) to right prefrontal cortex during affective scene viewing, and participants subsequently experienced dampened emotional responses to negative stimuli. Keuper and colleagues interpreted this finding as TMS-induced affective disengagement, resulting in less arousal. In summary, Allaert et al. (2019) found decreased arousal for negative stimuli using excitatory stimulation, wheres Keuper et al. found the same effect using inhibitory stimulation. These discrepancies across studies highlight the challenge of isolating specific cognitive processes modulated by tDCS or the more focal method of TMS.

An altogether more pessimistic account of the results is that tDCS had no neuromodulatory effects and, rather, these pupil response functions reflect random noise (Horvath et al., 2015a, 2015b). One might predict that simple repetition of taboo words would produce habituation effects such that "fuck" would spontaneously lose its luster in the post-stimulation condition regardless of the electrode montage. Our experiment lacked a no-stimulation (i.e., sham) control condition that might have yielded insight into test/retest differences in the absence of neuromodulation. Additional limitations of our design included a small and relatively homogeneous sample, imperfect sex matching (i.e., more females than males), and a restricted range of tasks (limited to word reading), warranting caution regarding generalizability. Replication using a larger sample and a wider range of individual difference measures (including physiological measures of arousal) is a crucial next step.

4.3. Future directions & concluding remarks

The observed effects offer a promising initial proof of concept for developing principled non-invasive brain stimulation routines for the treatment of neurogenic cursing. tDCS offers a portable, relatively low cost, and generally safe means of modulating brain functioning. Our results suggest applications of right cathodal stimulation may alleviate neurogenic cursing associated with disorders of hyperaousal and/or emotional lability as might occur in left hemisphere stroke. tDCS may also be useful in constraining mechanistic predictions about the relative contributions of cerebral lateralization versus a more anterior/posterior gradient of cortical control.

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Appendix A. Subjective cursing survey

PERSONAL USE AND EXPOSURE

Prompt: The following questions look at how often you **use** and **are exposed to taboo words** in several different settings and in different periods of your life. **Taboo words** can refer to curse words (ex. Shit, fuck) as well as words that evoke a strong reaction even though they might not be considered curse words (ex. idiot, crap, vagina, moron, anus). Please read each question carefully and rate your response based on the following scale:

All ratings provided on a 7 point Likert scale, with points labeled 1 = never, 7 = very often (3 or more times a day)

USE

When you were a child, how often did you **use** taboo words **at home?**

When you were a child, how often did you **use** taboo words **with friends?**

When you were a child, how often did you **use** taboo words **at school?**

When you were a child, how often did you **use** taboo words **on social media?**

At this point in your life, how often do you **use** taboo words **at home?**

At this point in your life, how often do you **use** taboo words **with friends?**

At this point in your life, how often do you **use** taboo words **at school?**

At this point in your life, how often do you **use** taboo words **on social media?**

EXPOSURE

When you were a child, how often did you **hear** taboo words **at home?**

When you were a child, how often did you **hear** taboo words **with friends?**

When you were a child, how often did you **hear** taboo words **at school?**

When you were a child, how often did you **hear** taboo words **on social media?**

When you were a child, how often did you **hear** taboo words **in the media? (Movies, television, music, books)**

At this point in your life, how often do you **hear** taboo words **at home?**

At this point in your life, how often do you **hear** taboo words **with friends?**

At this point in your life, how often do you **hear** taboo words **at school?**

At this point in your life, how often do you **hear** taboo words **on social media?**

At this point in your life, how often do you **hear** taboo words **in the media? (Movies, television, music, books)**

References

Adolphs, R., Jansari, A., & Tranel, D. (2001). Hemispheric perception of emotional valence from facial expressions. *Neuropsychology, 15*(4), 516.

Allaert, J., Sanchez-Lopez, A., De Raedt, R., Baeken, C., & Vanderhasselt, M.-A. (2019). Inverse effects of tDCS over the left versus right DLPC on emotional processing: A pupillometry study. *PLoS ONE, 14*(6), e0218327.

Alvarez, J. A., & Emory, E. (2006). Executive function and the frontal lobes: A meta-analytic review. *Neuropsychology Review, 16*(1), 17–42.

Aston-Jones, G., & Cohen, J. D. (2005). An integrative theory of locus coeruleus-norepinephrine function: Adaptive gain and optimal performance. *Annual Review of Neuroscience, 28*, 403–450.

Banich, M. T. (2009). Executive function: The search for an integrated account. *Current Directions in Psychological Science, 18*(2), 89–94.

Beatty, J. (1982). Task-evoked pupillary responses, processing load, and the structure of processing resources. *Psychological Bulletin, 91*(2), 276–292.

Beatty, J., & Lucero-Wagoner, B. (2000). The pupillary system. In J. T. Cacioppo, L. G. Tassinary, & G. G. Berntson (Eds.), Handbook of Psychophysiology (2nd ed., pp. 142–162). Cambridge University Press.

Bergen, B. K. (2016). *What the F: What swearing reveals about our language, our brains, and ourselves.* Basic Books.

Bikson, M., Datta, A., Rahman, A., & Scaturro, J. (2010). Electrode montages for tDCS and weak transcranial electrical stimulation: Role of "return" electrode's position and size. *Clinical Neurophysiology, 121*(12), 1976.

Bikson, M., Rahman, A., & Datta, A. (2012). Computational models of transcranial direct current stimulation. *Clinical EEG and Neuroscience, 43*(3), 176–183.

Binney, R. J., Ashaie, S. A., Zuckerman, B. M., Hung, J., & Reilly, J. (2018). Frontotemporal stimulation modulates semantically-guided visual search during confrontation naming: A combined tDCS and eye tracking investigation. *Brain and Language, 180*, 14–23.

Box, G. E. P., & Cox, D. R. (1964). An analysis of transformations. *Journal of the Royal Statistical Society: Series B, 26*(2), 211–243.

Bradley, M. M., Miccoli, L., Escrig, M. A., & Lang, P. J. (2008). The pupil as a measure of emotional arousal and autonomic activation. *Psychophysiology, 45*(4), 602–607.

Broca, P. (1863). Localisation des fonctions cérébrales: Siée du langage articulé. *Bulletin of the Society of Anthropology (Paris), 4*, 200–203.

Brunoni, A. R., Nitsche, M. A., Bolognini, N., Bikson, M., Wagner, T., Merabet, L., ... Fregni, F. (2012). Clinical research with transcranial direct current stimulation (tDCS): Challenges and future directions. *Brain Stimulation, 5*(3), 175–195. https://

doi.org/10.1016/j.brs.2011.03.002.
Brysbaert, M., & New, B. (2009). Moving beyond Kucera and Francis: A critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. Behavior Research Methods 41(4), 977–990. https://doi.org/41/4/977 [pii] 10.3758/BRM.41.4.977 [doi].
Brysbaert, M., Warriner, A. B., & Kuperman, V. (2013). Concreteness ratings for 40 thousand generally known English word lemmas. *Behavior Research Methods, 46*(3), 904–911. https://doi.org/10.3758/s13428-013-0403-5.
Coulson, S., & Van Petten, C. (2007). A special role for the right hemisphere in metaphor comprehension?: ERP evidence from hemifield presentation. *Brain Research, 1146*, 128–145.
Coulson, S., & Wu, Y. C. (2005). Right hemisphere activation of joke-related information: An event-related brain potential study. *Journal of Cognitive Neuroscience, 17*(3), 494–506.
Dronkers, N. F., Plaisant, O., Iba-Zizen, M. T., & Cabanis, E. A. (2007). Paul Broca's historic cases: High resolution MR imaging of the brains of Leborgne and Lelong. *Brain, 130*(5), 1432–1441. https://doi.org/10.1093/brain/awm042.
Eden, A. S., Schreiber, J., Anwander, A., Keuper, K., Laeger, I., Zwanzger, P., ... Dobel, C. (2015). Emotion regulation and trait anxiety are predicted by the microstructure of fibers between amygdala and prefrontal cortex. *The Journal of Neuroscience, 35*(15), 6020–6027. https://doi.org/10.1523/jneurosci.3659-14.2015.
Einhauser, W., Stout, J., Koch, C., & Carter, O. (2008). Pupil dilation reflects perceptual selection and predicts subsequent stability in perceptual rivalry. *PNAS Proceedings of the National Academy of Sciences of the United States of America, 105*(5), 1704–1709. https://doi.org/10.1073/pnas.0707727105.
Elman, J. A., Panizzon, M. S., Hagler, D. J., Eyler, L. T., Granholm, E. L., Fennema-Notestine, C., ... Kremen, W. S. (2017). Task-evoked pupil dilation and BOLD variance as indicators of locus coeruleus dysfunction. *Cortex, 97*, 60–69. https://doi.org/10.1016/j.cortex.2017.09.025.
Fernandez-Duque, D., Baird, J. A., & Posner, M. I. (2000). Executive attention and metacognitive regulation. *Consciousness and Cognition, 9*(2), 288–307.
Freeman, R. D., Zinner, S. H., Müller-Vahl, K. R., Fast, D. K., Burd, L. J., Kano, Y., ... Stern, J. S. (2009). Coprophenomena in Tourette syndrome. *Developmental Medicine & Child Neurology, 51*(3), 218–227.
Geller, J., Winn, M., Mahr, T., & Mirman, D. (2019). GazeR: A Package for Processing Gaze Position and Pupil Size Data.
Goodman-Bacon, A. (2018). Difference-in-differences with variation in treatment timing. National Bureau of Economic Research.
Gordon, W. A., Haddad, L., Brown, M., Hibbard, M. R., & Sliwinski, M. (2000). The sensitivity and specificity of self-reported symptoms in individuals with traumatic brain injury. *Brain Injury, 14*(1), 21–33.
Harlow, J. M. (1868). Recovery from the passage of an iron bar through the head. *History of Psychiatry, 4*(14), 274–281.
Hayes, T. R., & Petrov, A. A. (2016). Mapping and correcting the influence of gaze position on pupil size measurements. *Behavior Research Methods, 48*(2), 510–527.
Heilman, K. M., & Valenstein, E. (1979). Mechanisms underlying hemispatial neglect. *Annals of Neurology, 5*(2), 166–170.
Heilman, K. M., & Van Den Abell, T. (1980). Right hemisphere dominance for attention: The mechanism underlying hemispheric asymmetries of inattention (neglect). *Neurology, 30*(3) 327–327.
Hess, E. H., & Polt, J. M. (1960). Pupil size as related to interest value of visual stimuli. *Science, 132*(3423), 349–350.
Hess, E. H., & Polt, J. M. (1964). Pupil size in relation to mental activity during simple problem-solving. *Science, 143*(3611), 1190–1192.
Hillis, A. E. (2006). Neurobiology of unilateral spatial neglect. *The Neuroscientist, 12*(2), 153–163. https://doi.org/10.1177/1073858405284257.
Horn, J. D. V., Irimia, A., Torgerson, C. M., Chambers, M. C., Kikinis, R., & Toga, A. W. (2012). Mapping connectivity damage in the case of phineas gage. *PLoS ONE, 7*(5), e37454. https://doi.org/10.1371/journal.pone.0037454.
Horvath, J. C., Forte, J. D., & Carter, O. (2015b). Quantitative review finds no evidence of cognitive effects in healthy populations from single-session transcranial direct current stimulation (tDCS). *Brain Stimulation, 8*(3), 535–550.
Horvath, J. C., Forte, J. D., & Carter, O. (2015a). Evidence that transcranial direct current stimulation (tDCS) generates little-to-no reliable neurophysiologic effect beyond MEP amplitude modulation in healthy human subjects: A systematic review. *Neuropsychologia, 66*, 213–236.
Hughlings-Jackson, J. (1878). On affections of speech from disease of the brain. *Brain, 1*(3), 304–330.
Jacobson, L., Koslowsky, M., & Lavidor, M. (2012). tDCS polarity effects in motor and cognitive domains: A meta-analytical review. *Experimental Brain Research, 216*(1), 1–10. https://doi.org/10.1007/s00221-011-2891-9.
JASP Team. (2017). JASP (Version 0.8.5) [Computer software].
Jay, T. B. (1992). *Cursing in America: A Psycholinguistic Study of Dirty Language in the Courts, in the Movies, in the Schoolyards, and on the Streets.* John Benjamins Publishing.
Jay, T. B. (2000). *Why We Curse: A Neuro-psycho-social Theory of Speech.* John Benjamins Publishing Company.
Jay, T. B. (2009). The utility and ubiquity of taboo words. *Perspectives on Psychological Science, 4*(2), 153–161.
Kahneman, D., & Beatty, J. (1966). Pupil diameter and load on memory. *Science, 154*(3756), 1583–1585.
Kahneman, D., & Tversky, A. (1973). On the psychology of prediction. *Psychological Review, 80*(4), 237.
Keuper, K., Terrighena, E. L., Chan, C. C., Junghoefer, M., & Lee, T. (2018). How the dorsolateral prefrontal cortex controls affective processing in absence of visual awareness-insights from a combined EEG-rTMS Study. *Frontiers in Human Neuroscience, 12*, 412.
Kret, M. E., & Sjak-Shie, E. E. (2019). Preprocessing pupil size data: Guidelines and code. *Behavior Research Methods, 51*(3), 1336–1342.
Kushner, H. I. (2009). *A cursing brain? The histories of tourette Syndrome: The histories of tourette syndrome.* Harvard University Press.
Laeng, B., Orbo, M., Holmlund, T., & Miozzo, M. (2011). Pupillary Stroop effects. *Cognitive Processes, 12*(1), 13–21. https://doi.org/10.1007/s10339-010-0370-z.
Martino, D., Madhusudan, N., Zis, P., & Cavanna, A. E. (2013). Chapter One—An Introduction to the Clinical Phenomenology of Tourette Syndrome. In D. Martino & A. E. Cavanna (Eds.), International Review of Neurobiology (Vol. 112, pp. 1–33). Academic Press. https://doi.org/10.1016/B978-0-12-411546-0.00001-9.
Mathôt, S. (2018). Pupillometry: Psychology, physiology, and function. *Journal of Cognition, 1*(1).
Mathôt, S., Melmi, J.-B., Van der Linden, L., & Van der Stigchel, S. (2015). The mind-writing pupil: Near-perfect decoding of visual attention with pupillometry. *Journal of Vision, 15*(12), 176. https://doi.org/10.1167/15.12.176.
Papesh, M. H., & Goldinger, S. D. (2015). Pupillometry and memory: External signals of metacognitive control. *Handbook of biobehavioral approaches to self-regulation* (pp. 125–139). New York, NY: Springer. https://doi.org/10.1007/978-1-4939-1236-0_9.
Peterson, B. S., Staib, L., Scahill, L., Zhang, H., Anderson, C., Leckman, J. F., ... Webster, R. (2001). Regional brain and ventricular volumes in Tourette syndrome. *Archives of General Psychiatry, 58*(5), 427–440.
Price, A. R., McAdams, H., Grossman, M., & Hamilton, R. H. (2015). A meta-analysis of transcranial direct current stimulation studies examining the reliability of effects on language measures. *Brain Stimulation, 8*(6), 1093–1100.
Reilly, J., Kelly, A., Kim, S. H., Jett, S., & Zuckerman, B. (2018). The human task-evoked pupillary response function is linear: Implications for baseline response scaling in pupillometry. *Behavior Research Methods,* 1–14.
Reilly, J., Kelly, A., Zuckerman, B. M., Twigg, P. P., Wells, M., Jobson, K. R., & Flurie, M. (2020). Building the perfect curse word: A psycholinguistic investigation of the form and meaning of taboo words. *Psychonomic Bulletin & Review*. https://doi.org/10.3758/s13423-019-01685-8.
Ringman, J. M., Kwon, E., Flores, D. L., Rotko, C., Mendez, M. F., & Lu, P. (2010). The use of profanity during letter fluency tasks in frontotemporal dementia and Alzheimer's disease. *Cognitive and Behavioral Neurology, 23*(3), 159.
Roesmann, K., Dellert, T., Junghoefer, M., Kissler, J., Zwitserlood, P., Zwanzger, P., & Dobel, C. (2019). The causal role of prefrontal hemispheric asymmetry in valence processing of words–Insights from a combined cTBS-MEG study. *NeuroImage, 191*, 367–379.
Rondeel, E., Van Steenbergen, H., Holland, R., & van Knippenberg, A. (2015). A closer look at cognitive control: Differences in resource allocation during updating, inhibition and switching as revealed by pupillometry. *Frontiers in Human Neuroscience, 9*, 494.
Speedie, L. J., Wertman, E., Ta'ir, J., & Heilman, K. M. (1993). Disruption of automatic speech following a right basal ganglia lesion. *Neurology, 43*(9) 1768–1768.
Stephens, R., Atkins, J., & Kingston, A. (2009). Swearing as a response to pain. *NeuroReport, 20*(12), 1056–1060. https://doi.org/10.1097/WNR.0b013e32832e64b1.
Stephens, R., Spierer, D. K., & Katehis, E. (2018). Effect of swearing on strength and power performance. *Psychology of Sport and Exercise, 35*, 111–117. https://doi.org/10.1016/j.psychsport.2017.11.014.
Stuss, D. T., & Knight, R. T. (2002). Principles of frontal lobe function. *Oxford University Press*. https://doi.org/10.1093/acprof:oso/9780195134971.001.0001.
Tryon, W. W. (1975). Pupillometry: A survey of sources of variation. *Psychophysiology, 12*(1), 90–93.
Van Lancker, D., & Cummings, J. L. (1999). Expletives: Neurolinguistic and neurobehavioral perspectives on swearing. *Brain Research. Brain Research Reviews, 31*(1), 83–104.
Van Lancker, D. R., & Kempler, D. (1987). Comprehension of familiar phrases by left-but not by right-hemisphere damaged patients. *Brain and Language, 32*(2), 265–277.
Warriner, A. B., Kuperman, V., & Brysbaert, M. (2013). Norms of valence, arousal, and dominance for 13,915 English lemmas. *Behavior Research Methods, 45*(4), 1191–1207. https://doi.org/10.3758/s13428-012-0314-x.
Zavagno, D., Tommasi, L., & Laeng, B. (2017). The eye Pupil's response to static and dynamic illusions of luminosity and darkness. 2041669517717754 *I-Perception, 8*(4), https://doi.org/10.1177/2041669517717754.
Zekveld, A. A., Heslenfeld, D. J., Johnsrude, I. S., Versfeld, N. J., & Kramer, S. E. (2014). The eye as a window to the listening brain: Neural correlates of pupil size as a measure of cognitive listening load. *Neuroimage, 101c*, 76–86. https://doi.org/10.1016/j.neuroimage.2014.06.069.
Zelazo, P. D., Craik, F. I., & Booth, L. (2004). Executive function across the life span. *Acta Psychologica, 115*(2–3), 167–183.
Zelazo, P. D., & Cunningham, W. A. (2007). Executive function: Mechanisms underlying emotion regulation. *Handbook of emotion regulation* (pp. 135–158). The Guilford Press.