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Emotion processing in children who do and do not stutter: An ERP study of electrocortical reactivity and regulation to peer facial expressions

Evan R. Usler [a,*], Christine Weber [b]

[a] Department of Communication Sciences and Disorders, College of Health Sciences, University of Delaware, 100 Discovery Blvd., Newark, DE, 19713, United States
[b] Department of Speech, Language, and Hearing Sciences, Purdue University, Lyles-Porter Hall, 715 Clinic Drive, West Lafayette, IN, 47907, United States

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ABSTRACT

Purpose: Event-related brain potentials (ERPs) were used to investigate the neural correlates of emotion processing in 5- to 8-year-old children who do and do not stutter.
Methods: Participants were presented with an audio contextual cue followed by images of threatening (angry/fearful) and neutral facial expressions from similarly aged peers. Three conditions differed in audio-image pairing: neutral context-neutral expression (neutral condition), negative context-threatening expression (threat condition), and reappraisal context-threatening expression (reappraisal condition). These conditions reflected social stimuli that are ecologically valid to the everyday life of children.
Results: P100, N170, and late positive potential (LPP) ERP components were elicited over parietal and occipital electrodes. The threat condition elicited an increased LPP mean amplitude compared to the neutral condition across our participants, suggesting increased emotional reactivity to threatening facial expressions. In addition, LPP amplitude decreased during the reappraisal condition— evidence of emotion regulation. No group differences were observed in the mean amplitude of ERP components between children who do and do not stutter. Furthermore, dimensions of childhood temperament and stuttering severity were not strongly correlated with LPP elicitation.
Conclusion: These findings are suggestive that, at this young age, children who stutter exhibit typical brain activation underlying emotional reactivity and regulation to social threat from peer facial expressions.

1. Introduction

Developmental stuttering, also known as Childhood-Onset Fluency Disorder (DSM-5; American Psychiatric Association, 2013), is a neurodevelopmental disorder typified by the persistent manifestation of disfluent speech production. Negative psychosocial consequences associated with stuttering have been observed soon after onset of the disorder (Ambrose & Yairi, 1994; Boey et al., 2009), and long-term stuttering has been associated with excessive anxiety and reduced well-being (Blumgart, Tran, & Craig, 2014; Craig & Tran,

* Corresponding author.
E-mail address: eusler@udel.edu (E.R. Usler).

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2014; Iverach, Rapee, Wong, & Lowe, 2017). In addition to speech motor and language factors, multifactoral theories of stuttering acknowledge the contribution of emotion to the etiology and nature of stuttering (Conture & Walden, 2012; Smith & Weber, 2017). Children who stutter (CWS) have been observed to exhibit high levels of autonomic nervous activation during their stuttered speech compared to when they speak fluently (Walsh & Usler, 2019). However, physiological arousal and emotion are not always linked (Mauss, Wilhelm, & Gross, 2004). Other studies have investigated potential group differences between CWS and children who do not stutter (CWNS) in childhood temperament (for reviews, see Alm, 2014; Jones, Choi, Conture, & Walden, 2014; Kefalianos, Onslow, Block, Menzies, & Reilly, 2012). Temperament has been defined by Rothbart and colleagues (Rothbart, Ahadi, Hershey, & Fisher, 2001) as stable, trait-like individual differences in emotional reactivity (often categorized as the dimensions of negative affect and extraversion/surgency) and emotion regulation (also known as the dimension of effortful control). Emotional reactivity refers to the arousal of cognitive, autonomic, and endocrine processes as attention is oriented towards a stimulus and appraised of its motivational significance, and is often measured in terms of intensity, latency, and duration (Gross, 1998). Emotion regulation is the modulation of emotional reactivity by executive processes (Cole, Martin, & Dennis, 2004; Gross, 1998). One such regulatory process is cognitive reappraisal – the reinterpretation of the salience of a stimulus given a change in context (Goldin, McRae, Ramel, & Gross, 2008). The ability to effectively regulate one's emotional reactivity by appropriately appraising threatening stimuli, such as angry or fearful faces, is critical for healthy wellbeing and the development of social skills (John & Gross, 2004).

In a review of the research literature concerning the temperament of CWS, Jones and colleagues stated that, compared to CWNS, preschool-aged CWS "are more emotionally reactive, more negative in their affect/emotions, and higher in anger/frustration…[and] less able to regulate their emotions or attention" (Jones, Choi et al., 2014, p.120). Behavioral measures indicate that compared to CWNS, preschool-age CWS demonstrate less efficient executive attention (Anderson & Wagovich, 2017; Eggers, De Nil, & Van den Bergh, 2012; Schwenk, Conture, & Walden, 2007), increased emotional reactivity, and less efficient emotion regulation compared to fluent controls (Eggers, De Nil, & Van den Bergh, 2013; Karrass et al., 2006; Ntourou, Conture, & Walden, 2013). Findings from caretaker reporting, such as use of the Children's Behavior Questionnaire (CBQ; Putnam & Rothbart, 2006; Rothbart et al., 2001), are consistent with direct observations of behavior in CWS, indicating a relatively higher level of emotional reactivity and a reduced ability to regulate that reactivity despite considerable individual differences (e.g., Eggers, De Nil, & Van den Bergh, 2010). Psychophysiological measures indicated higher sympathetic arousal in 3-year-old, but not 4-year-old, CWS during a rapid-picture naming task (Zengin-Bolatkale, Conture, & Walden, 2015). In addition to exhibiting comparably higher skin conductance, young CWS also exhibited lower baseline parasympathetic activity as indexed by respiratory sinus arrhythmia (Jones, Buhr et al., 2014). Despite these findings of group differences in childhood temperament between CWS and CWNS, mixed results and considerable individual differences reveal CWS to be a heterogenous group in regards to degree of influence emotional factors have on the disorder (Conture & Walden, 2012; Smith & Weber, 2017). Walsh and Usler (2019) did not find differences in temperament between preschool aged CWS and CWNS, nor were strong associations between temperament, communication attitude and physiological measures of sympathetic arousal observed. These previous ambiguous findings across studies and incongruities between behavioral and autonomic measures of emotion associated with childhood stuttering highlight the potential benefit of using neurophysiological measures to investigate the neural correlates of emotional reactivity and emotion regulation that may distinguish CWS and CWNS.

1.1. ERP indices of emotional reactivity and regulation

Event-related brain potentials (ERPs) are time-locked and averaged fluctuations in electroencephalography (EEG) that reflect a neural process (Luck, 2014), including visual/attentional processes and indices of emotional arousal (for review, see Hajcak, Weinberg, MacNamara, & Foti, 2012). Threatening facial expressions, which are negatively valenced and arousing, quickly capture visual and attentional processes associated with electrocortical potentiation across occipital and parietal brain regions (Codispoti, Ferrari, & Bradley, 2007; Öhman, Flykt, & Esteves, 2001; Vuilleumier, Armony, Driver, & Dolan, 2001; Wangelin, Löw, McTeague, Bradley, & Lang, 2010). Specific to the current study, ERPs such as the P100, N170, and late positive potential (LPP) have indexed neural correlates of emotion processing elicited by facial expressions (e.g., Sun, Ren, & He, 2017). The P100 is a positive deflection elicited over facial expressions over occipital-parietal electrodes approximately 100 ms after stimulus onset (Batty & Taylor, 2003, 2006; Holmes, Nielsen, & Green, 2008). The P100 is often followed by the N170, a negative deflection associated with face processing that can also be modulated by the emotional salience of faces (Hinojosa, Mercado, & Carretié, 2015). Previous studies have observed P100 amplitude potentiation to threatening compared to non-threatening facial expressions—an effect particularly strong in clinically anxious populations—and represents rapid attention allocation to threat (Bar-Haim, Lamy, & Glickman, 2005; Mueller et al., 2008; Santesso et al., 2008). A meta-analysis by Hinojosa et al. (2015) also revealed increased N170 amplitude to threatening compared to non-threatening facial expressions. Studies of typically developing children, however, have revealed P100 and N170 modulation to facial expressions to be age-related and highly variable (e.g., Batty & Taylor, 2006). In a recent study of typically developing children by the current authors, no significant P100 and N170 modulation was observed in response to threatening facial expressions from same-aged peers (Usler, Foti, & Weber, 2020).

The LPP is an amalgamation of positive deflections that emerges approximately 300 ms after stimulus onset in occipital and parietal electrodes with a prolonged elicitation (Foti, Hajcak, & Dien, 2009; Hajcak, Dunning, & Foti, 2009). LPP amplitude has been well established to be an index of sustained attention sensitive to the salience of emotional stimuli, such as angry and fearful expressions (for reviews, see Hajcak et al., 2012; Olofsson, Nordin, Sequeira, & Polich, 2008). Increased LPP amplitude has also elicited by emotional scenes and facial expressions in children, although the duration of LPP elicitation is shorter—usually lasting for one second after stimulus onset (Hajcak & Dennis, 2009; Hua et al., 2014; Kujawa, Hajcak, Torpey, Kim, & Klein, 2012; MacNamara et al., 2016; Solomon, DeCicco, & Dennis, 2012). Like adults, this increase in LPP amplitude is a marker of heightened anxiety and fear in children

(Kujawa, MacNamara, Fitzgerald, Monk, & Phan, 2015).

LPP elicitation can also reflect neural correlates of emotion regulation, such as cognitive reappraisal, that reduce reactivity to a stimulus. For example, the presentation of a preceding auditory cue affects the salience of subsequent emotional stimuli, including a reduction in LPP amplitude, indicating regulation of emotional reactivity (Foti & Hajcak, 2008; Hajcak & Nieuwenhuis, 2006; Hajcak, Moser, & Simons, 2006; MacNamara, Foti, & Hajcak, 2009). ERP studies of cognitive reappraisal with children have produced mixed results (DeCicco, O'Toole, & Dennis, 2014; DeCicco, Solomon, & Dennis, 2012; Van Cauwenberge, Van Leeuwen, Hoppenbrouwers, & Wiersema, 2017). LPP amplitude in school-aged children has been found to modulate based on the valance/salience of audio contextual cues associated with a visual emotional stimulus (Dennis & Hajcak, 2009), but not in other studies (DeCicco et al., 2012, 2014). Mixed findings involving LPP modulation as a neural marker of cognitive reappraisal may be due to developmental changes in the neural correlates of emotion regulation throughout childhood (Van Cauwenberge et al., 2017). For example, DeCicco et al. (2014) argued that neural correlates of cognitive reappraisal may not develop until older childhood given their finding that a positive contextual narrative did not influence LPP amplitude to negative images in school-age children. However, the provision of neutral descriptions, in comparison to negative descriptions, resulted to a decreased LPP in response to negative pictures in preschool and school-age children (Dennis & Hajcak, 2009; Hua, Han, & Zhou, 2015). In sum, the observation of LPP modulation during cognitive reappraisal is likely contingent on the age of the child, as well as contextual variables of the experimental paradigm.

ERPs provide a potential marker of atypical emotional reactivity and emotion regulation in CWS compared to CWNS; however, the application of electrophysiological measures in investigating the emotional processes of CWS has been limited. Arnold, Conture, Key, and Walden (2011) reported no differences in EEG indices reflecting emotional reactivity between preschool aged CWS and CWNS. In a recent study, Zengin-Bolatkale, Conture, Key, Walden, and Jones (2018) observed an increased LPP amplitude between 1000−1500 ms post onset of unpleasant pictures in preschool-aged CWS compared to CWNS over the Pz electrode. No differences between CWS and CWNS were observed during a related reappraisal task. This ERP study provided evidence that the neural correlates of emotional reactivity, but not emotion regulation, may be associated with childhood stuttering. CWS, on average, may be more reactive to negative visual stimuli compared to fluent peers. However, further research is necessary to discern potential group differences in ERP elicitation underlying emotional reactivity and regulation to social stimuli, such as child facial expressions.

1.2. Purpose of the study

The current study aims to identify differences in ERP activation underlying emotion processing (P100, N170, LPP) of threatening facial expressions (angry and fearful) in 5- to 8-year-old CWS and CWNS. We hypothesized CWS would exhibit increased emotional reactivity (indexed by LPP potentiation to a threat condition relative to a neutral condition) compared to CWNS over parietal-occipital electrode sites post onset of the facial expression. We also expected to observe group differences in sensory ERP components such as the P100 and N170 to threatening facial expressions (Hinojosa et al., 2015; Mueller et al., 2008). Given behavioral studies are suggestive that CWS may be less effective in emotion regulation compared to fluent peers (e.g., Ntourou et al., 2013), we hypothesized that CWS would be less effective than CWNS in cognitive reappraisal (indexed by a reduction in LPP amplitude to a reappraisal condition relative to the threat condition).

A secondary analysis of the current study was to determine if individual differences in the neural correlates of emotion processing were associated with dimensions of childhood temperament. Given the exploratory nature of this investigation, no specific hypotheses were proposed. Parental reporting of childhood temperament, including negative affect, extraversion, and effortful control as measured by the CBQ, were also examined. Given the ambiguity of research findings regarding temperamental differences between CWS and CWNS, and the lack of associations between temperament and sympathetic arousal in CWS (e.g., Walsh & Usler, 2019), putative group differences in the CBQ were not expected.

2. Methods

2.1. Participants

This study was approved by the Institutional Review Board at Purdue University. Before data were collected, written informed consent from parents and assent from children were obtained. Participants included children who stutter (CWS; $N = 19$, 6 females) and CWNS ($N = 19$, 6 females) between the ages of 5;5 and 9;0. CWNS and CWS participants were comparable in age, gender, handedness, and socioeconomic status (SES). CWS and CWNS groups each included two left-handed participants. Mean age (in months) was also comparable between CWS (age in months: $M = 81.58$, $SE = 2.60$, $range = 66–108$), and CWNS, (age in months: $M = 80.84$, $SE = 3.08$, $range = 65–103$), $F(1, 36) = .03$, $p = .86$. All participants were reported by a parent to exhibit normal or corrected-to-normal vision and normal hearing, which was confirmed by a hearing screening at 20 dB HL for 500, 1000, 2000, 4000, and 6000 Hz. No participants had significant medical conditions or developmental disabilities. Hollingshead's education 7-point scale (4 = high school, 5 = some college, 6 = college degree, 7 = graduate or professional degree) was used to evaluate the level of maternal education as a measure of SES (Hollingshead, 1975). Both groups had a median SES of 6 (range = 4–7), with an independent samples median test resulting in no group differences in SES ($p = .30$). CWS were recruited from the participant pool of the longitudinal Purdue Stuttering Project and were diagnosed as stuttering upon entrance to the longitudinal project according to the criteria developed by Yairi and Ambrose (2005). These criteria included 1) exhibiting stuttering according to a parent and the project speech-language pathologist (SLP); 2) demonstrating a stuttering severity rating of 2 or higher on an 8-point (0–7) scale by the parent and the project SLP; and 3) producing at least 3 stuttering-like disfluencies per 100 syllables of spontaneous speech (unless the SLP found this speech sample to be unrepresentative of the other indices and parent reporting). Stuttering-like disfluencies were quantified using a weighted stuttering index of percent syllables stuttered, with dysrhythmic phonations weighted more heavily than repetitions (Yairi & Ambrose, 2005). Data were collected for this study from CWS within the first few years of initial diagnosis, at which time the participant was deemed as persisting in stuttering according to the project SLP and parent.

2.2. Stimuli

The experimental paradigm used in the current study included a total of 150 trials divided into three conditions: neutral, threat, and reappraisal. This paradigm was recently used in a previous study of typically developing children by the authors (e.g., Usler et al., 2020). For each condition, audio sentences provided a context in which to interpret the subsequent target facial expression. Neutral facial expressions were preceded by a congruent neutral context. In the threat condition, fearful and angry facial expressions were preceded by a sentence of congruent negative context. In the reappraisal condition, the threatening facial expressions were preceded by an incongruent reappraisal context. Table 1 provides the auditory cue stimuli presented in this study. The experimental design consisted of two blocks (A and B). Block A consisted of 60 trials of the threat condition (30 angry / 30 fearful) and 15 trials of the neutral condition. Block B consisted of 60 trials of the reappraisal condition (30 angry / 30 fearful) and 15 trials of the neutral condition. Trials were sequenced quasi-randomly within each block to reduce redundancy in the presentation of condition or facial expression. Each block was presented once and in alternating order between subjects to prevent a confounding order effect. The neutral, fearful, and angry facial expressions included those of ten[1] (5 male, 5 female) child actors from the Child Affective Facial Expression set (CAFE; LoBue & Thrasher, 2015). Trials for all three conditions began with a "ready?" screen and commenced with a button press. The appearance of a circular fixation point (duration of 2500 ms and of alternating size and color) was followed by the presentation of a facial expression (2000 ms). During the appearance of the circular fixation point, the auditory contextual sentence was presented. Given differences in the duration of the different sentences (1230–2021 ms) during the presentation of the circular fixation point (2500 ms), the interstimulus interval between the offset of the sentence and the onset of the face image was randomized (479–1270 ms). Brief breaks (of approximately 1 min) occurred at regular intervals (every 15 trials), during which time the child played with toy building set or fishing game.

2.3. Measures

Parental reporting of temperamental attributes related to emotional reactivity and regulation was undertaken through parental completion of the Children's Behavior Questionnaire – Short Form Version I (CBQ; Putnam & Rothbart, 2006), a standardized assessment of childhood temperament. Parents rated their child using a 7-point Likert scale on 94 items. Temperament scores were not obtained from one CWS participant. Three composite dimensions of temperament were analyzed and Cronbach's alpha (in parentheses) indicated parental input was reliable for the majority of dimension subfactors: Extraversion [6 subfactors: approach/positive anticipation (.74), impulsivity (.80), high intensity pleasure (.85), activity level (.85), (reversed) shyness (.89), and smiling/laughter (.70)]; Negative Affect [5 subfactors: anger/frustration (.85), fear (.70), sadness (.77), discomfort (.84), (reversed) falling reactivity/soothability (.85)]; and Effortful Control [4 subfactors: attentional focusing (.78), inhibitory control (.33), low intensity pleasure (.82), and perceptional sensitivity (.83)].

2.4. Procedures

Before the start of the ERP task, participants sat in a sound-attenuating booth. Parents were able to watch their children through a live video from outside the booth. Before beginning the ERP paradigm, participants were shown a set of sample facial expressions (that were also from the CAFE set, but not used in the paradigm) to confirm that the participant could identify the emotional valence of each corresponding facial expression. An accompanying experimenter sat next to the participant through presentation of the stimuli presentation to manually begin each trial and to ensure the participant was on task. The experimenter spoke the following instructions to the participant before starting the task: "While you sit in this chair, you will see the faces of children your age on the screen. It is important to keep your arms, legs, and head as still as you can while you are watching the screen. When you are finished, you will get to pick out a prize!" At the beginning of each block, the experimenter presented the participant with a specific context for that block. Before Block A (which included the emotional condition), the following sentences were added: "Some of these kids are having a bad day. They may look mad, afraid, or just fine." Before Block B (which included the reappraisal condition), the participants were instead told, "Some of these kids are pretending. They may look mad or afraid, but they are just playing a game, they are really just fine." The ERP task is illustrated in Fig. 1.

[1] CAFE photographs used: 10025-angry_F-EA-32, 10405-fearful_F-EA-32, 10769-neutral_F-EA-32, 10062-angry_M-AS-06, 10432-fearful_M-AS-06, 10814-neutral_M-AS-06, 10068-angry_M-EA-06b-2, 10436-fearful_M-EA-06b, 10820-neutral_M-EA-06b, 10079-angry_M-EA-20, 10441-fearful_M-EA-20, 10832-neutral_M-EA-20, 10096-angry_M-LA-09, 10450-fearful_M-LA-09, 10855-neutral_M-LA-09, 9988-angry_F-AA-13, 10381-fearful_F-AA-13, 10737-neutral_F-AA-13, 9990-angry_F-AA-15, 10383-fearful_F-AA-15, 10739-neutral_F-AA-15, 10018-angry_F-EA-25, 10400-fearful_F-EA-25, 10765-neutral_F-EA-25, 10036-angry_F-LA-05, 10411-fearful_F-LA-05-2, 10781-neutral_F-LA-05, 10037-angry_F-LA-12, 10415-fearful_F-LA-12, 10788-neutral_F-LA-12.

Table 1
Auditory sentence stimuli for each condition.

Condition	Auditory Sentence	Facial Expression
Neutral	Joe is seven.	Neutral
	Joe looks outside.	
	Joe sits in the chair.	
Threat	Joe is mad.	Angry
	Joe lost his candy.	
	Joe broke his toy.	
	Joe is scared.	Fearful
	Joe saw a ghost.	
	Joe heard a scream.	
Reappraisal	Joe is acting.	Angry
	Joe is playing.	
	Joe is pretending.	
	Joe is acting.	Fearful
	Joe is playing.	
	Joe is pretending.	

2.5. Electroencephalographic recording

Using the Biosemi ActiveTwo system, EEG signals time-locked to the onset of the visual facial expression were recorded from the scalp with a 32 Ag-Cl electrode elastic cap (Electro-Cap International, Inc.). Electrodes were positioned in homologous locations (FP1/2, AF3/4, F3/4, F7/8, FC1/2, FC5/6, C3/4, T7/8, CP1/2, CP5/6, P3/4, P7/8, PO3/4, O1/2), including midline locations (FZ, CZ, PZ, OZ), that are consistent with the international 10−10 system (Acharya, Hani, Cheek, Thirumala, & Tsuchida, 2016). Eye blinks were monitored with bipolar recordings from electrodes placed on the left superior and inferior orbital ridges. Bipolar recordings were taken from electrodes placed on the left and right outer canthi to monitor horizontal eye movements. Electrodes were also placed on the left and right mastoids. Recordings were then referenced to an average of the electrode recordings from the left and right mastoid placements. The EEG was digitized online at a rate of 512 Hz and band-pass filtered between 0.1 and 100 Hz.

2.6. ERP analyses

EEG waveforms were downsampled to 256 Hz and low-pass filtered at 30 Hz using EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014) in MATLAB (Mathworks). This low-pass filtering improves the signal-to-noise ratio of EEG waveforms by removing sources of high frequency artifact, such as 60 Hz line noise, from the signal (Luck, 2014). Independent component analysis (ICA) decomposition of the EEG using the 'runica' toolbox in EEGLAB was performed to isolate and remove vertical and horizontal eye movement artifact, which usually occurred during blinking. Relative to the onset of the target facial expression, the EEG waveforms were isolated into time-locked -200 and 2000 ms trials. Trials with movement or other extraneous artifact were removed from analysis using an automatic artifact rejection algorithm. Trials were then averaged for each participant by condition to create a grand average for each condition (neutral, threat, reappraisal). The mean number of accepted trials for CWS and CWNS are detailed in Table 2.

ERP components were analyzed across a posterior region of interest (P7, PO3, O1, P8, PO4, O2), as displayed in Fig. 2. These parietal-occipital electrodes were chosen to capture the distribution of ERP elicitation to facial expressions in children as reported by previous literature (e.g., Kujawa, Hajcak et al., 2012). The selection of time windows for the statistical analysis of ERPs were identified by visual inspection of grand averages and were similar to those used in previous studies with children (e.g., Kujawa, Klein, & Hajcak, 2012; Thom et al., 2013). ERP waveforms were analyzed within the following windows: P100 (130−170 ms), N170 (170−270 ms) and LPP (300−1000 ms). ERPs were measured in mean amplitude (in μV) relative to baseline (correction set -200 to 0 ms) as the time (in ms) of the most negative or positive point within the specified temporal window (Luck, 2014).

Statistical analyses were performed using SPSS Statistics for Windows (IBM Corp., Version 25.0), to evaluate differences in ERP mean amplitude using a repeated-measures 3 (Condition: neutral, threat, reappraisal) x 2 (Hemisphere: left, right) x 3 (Electrode site) ANOVA with Group (CWS, CWNS) included as a between-subjects factor. An alpha level of $p < .05$ was used to determine statistically significant differences. If a significant Condition effect was observed, further analysis was conducted with a Bonferroni-corrected post-hoc test. Violations in sphericity were corrected by Huynh–Feldt adjusted *p*-values when the degrees of freedom of the numerator were greater than 1 (Hays, 1994). Effect sizes, indexed by partial eta squared (η_p^2), were reported for all significant findings. To ensure internal consistency of ERPs for the CWS and CWNS, split-half reliabilities in LPP elicitation were calculated for the threat and reappraisal conditions. Split-half reliability to the threat condition was .91 for CWS and .80 for CWNS. Split-half reliability to the reappraisal condition was .92 for CWS and .78 for CWNS.

To determine the effects of threat and reappraisal conditions on LPP elicitation across the six occipital and parietal electrodes for each participant, a *threat effect* (ΔLPP mean amplitude to the threat condition relative to the neutral condition) and *reappraisal effect* (ΔLPP mean amplitude to the reappraisal condition relative to the threat condition) were calculated. In an exploratory analysis, Pearson correlations (two-tailed) were calculated to determine possible relationships these threat and reappraisal effects, stuttering severity, and dimensions of childhood temperament based on the CBQ: negative affect, extraversion, and effortful control.

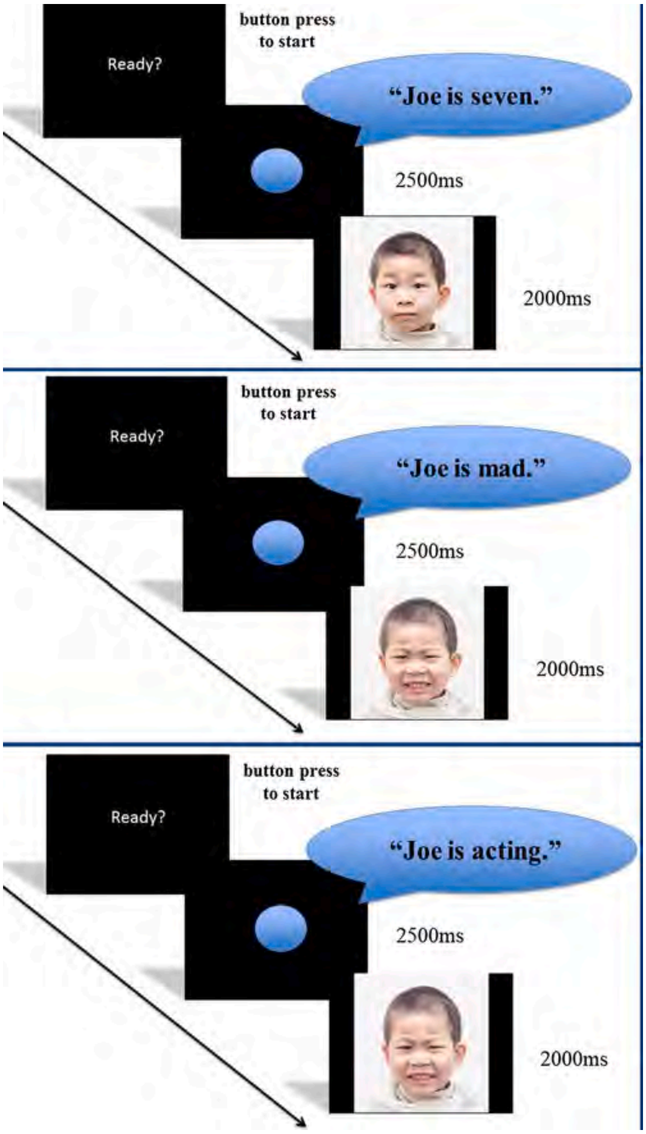

Fig. 1. Experimental paradigm with neutral, threat (angry), and reappraisal (angry) conditions (fearful expression not shown).

Table 2
Means (SE) for the number of trials accepted for each condition.

Condition	CWS	CWNS	Group Statistics
Neutral	27.47 (.68)	27.26 (.59)	F (1,36) = .06, p = .82
Threat (angry)	28.00 (.33)	27.05 (.52)	F(1,36) = 2.38, p = .13
Threat (fearful)	28.05 (.42)	26.37 (.74)	F(1,36) = 3.92, p = .06
Reappraisal (angry)	27.74 (.69)	26.79 (.67)	F(1,36) = .98, p = .33
Reappraisal (fearful)	27.11 (.58)	26.84 (.53)	F(1,36) = .11, p = .74

3. Results

The purpose of this study was to investigate the relationship between neural correlates of emotion processing and childhood stuttering by comparing the ERP elicitation to threatening child facial expressions in matched groups of school-aged CWS ($N = 19$) and CWNS ($N = 19$). Based on previous literature (e.g., Jones, Choi et al., 2014), it was predicted that CWS, on average, would exhibit a heightened emotional reactivity and less effective emotional regulation compared to CWNS. Lastly, possible associations between LPP elicitation and dimensions of childhood temperament and stuttering severity were explored. Grand average ERP waveforms elicited by

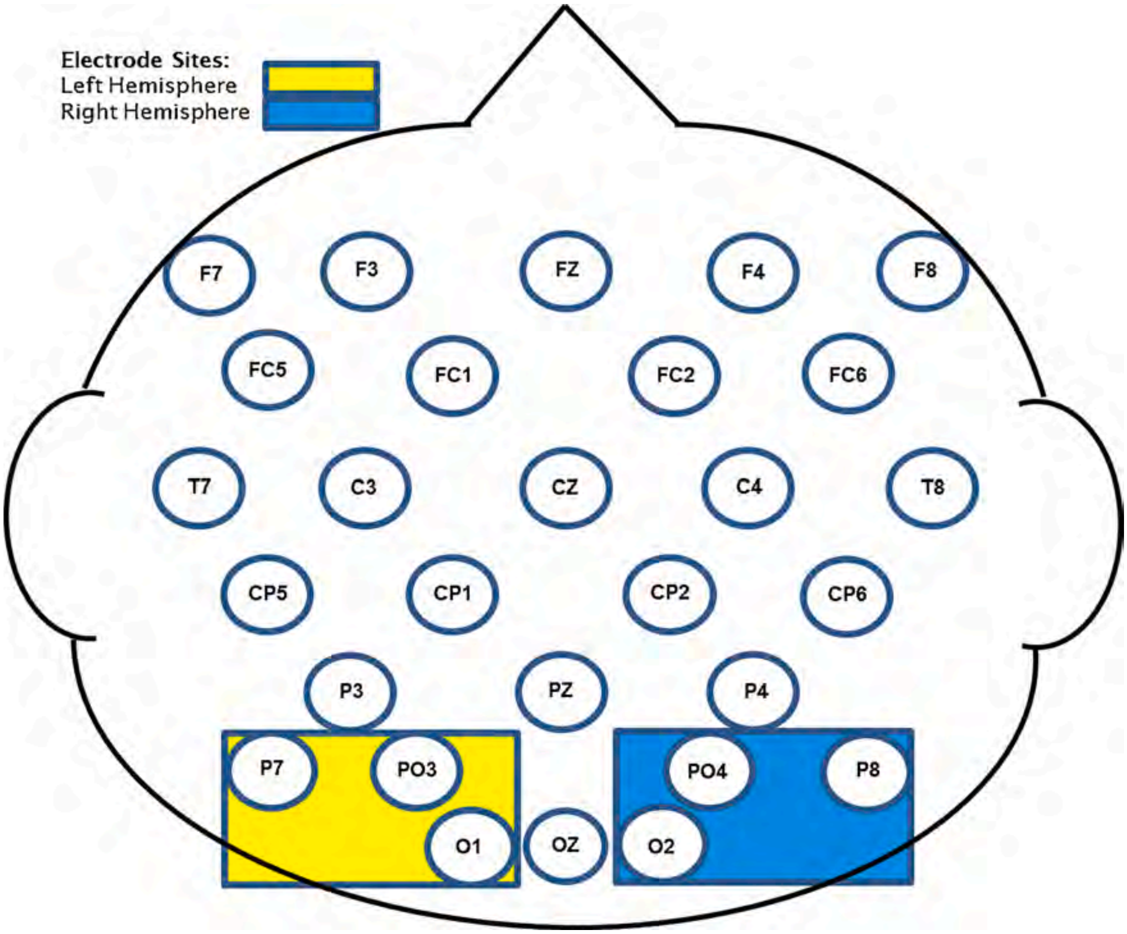

Fig. 2. Electrode configuration.

neutral, threat, and reappraisal conditions are illustrated in Fig. 3.

3.1. ERPs

As displayed in Fig. 3, bilateral P100, N170, and LPP components were observed at parietal and occipital sites. P100 and N170 amplitude did not significantly differ across conditions or hemispheres, *ps* > .05. However, mean amplitude of the LPP was modulated: a significant Condition effect was found, $F(2,72) = 5.96$, $p = .004$, $\eta_p^2 = .14$, with a Bonferroni pairwise comparison revealing an increased LPP to emotion compared to neutral ($p = .004$) and reappraisal conditions ($p = .03$). These differences suggest that our participants were more emotionally reactive to the emotional condition but were able to regulate that reactivity during the reappraisal condition. LPP mean amplitude was also higher over the right compared to left hemisphere, $F(1,36) = 11.22$, $p = .002$, $\eta_p^2 = .24$. No differences in LPP amplitude were found between CWS and CWNS, $F(2,72) = .81$, $p = .45$.

3.2. Threat and reappraisal effects, childhood temperament, and stuttering severity

Indices of extraversion, negative affect, and effortful control for CWS and CWNS were calculated from CBQ scores. Mean scores and standard errors (*in italics*) are provided in Table 3 and reveal that CWS and CWNS did not significantly differ in temperamental dimensions of negative affect, extraversion, and effortful control. To determine if threat and reappraisal effects were associated with CBQ scores, Pearson correlations were calculated and found to not be significant for CWS and CWNS ($-.12 \leq rs \leq .31$). Stuttering severity was indexed by a subjective rating on an 8-point (0–7) scale by the project SLP and by a weighted stuttering index score (Yairi & Ambrose, 2005). CWS demonstrated a mean severity rating of 2.25 (*SE* = 0.19, *range* = 1–3) and a weighted stuttering index of 5.06 (*SE* = 3.76, *range* = 0.30–32.61). Weighted stuttering index scores for four CWS participants were recorded approximately one year prior to participation in the current study. Stuttering severity as indexed by SLP rating was negatively correlated with level of extraversion, $r = -.49$, $p = .04$. No other correlations between threat and reappraisal effects, stuttering severity, and temperamental dimensions were statistically significant.

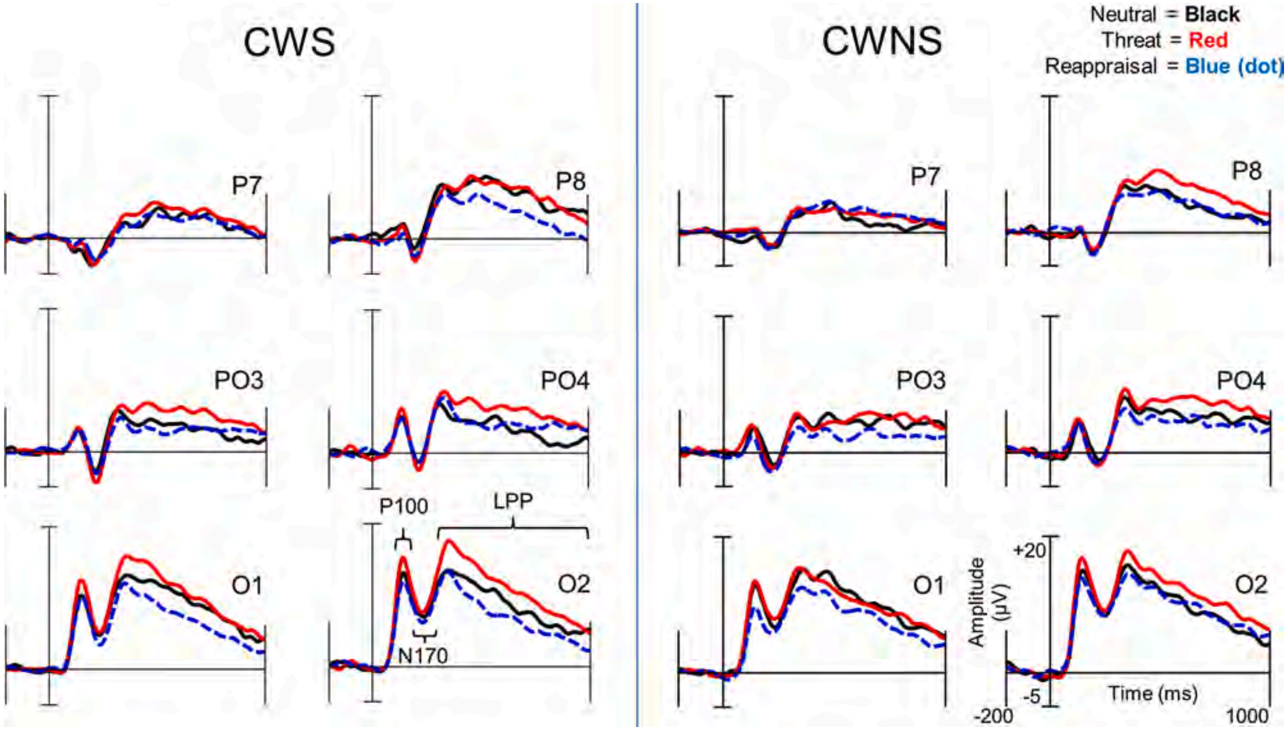

Fig. 3. Grand averaged ERPs for CWNS (a) including neutral (black), emotional (red), and reappraisal (blue) conditions and topographical maps of ERP activation (b). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

Table 3
Mean Scores and Standard Errors for CBQ Scores of Negative Affect, Extraversion, and Effortful Control. Standard errors in italic.

Dimension	CWS	CWNS	Group Statistics
Negative Affect	3.56 (*.20*)	4.02 (*.15*)	$F(1, 35) = 3.41, p = .07$
Extraversion	4.54 (*.14*)	4.72 (*.14*)	$F(1, 35) = .88, p = .36$
Effortful Control	5.18 (*.12*)	5.21 (*.11*)	$F(1, 35) = .03, p = .86$

4. Discussion

The purpose of this study was to determine if the neural correlates of emotional reactivity and regulation to facial expressions of similarly aged peers differed between 5- to 8-year-old CWS and CWNS. P100, N170, and LPP components were elicited in CWS and CWNS across parietal and occipital electrode sites. These sequences of elicited ERPs were similar to that recorded by previous studies of affective face processing in children (Hajcak & Dennis, 2009; Kujawa, Hajcak et al., 2012; Kujawa, Klein et al., 2012; MacNamara et al., 2016). P100 and N170 components were similarly elicited in amplitude across conditions and groups, and thus were not significantly modulated by threat or reappraisal conditions. Although P100 amplitude to the threat versus neutral condition was visually apparent over occipital electrodes, these amplitude differences were not statistically significant.

Increased LPP amplitude to the threat relative to the neutral condition, an indicator of increased emotional reactivity, was similarly observed in previous studies with typically developing children to adult facial expressions of anger and fear (e.g., Hajcak & Dennis, 2009; Hua et al., 2014; Kujawa, Hajcak et al., 2012; MacNamara et al., 2016; Solomon et al., 2012). We also observed a right hemispheric bias in LPP elicitation to the threat condition, which is consistent with previous observations of right hemispheric specialization for emotion processing (Cunningham, Raye, & Johnson, 2005; Keil et al., 2002; LeGrand, Mondloch, Maurer, & Brent, 2003). LPP elicitation was significantly lower in amplitude for reappraisal compared to the threat condition – evidence that our CWS and CWNS participants down-regulated their reactivity (Foti & Hajcak, 2008; Hajcak & Nieuwenhuis, 2006; Hajcak et al., 2006; MacNamara et al., 2009). An alternative argument is that differences in LPP elicitation between conditions may not represent emotion modulation, but other differences in task-related cognitive processes. However, it is unlikely that changes in LPP amplitude reflected shifts in attention or distractibility because early sensory ERPs (P100 and N170) did not significantly modulate between conditions, consistent with a previous study of typically developing children (Usler et al., 2020).

We predicted that our school-age CWS participants would exhibit ERP markers of increased emotional reactivity and less effective emotion regulation compared to fluent peers. Inconsistent with our hypothesis, ERP indices of emotional reactivity and regulation were similar between CWS and typically developing peers. This finding is consistent with the lack of group differences in childhood temperament indexed by the CBQ—CWS and CWNS did not differ across temperamental dimensions of negative affect, extraversion, and effortful control. The current study generally found no significant correlations between LPP elicitation and dimensions of childhood temperament—evidence that electrocortical indices of emotional processes may not be strongly linearly correlated with reporting of childhood temperament, such as negative affect. This lack of correlation was similarly observed in previous studies who failed to reliably find strong correlations between self-reported traits of negative affect and LPP modulation to emotional stimuli (Speed et al., 2015). Speed et al. (2015) did report a significant correlation between level of extraversion and LPP modulation in adolescents; however, we did not observe such an association in our CWS and CWNS. Our results support the view that emotion processing does not serve as a uniform etiological factor associated with childhood stuttering (Smith & Weber, 2017; Walden et al., 2012). The considerable individual differences in ERP elicitation we observed across our participants are suggestive that CWS exhibit heterogeneous responses to emotional stimuli. CWS, at least in the school-age years, should not be characterized as a homogeneous population that exhibits increased emotional reactivity as indexed by LPP potentiation, such as children with anxiety disorders (Carthy, Horesh, Apter, Edge, & Gross, 2010; Kujawa et al., 2015).

Our ERP and behavioral findings differ from previous evidence that CWS, on average, demonstrate greater reactivity and less effective regulation compared to fluent children (for review, see Jones, Choi et al., 2014). Previous studies of speech and non-speech tasks have reported group differences between CWS and CWNS in aspects of emotional reactivity and regulation (e.g., Jones, Buhr et al., 2014; Jones, Choi et al., 2014; Karrass et al., 2006; Kefalianos et al., 2012; Kraft, Ambrose, & Chon, 2014; Ntourou et al., 2013; Schwenk et al., 2007; Zengin-Bolatkale et al., 2015, 2018). However, the null findings of the current study do not directly contradict evidence that emotion contributes to the etiology and maintenance of childhood stuttering. First, our study was conducted with school-age CWS, while previous studies often involved younger, preschool-age CWS. Second, our paradigm did not require speech production. Third, the stimuli we presented were child facial expressions, which are known to be less emotionally salient than provocative and emotionally arousing scenes (e.g., Kujawa, Klein et al., 2012), such as those depicted in the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008). These stimuli may not have been salient enough to reveal group differences in the neural correlates of emotion processing. It should be noted that we did observe that the CWS with more severe stuttering behaviors also exhibited less extraversion, as measured by the CBQ. This behavioral finding is consistent with previous observations of a relationship between stuttering and perceived introversion in childhood (Fowlie & Cooper, 1978), although other studies using the CBQ did not find this correlation (Eggers et al., 2010). Regarding the finding of greater LPP amplitude characterizing CWS compared to CWNS by Zengin-Bolatkale et al. (2018), this group difference was observed in response to unpleasant scenes within a 1000−1500 ms window. No group differences were observed in an earlier 500−1000 ms window, which would overlap temporally with the LPP analysis of our current study. Thus, both the current study and that by Zengin-Bolatkale et al. (2018) did not find neural correlates of emotional reactivity or regulation distinguishing CWS from fluent peers within a second post stimulus onset.

The current study supports recent findings that did not observe differences in measures of temperament and sympathetic arousal between young CWS and CWNS (e.g., Walsh & Usler, 2019). Further research is necessary to determine how environmental stressors and childhood temperament contribute to individualized profiles of stuttering behavior across the lifespan. It is possible that clinically relevant differences in the emotional domain may emerge beyond the school-age years and there is a need for a similar line of research in adults who stutter. A considerable subset of adults who stutter exhibit symptoms of social anxiety, such as a fear of negative evaluation (Brundage, Winters, & Beilby, 2017). It is reasonable to speculate that ERP markers of threat processing in these adults may be potentiated similar to other clinically anxious populations (Bar-Haim et al., 2005). It also remains unclear how individual differences in emotional processes interact dynamically with other factors, such as linguistic and speech motor factors, to influence the neurodevelopmental trajectories in stuttering chronicity and severity. Elucidation of the role of emotion processing in shaping the neurodevelopmental pathways towards either recovery or persistence will also have considerable clinical implications. Regarding informing clinical practice, our findings suggest that the contribution of emotional or temperamental factors on childhood stuttering is complex and multifactorial (Walden et al., 2012). The relatively low emotional salience and lack of speech-language demands characterizing the current task may have been too subtle to elicit group differences in emotion processing. Emotion processing, evidenced by LPP modulation, is influenced by the contextual environment, stimuli parameters, and task demands such as working memory load and attention orientation (de Gelder & Vroomen, 2000; Hajcak et al., 2009; Luo, Feng, He, Wang, & Luo, 2010; Wieser & Brosch, 2012; Wieser et al., 2014). In addition to cognitive, linguistic, and motoric demands, clinicians should consider the emotional demands of speech on the client during any therapeutic intervention.

5. Limitations

This study is an initial step in investigating the development of neural correlates for emotional reactivity and regulation to social stimuli; however, limitations include its cross-sectional design, the small number of CWS participants, the focus on negative emotion, and the limited number of temperamental characteristics studied. Longitudinal studies are necessary to determine the dynamic and multimodal development of emotional processes, particularly sensory modalities beyond facial expression. Also, recruitment of CWS did not discriminate based on current or history of therapy for stuttering or other speech-language disorders. This was done to ensure the largest possible number of CWS participants in the study. The potential influence of positive emotion on stuttering was not investigated. Given that heightened positive emotionality may be associated with increased stuttering frequency (Choi, Conture, Walden, Jones, & Kim, 2016), future lines of ERP research may be fruitful in studying positive emotion. Lastly, more nuanced study of temperamental characteristics, including behavioral analyses, may find significant correlations with ERP elicitation. Although experimenters paid attention to participants' reactivity to the visual stimuli during the experiment and did not notice self-regulation behaviors, these behaviors were not coded for in the current study. The addition of behavioral analyses, such as eye tracking, to compliment ERP measures should be used in future studies to bolster the argument that LPP reduction between conditions reflect cognitive appraisal.

6. Conclusion

The presentation of child facial expressions modulated ERP elicitation in 5- to 8-year-old CWS and CWNS. Neural processes reflecting emotional reactivity were similarly enhanced by the perception of threat and down-regulated by cognitive reappraisal in CWS and CWNS. These modulations were most profound over the right hemisphere, consistent with previous literature in adults that emphasize a right hemispheric bias for emotion processing. Neural activity underlying emotional reactivity and regulation in CWS and CWNS did not differ, but appears to be dynamic in response to changing multimodal context and does not appear to be associated with parental reporting of childhood temperament or stuttering severity.

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References

Acharya, J., Hani, A., Cheek, J., Thirumala, P., & Tsuchida, T. (2016). American clinical neurophysiology society guideline 2: Guidelines for standard electrode position nomenclature. *Journal of Clinical Neurophysiology, 33*(4), 308–311.

Alm, P. A. (2014). Stuttering in relation to anxiety, temperament, and personality: Review and analysis with focus on causality. *Journal of Fluency Disorders, 40*, 5–21.

Ambrose, N., & Yairi, E. (1994). The development of awareness of stuttering in preschool children. *Journal of Fluency Disorders, 19*, 229–245.

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Arlington, VA: American Psychiatric Publishing.

Anderson, J. D., & Wagovich, S. A. (2017). Explicit and implicit verbal response inhibition in preschool-age children who stutter. *Journal of Speech, Language, and Hearing Research, 60*(4), 836–852.
Arnold, H. S., Conture, E. G., Key, A. P. F., & Walden, T. (2011). Emotional reactivity, regulation, and childhood stuttering: A behavioral and electrophysiological study. *Journal of Communication Disorders, 44*, 276–293.
Bar-Haim, Y., Lamy, D., & Glickman, S. (2005). Attentional bias in anxiety: A behavioral and ERP study. *Brain and Cognition, 59*(1), 11–22.
Batty, M., & Taylor, M. J. (2003). Early processing of the six basic facial emotional expressions. *Cognitive Brain Research, 17*(3), 613–620.
Batty, M., & Taylor, M. J. (2006). The development of emotional face processing during childhood. *Developmental Science, 9*(2), 207–220.
Blumgart, E., Tran, Y., & Craig, A. (2014). Social support and its association with negative affect in adults who stutter. *Journal of Fluency Disorders, 40*, 83–92.
Boey, R. A., Van de Heyning, P. H., Wuyts, F. L., Heylen, L., Stoop, R., & De Bodt, M. S. (2009). Awareness and reactions of young stuttering children aged 2–7 years old towards their speech disfluency. *Journal of Communication Disorders, 42*(5), 334–346.
Brundage, S. B., Winters, K. L., & Beilby, J. M. (2017). Fear of negative evaluation, trait anxiety, and judgment bias in adults who stutter. *American Journal of Speech-Language Pathology, 26*(2), 498–510.
Carthy, T., Horesh, N., Apter, A., Edge, M. D., & Gross, J. J. (2010). Emotional reactivity and cognitive regulation in anxious children. *Behaviour Research and Therapy, 48*(5), 384–393.
Choi, D., Conture, E. G., Walden, T. A., Jones, R. M., & Kim, H. (2016). Emotional diathesis, emotional stress, and childhood stuttering. *Journal of Speech, Language, and Hearing Research, 59*(4), 616–630.
Codispoti, M., Ferrari, V., & Bradley, M. M. (2007). Repetition and event-related potentials: Distinguishing early and late processes in affective picture perception. *Journal of Cognitive Neuroscience, 19*(4), 577–586.
Cole, P. M., Martin, S. E., & Dennis, T. A. (2004). Emotion regulation as a scientific construct: Methodological challenges and directions for child development research. *Child Development, 75*(2), 317–333.
Conture, E. G., & Walden, T. A. (2012). Dual diathesis-stressor model of stuttering. In L. Beliakova, & Y. Filatova (Eds.), *Theoretical issues of fluency disorders* (pp. 94–127). Moscow: Vlados.
Craig, A., & Tran, Y. (2014). Trait and social anxiety in adults with chronic stuttering: Conclusions following meta-analysis. *Journal of Fluency Disorders, 40*, 35–43.
Cunningham, W. A., Raye, C. L., & Johnson, M. K. (2005). Neural correlates of evaluation associated with promotion and prevention regulatory focus. *Cognitive, Affective & Behavioral Neuroscience, 5*(2), 202–211.
de Gelder, B., & Vroomen, J. (2000). The perception of emotions by ear and by eye. *Cognition & Emotion, 14*(3), 289–311.
DeCicco, J. M., O'Toole, L. J., & Dennis, T. A. (2014). The late positive potential as a neural signature for cognitive reappraisal in children. *Developmental Neuropsychology, 39*(7), 497–515.
DeCicco, J. M., Solomon, B., & Dennis, T. A. (2012). Neural correlates of cognitive reappraisal in children: An ERP study. *Developmental Cognitive Neuroscience, 2*(1), 70–80.
Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods, 134*(1), 9–21.
Dennis, T. A., & Hajcak, G. (2009). The late positive potential: a neurophysiological marker for emotion regulation in children. *Journal of Child Psychology and Psychiatry, 50*(11), 1373–1383.
Eggers, K., De Nil, L. F., & Van den Bergh, B. R. H. (2010). Temperament dimensions in stuttering and typically developing children. *Journal of Fluency Disorders, 35*(4), 355–372.
Eggers, K., De Nil, L. F., & Van den Bergh, B. R. H. (2012). The efficiency of attentional networks in children who stutter. *Journal of Speech Language and Hearing Research, 55*(3), 946–959.
Eggers, K., De Nil, L. F., & Van den Bergh, B. R. H. (2013). Inhibitory control in childhood stuttering. *Journal of Fluency Disorders, 38*(1), 1–13.
Foti, D., & Hajcak, G. (2008). Deconstructing reappraisal: Descriptions preceding arousing pictures modulate the subsequent neural response. *Journal of Cognitive Neuroscience, 20*(6), 977–988.
Foti, D., Hajcak, G., & Dien, J. (2009). Differentiating neural responses to emotional pictures: Evidence from temporal-spatial PCA. *Psychophysiology, 46*(3), 521–530.
Fowlie, G. M., & Cooper, E. B. (1978). Traits attributed to stuttering and nonstuttering children by their mothers. *Journal of Fluency Disorders, 3*(4), 233–246.
Goldin, P. R., McRae, K., Ramel, W., & Gross, J. J. (2008). The neural bases of emotion regulation: Reappraisal and suppression of negative emotion. *Biological Psychiatry, 63*(6), 577–586.
Gross, J. J. (1998). The emerging field of emotion regulation: An integrative review. *Review of General Psychology, 2*(3), 271–299.
Hajcak, G., & Dennis, T. A. (2009). Brain potentials during affective picture processing in children. *Biological Psychology, 80*(3), 333–338.
Hajcak, G., & Nieuwenhuis, S. (2006). Reappraisal modulates the electrocortical response to unpleasant pictures. *Cognitive, Affective & Behavioral Neuroscience, 6*(4), 291–297.
Hajcak, G., Dunning, J. P., & Foti, D. (2009). Motivated and controlled attention to emotion: Time-course of the late positive potential. *Clinical Neurophysiology, 120*(3), 505–510.
Hajcak, G., Moser, J. S., & Simons, R. F. (2006). Attending to affect: Appraisal strategies modulate the electrocortical response to arousing pictures. *Emotion, 6*(3), 517–522.
Hajcak, G., Weinberg, A., MacNamara, A., & Foti, D. (2012). ERPs and the study of emotion. In S. J. Luck, & E. S. Kappenman (Eds.), *The Oxford handbook of event-related potential components*. Oxford: Oxford University Press.
Hays, W. L. (1994). *Statistics* (5th). Fort Worth, TX: Harcourt Brace College Publishers.
Hinojosa, J. A., Mercado, F., & Carretié, L. (2015). N170 sensitivity to facial expression: A meta-analysis. *Neuroscience and Biobehavioral Reviews, 55*, 498–509.
Hollingshead, A. B. (1975). *Four factor index of social status*. New Haven, CT: Yale University Department of Sociology.
Holmes, A., Nielsen, M. K., & Green, S. (2008). Effects of anxiety on the processing of fearful and happy faces: An event-related potential study. *Biological Psychology, 77*(2), 159–173.
Hua, M., Han, Z. R., Chen, S., Yang, M., Zhou, R., & Hu, S. (2014). Late positive potential (LPP) modulation during affective picture processing in preschoolers. *Biological Psychology, 101*, 77–81.
Hua, M., Han, Z. R., & Zhou, R. (2015). Cognitive reappraisal in preschoolers: Neuropsychological evidence of emotion regulation from an ERP study. *Developmental Neuropsychology, 40*(5), 279–290.
Iverach, L., Rapee, R. M., Wong, Q. J. J., & Lowe, R. (2017). Maintenance of social anxiety in stuttering: A cognitive-behavioral model. *American Journal of Speech-Language Pathology, 26*(2), 540.
John, O. P., & Gross, J. J. (2004). Healthy and unhealthy emotion regulation: Personality processes, individual differences, and life span development. *Journal of Personality, 72*(6), 1301–1334.
Jones, R. M., Buhr, A. P., Conture, E. G., Tumanova, V., Walden, T. A., & Porges, S. W. (2014). Autonomic nervous system activity of preschool-age children who stutter. *Journal of Fluency Disorders, 41*, 12–31.
Jones, R. M., Choi, D., Conture, E., & Walden, T. (2014). Temperament, emotion, and childhood stuttering. *Seminars in Speech and Language, 35*(2), 114–131.
Karrass, J., Walden, T. A., Conture, E. G., Graham, C. G., Arnold, H. S., Hartfield, K. N., et al. (2006). Relation of emotional reactivity and regulation to childhood stuttering. *Journal of Communication Disorders, 39*(6), 402–423.
Kefalianos, E., Onslow, M., Block, S., Menzies, R., & Reilly, S. (2012). Early stuttering, temperament and anxiety: Two hypotheses. *Journal of Fluency Disorders, 37*(3), 151–163.
Keil, A., Bradley, M. M., Hauk, O., Rockstroh, B., Elbert, T., & Lang, P. J. (2002). Large-scale neural correlates of affective picture processing. *Psychophysiology, 39*(5), 641–649.
Kraft, S. J., Ambrose, N., & Chon, H. C. (2014). Temperament and environmental contributions to stuttering severity in children: The role of effortful control. *Seminars in Speech and Language, 35*(2), 80–94.

Kujawa, A., MacNamara, A., Fitzgerald, K. D., Monk, C. S., & Phan, K. L. (2015). Enhanced neural reactivity to threatening faces in anxious youth: Evidence from event-related potentials. *Journal of Abnormal Child Psychology, 43*(8), 1493–1501.
Kujawa, A., Hajcak, G., Torpey, D., Kim, J., & Klein, D. N. (2012). Electrocortical reactivity to emotional faces in young children and associations with maternal and paternal depression. *Journal of Child Psychology and Psychiatry and Allied Disciplines, 53*(2), 207–215.
Kujawa, A., Klein, D. N., & Hajcak, G. (2012). Electrocortical reactivity to emotional images and faces in middle childhood to early adolescence. *Developmental Cognitive Neuroscience, 2*, 458–467.
Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2008). *International affective picture system (IAPS): Affective ratings of pictures and instruction manual. Technical Report A-8*. Gainesville, FL: University of Florida.
LeGrand, R., Mondloch, C. J., Maurer, D., & Brent, H. P. (2003). Expert face processing requires visual input to the right hemisphere during infancy. *Nature Neuroscience, 6*(10), 1108–1112.
LoBue, V., & Thrasher, C. (2015). The Child Affective Facial Expression (CAFE) set: Validity and reliability from untrained adults. *Frontiers in Psychology*, 5.
Lopez-Calderon, J., & Luck, S. J. (2014). ERPLAB: An open-source toolbox for the analysis of event-related potentials. *Frontiers in Human Neuroscience, 8*, 213.
Luck, S. J. (2014). *An introduction to the event-related potential technique*. Cambridge, Massachusetts: MIT Press.
Luo, W., Feng, W., He, W., Wang, N.-Y., & Luo, Y.-J. (2010). Three stages of facial expression processing: ERP study with rapid serial visual presentation. *NeuroImage, 49*(2), 1857–1867.
MacNamara, A., Foti, D., & Hajcak, G. (2009). Tell me about it: Neural activity elicited by emotional pictures and preceding descriptions. *Emotion, 9*(4), 531–543.
MacNamara, A., Vergés, A., Kujawa, A., Fitzgerald, K. D., Monk, C. S., & Phan, K. L. (2016). Age-related changes in emotional face processing across childhood and into young adulthood: Evidence from event-related potentials. *Developmental Psychobiology, 58*(1), 27–38.
Mauss, I., Wilhelm, F., & Gross, J. (2004). Is there less to social anxiety than meets the eye? Emotion experience, expression, and bodily responding. *Cognition & Emotion, 18*(5), 631–642.
Mueller, E. M., Hofmann, S. G., Santesso, D. L., Meuret, A. E., Bitran, S., & Pizzagalli, D. A. (2008). Electrophysiological evidence of attentional biases in social anxiety disorder. *Psychological Medicine, 39*(07), 1141. https://doi.org/10.1017/s0033291708004820.27.
Ntourou, K., Conture, E. G., & Walden, T. A. (2013). Emotional reactivity and regulation in preschool-age children who stutter. *Journal of Fluency Disorders, 38*(3), 260–274.
Öhman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: Detecting the snake in the grass. *Journal of Experimental Psychology General, 130*(3), 466–478.
Olofsson, J. K., Nordin, S., Sequeira, H., & Polich, J. (2008). Affective picture processing: An integrative review of ERP findings. *Biological Psychology, 77*(3), 247–265.
Putnam, S. P., & Rothbart, M. K. (2006). Development of short and very short forms of the Children's Behavior Questionnaire. *Journal of Personality Assessment, 87*(1), 102–112.
Rothbart, M. K., Ahadi, S. A., Hershey, K. L., & Fisher, P. (2001). Investigations of temperament at three to seven years: The Children's Behavior Questionnaire. *Child Development, 72*(5), 1394–1408.
Santesso, D. L., Meuret, A. E., Hofmann, S. G., Mueller, E. M., Ratner, K. G., Roesch, E. B., et al. (2008). Electrophysiological correlates of spatial orienting towards angry faces: A source localization study. *Neuropsychologia, 46*(5), 1338–1348.
Schwenk, K. A., Conture, E. G., & Walden, T. A. (2007). Reaction to background stimulation of preschool children who do and do not stutter. *Journal of Communication Disorders, 40*(2), 129–141.
Smith, A., & Weber, C. (2017). How stuttering develops: The multifactorial dynamic pathways theory. *Journal of Speech Language and Hearing Research, 60*(9), 2483.
Solomon, B., DeCicco, J. M., & Dennis, T. A. (2012). Emotional picture processing in children: An ERP study. *Developmental Cognitive Neuroscience, 2*(1), 110–119.
Speed, B. C., Nelson, B. D., Perlman, G., Klein, D. N., Kotov, R., & Hajcak, G. (2015). Personality and emotional processing: A relationship between extraversion and the late positive potential in adolescence. *Psychophysiology, 52*(8), 1039–1047.
Sun, L., Ren, J., & He, W. (2017). Neural correlates of facial expression processing during a detection task: An ERP study. *PloS One, 12*(3), Article e0174016.
Thom, N., Knight, J., Dishman, R., Sabatinelli, D., Johnson, D. C., & Clementz, B. (2013). Emotional scenes elicit more pronounced self-reported emotional experience and greater EPN and LPP modulation when compared to emotional faces. *Cognitive, Affective and Behavioral Neuroscience, 14*(2), 849–860.
Usler, E., Foti, D., & Weber, C. (2020). Emotional reactivity and regulation in 5- to 8-year-old children: An ERP study of own-age face processing. *International Journal of Psychophysiology, 156*, 60–68.
Van Cauwenberge, V., Van Leeuwen, K., Hoppenbrouwers, K., & Wiersema, J. R. (2017). Developmental changes in neural correlates of cognitive reappraisal: An ERP study using the late positive potential. *Neuropsychologia, 95*, 94–100.
Vuilleumier, P., Armony, J. L., Driver, J., & Dolan, R. J. (2001). Effects of attention and emotion on face processing in the human brain: An event-related fMRI study. *Neuron, 30*(3), 829–841.
Walden, T. A., Frankel, C. B., Buhr, A. P., Johnson, K. N., Conture, E. G., & Karrass, J. M. (2012). Dual diathesis-stressor model of emotional and linguistic contributions to developmental stuttering. *Journal of Abnormal Child Psychology, 40*(4), 633–644.
Walsh, B., & Usler, E. (2019). Physiological correlates of fluent and stuttered speech production in preschool children who stutter. *Journal of Speech Language and Hearing Research, 62*(12), 4309–4323.
Wangelin, B. C., Löw, A., McTeague, L. M., Bradley, M. M., & Lang, P. J. (2010). Aversive picture processing: Effects of a concurrent task on sustained defensive system engagement. *Psychophysiology, 48*(1), 112–116.
Wieser, M. J., & Brosch, T. (2012). Faces in context: A review and systematization of contextual influences on affective face processing. *Frontiers in Psychology, 3*.
Wieser, M. J., Gerdes, A. B. M., Büngel, I., Schwarz, K. A., Mühlberger, A., & Pauli, P. (2014). Not so harmless anymore: How context impacts the perception and electrocortical processing of neutral faces. *NeuroImage, 92*, 74–82.
Yairi, E., & Ambrose, N. G. (2005). *Early childhood stuttering: For clinicians by clinicians*. Austin, Tex: pro-ed.
Zengin-Bolatkale, H., Conture, E. G., Key, A. P., Walden, T. A., & Jones, R. M. (2018). Cortical associates of emotional reactivity and regulation in childhood stuttering. *Journal of Fluency Disorders, 56*, 81–99.
Zengin-Bolatkale, H., Conture, E. G., & Walden, T. A. (2015). Sympathetic arousal of young children who stutter during a stressful picture naming task. *Journal of Fluency Disorders, 46*, 24–40.