Distraction by vocal anger in children and adolescents with hyperactivity

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Abstract

Children with inattention and hyperactivity often present difficulties in recognising anger from other people's voices. Research has shown enhanced brain activity (N100) to vocal anger, possibly reflecting preattentive hyper-vigilance to vocal anger, in children with clinical levels of inattention and hyperactivity. In this study we investigated the preattentive processing of vocal anger, by testing whether children with inattention and hyperactivity are distracted by task-irrelevant auditory anger stimuli. A total of 194 participants (50 adults, 51 adolescents, 93 children) took part in a cross-modal oddball paradigm wherein emotional (angry, happy) voices were oddballs and neutral voices were standard while participants performed a visual categorisation task. Questionnaires measures were used to screen for inattention and hyperactivity. Reaction times measures demonstrated that overall, hyperactivity predicted slower performance via distraction by threat-related (e.g., angry) stimuli. The results suggest that vocal anger can capture attention in a pre-attentive (automatic) way in children with high levels of inattention and hyperactivity. Implications for theory and clinical practice are discussed.

Introduction

Hyperactivity and inattention are symptom dimensions of Attention-Deficit/Hyperactivity Disorder (ADHD), the most common neurodevelopmental disorder of childhood (APA; American Psychiatric Association, 2000). At least 5% of school-aged children have difficulties with hyperactivity, impulsivity, and inattention at levels below the threshold for diagnostic criteria for ADHD (Sayal et al., 2017). Children with symptoms of ADHD often present emotional problems such as anxiety (Duchesne, et al., 2010) and depression (Jensen et al., 2001). In addition, up to 60% of individuals with inattention and hyperactivity often present conduct problems, a range of defiant and aggressive behaviours including anger and irritability (e.g., temper tantrums), and oppositional behaviours (Nock, et al., 2007; Connor & Doerfler, 2008).

Cognitive processes including executive dysfunction have been implicated in ADHD pathophysiology. Konrad and colleagues (2016) used event-related functional magnetic resonance imaging (fMRI) to investigate brain activations related to alerting (e.g., achieving and maintaining an alert state), orienting and reorienting (e.g., processing stimuli outside the current focus of attention) and executive control (e.g., resolving conflicts between responses) in 16 boys with ADHD and 16 healthy boys aged 8-12 years. Behaviourally, they found that children with ADHD showed impairment only in their executive control system compared to controls. On a neural level, children with ADHD recruited deviant brain regions for all attentional networks, including alertness, orienting and reorienting and executive control, compared to controls (Konrad, et al., 2006).

More recently, research has focused on motivational processes (Sonuga-Barke & Fairchild, 2012) as a causal mechanism for ADHD. Emotion dysregulation (e.g. difficulty to recognise, attend to and regulate emotion) is increasingly considered an important clinical feature of ADHD (Shaw, et al., 2014). However, it is not clear whether emotion dysregulation in ADHD reflects deviant attentional mechanisms (Barkley, 2015) or atypical perceptual emotion processing (Chronaki et al.,2015a). Research has suggested that executive dysfunction, and emotional dysregulation may contribute independently to symptoms of hyperactivity/impulsivity in children (Sjowall et al., 2013) and adults (Sjöwall & Thorell, 2019). It is possible that individual differences in emotional self-regulation may be related to impairments in orienting and reorienting of attention under conditions of emotional distractors. Some children with symptoms of ADHD present difficulties with processing positive (e.g., reward) or aversive (e.g., delay) stimuli (Chronaki, et al., 2019; Chronaki, et al., 2017) as well as emotional stimuli (Chronaki, et al., 2015a). Therefore, there has been a renewed interest in the way children with ADHD recognise emotions from facial and vocal expressions (Arango-Tobón,et al., 2023). Research has shown that preschoolers with inattention and hyperactivity are less accurate in recognising emotions (e.g., angry, happy) from facial expressions (Chronaki et al., 2013). Reduced sensitivity to negative emotions (e.g., anger, sadness) from facial expressions has consistently been reported in primary school-aged children with hyperactivity (Corbett & Glidden, 2000; Kats-Gold, et al., 2007). This pattern of findings is consistent with research showing that measures of emotional functioning (anger regulation, anger recognition, and regulation of happiness) contributed significantly to discriminating between children with ADHD and controls, over and above the influence of executive functioning (e.g., working memory, inhibition; Sjowall et al., 2013). Previous research has focused on facial emotion processing and few studies have investigated vocal emotion recognition in children with inattention and hyperactivity. Vocal modalities may represent separate processes underlying recognition of emotion and these processes may be distinct from visual modalities (Schirmer & Adolphs, 2017). Emotional prosody refers to changes in the intonation of the voice, according to the speaker's emotional state (Hargrove, 1997). Behavioural evidence indicates that children with symptoms of ADHD present a specific difficulty in recognising negative vocal expressions such as anger (Chronaki et al., 2013). Vocal anger is an expression of hostility and may act as trigger for negative emotional outbursts in children with ADHD which contribute to coercive cycles of parent–child interaction (Johnston & Jassy, 2007). Difficulties in recognising signals of anger in adult voices, may result in difficulties in responding to adult instructions and commands seen in children with inattention and hyperactivity.

More recently, research using Event-Related Potentials has investigated the neural processing of vocal anger in 25 6-11-year-old children with ADHD and 25 typically developing controls, using a vocal emotion recognition task. Results showed that compared to controls, children with ADHD displayed enhanced N100 and attenuated P300 components to vocal anger (Chronaki, et al., 2015a). These results suggest atypical neural activity during the early perceptual stages of vocal anger processing in ADHD. In addition, as ADHD is often comorbid with Conduct Disorder (CD), and atypicalities in emotion recognition are also reported in CD (Fairchild, et al., 2009), this research sought to explore whether CD comorbidity contributed to the ERP results. The study found that while the N100 effects were robust when excluding participants with comorbid CD, the P300 effects were partly accounted by the presence of comorbid CD (Chronaki, et al., 2015a).

As the auditory N100 component is thought to reflect a rapid 'early selection' mechanism underlying auditory attention (Woldorff et al., 1993), the N100 findings are consistent with the idea of preattentive hyper-vigilance to vocal anger in ADHD. This is consistent with research in the facial emotion processing in ADHD. For instance, Williams and colleagues (2018) found increased facial anger-related modulation of the N170, suggesting atypicalities in the early perceptual processing of angry faces. The idea of rapid, almost automatic, initial hyper-orientation to a threatening (e.g., angry) tone in others' voices in children with ADHD, has not been tested experimentally so far. Our recent meta-analysis in vocal emotion recognition in ADHD has confirmed that existing studies in this area have only measured explicit emotion recognition (e.g., tasks where the participant is instructed to explicitly identify the emotion in the voice) and no previous studies in ADHD have examined the vigilance to emotion in voices when emotion is ignored rather than attended to (e.g., preattentive processing; Sells et al., 2023).

The cognitive system is open to the processing of task-irrelevant stimuli in our environment (Marsh, et al., 2021). In particular, the auditory modality plays an indispensable sentinel-like role - preattentively processing the auditory scene and alerting the cognitive system to important environmental changes (Johnston & Strayer, 2001), regardless of its relation to ongoing thought or behaviour (Hughes, et al, 2007; Vachon, et al., 2017). The impact of ignoring auditory distractors on ongoing task performance can be studied with the cross-modal oddball paradigm (Parmentier et al., 2008). Here, participants are requested to categorize visual stimuli while ignoring auditory distractors that are presented immediately before each target. For most trials the same sound is presented (i.e., the 'standard'). However, on infrequent trials a new sound (i.e., the 'deviant') is introduced. This infrequent and unexpected acoustical change in the otherwise repetitive or continuous auditory sequence captures attention from the focal task, resulting in slowed, or more error-prone, responses to a target (e.g., Escera et al., 1998; Hughes et al., 2007; Näätänen, 1990; Parmentier et al., 2008; Schröger & Wolff, 1998). In such cases, the irrelevant stimulations may have no inherent motivational value, and thus the physical properties of the deviant per se do not drive the disruption. Rather attentional capture occurs because the deviant violates the prevailing context – e.g., a predictable pattern of regularity extracted from sounds within the sequence (Bendixen, et al., 2008). The processes that precede attentional capture are suggested to be preattentive because they occur in the absence of attention. Thus, the notion of obligatory processing of the physical properties of the auditory environment are founded on the attentional response to the deviant event.

In contrast to this *aspecific* form of attentional capture, several studies provide evidence for a specific form of attentional capture that is attributable to the particular properties (e.g., semantic features) of a to-be-ignored sound (cf. Eimer, 1996). For example, using a cross-modal oddball task within which participants were required to categorise a visual digit as odd or even while ignoring a deviant sound with an onset that shortly precedes the digit, slowed responses to a greater extent for hungry participants if the deviant was a food-related compared to non-food-related word (Parmentier, Pacheco-Unguetti, & Valero, 2018). This suggests that unexpected words undergo involuntary semantic analysis and builds on previous work wherein the congruency of deviant sounds i.e., "left" or "right", influenced the categorisation of left against right visual arrows (Parmentier et al., 2011; Parmentier et al., 2018). In the case of food-related words the disruption produced by the automatic semantic analysis, occurred independently of the demands of the focal task (see also Vachon et al., 2020). Therefore, it follows that the emotional valence of deviants, in the absence of any relationship to the focal task, should have a greater disruptive impact particularly for participants with vocal-emotion processing differences.

While several studies reveal additional disruption from high compared to low valence words (Buchner et al., 2004; Marsh et al., 2018), very few studies have investigated the potentially differential impact of to-be-ignored distractors that differ in terms of spoken emotional valence. In a study by Kattner and Ellermeier (2018) a sequence of distractors spoken with angry and happy articulation produced greater disruption of visual-verbal serial recall than distractors spoken with neutral or fearful intonation (see also Kattner et al., 2023). However, rather than attributable to attentional capture, the additional disruption produced by a distractor spoken with angry and happy prosody over neutral prosody was attributed to its acoustic properties: the fluctuating emotional prosody of irrelevant speech conveys greater acoustic change than neutral prosody. Since acoustic change is the principal determinant of disruption of visual-verbal serial recall (i.e., the changing-state effect; Jones et al., 1992), it is likely the pre-categorical, rather than post-categorical (i.e., semantic) features of the speech that drive the additional disruption of angry over neutral prosody. Support for this suggestion was gleaned from the failure of distractors with angry and happy intonation to disrupt a task devoid of serial recall (the missing-item task) that is sensitive to attentional capture effects (e.g., Hughes et al., 2007) but immune to disruption produced via the changing-state effect (Beaman & Jones, 1998; Jones & Macken, 1993). Arguably the use of a cross-modal oddball paradigm (e.g., Parmentier et al., 2008) has the capability to detect differences in the power of angry against happy and neutral spoken distractors to capture attention. A useful feature of the cross-modal oddball paradigm is that distraction by a deviant can typically be seen in a slowing of the response to a target immediately following the deviant, but also a slowing of the response on the next trial wherein a standard is presented (e.g., Pacheco-Unguetti & Parmentier, 2014). It is thought that such postdeviance distraction represents the completion of a reconfiguration of the task set after the switch of attention toward the deviant on the preceding trial, while the earlier deviant distraction represents orientation to (and from the deviant) and a reactivation of the relevant task set (e.g., Parmentier & Andrés, 2010).

A preattentive gating mechanism determines to what degree auditory stimuli capture awareness (Jääskeläinen et al., 2004). There is debate in the literature as to whether emotional expressions are processed outside conscious awareness (Pessoa & Adolphs, 2010). In the adult literature, there is evidence for a rapid and involuntary capture of attention by facial (Vuilleumier & Pourtois, 2007) and vocal (Lima, et al., 2019) emotional expressions. Little is known, however, on the involuntary capture of attention by vocal anger in children and adolescents. The processing of stimuli that require no attentional resources to be perceived (e.g., 'preattentive' processing) can be measured via the cross-modal oddball task (Parmentier et al., 2008; Squires et al., 1975) wherein the processes that lead up to attentional capture are arguably preattentive since they occur without attention and the auditory stimuli are to-be-ignored. On this reasoning, any differential disruption (e.g., via attentional capture) produced by distractors differing in spoken valence must be attributable to the obligatory processing of the auditory environment. It can be argued that stimuli with negative emotional valence are likely to grab attention and diminish task performance more than neutral stimuli. An example of such negative stimuli are disgusting words. A recent study found that disgusting and neutral auditory words that were perceptually decoupled from the target stimuli produced significant but equivalent levels of distraction (Parmentier et al., 2019). The idea that anger from others' voices can grab attention and produce distraction more than a neutral tone of voice in children with symptoms of ADHD has not been investigated so far.

In this study we used a cross-modal oddball paradigm wherein emotional (angry, happy) voices were the deviants (i.e., oddballs) and neutral voices were the standards. First, we predicted an oddball effect wherein the deviant vocal stimuli (angry, happy) will lead to prolonged reaction times in the task. Specifically, we expected a difference between angry against standard and happy against standard (neutral). Similarly, we predicted prolonged reaction times on the next trial wherein a standard is presented (e.g., postdeviance distraction). For this reason, we measured, the accuracy and reaction time for neutral voice trials that directly followed the happy deviants and the angry deviants. Second, we aimed to investigate the possibility of early preattentive hyper-vigilance to vocal anger in ADHD. We predicted that children with inattention and hyperactivity not only will be less accurate and slower to respond to a target immediately following the angry, against happy, voices as deviant distractors (deviance distraction), but they will also demonstrate a slowing of the response on the next trial wherein a standard is presented (e.g., postdeviance distraction).

Methods

Participants

From 250 participants initially approached, 198 individuals (148 children and 50 adults) participated in the study. Four child participants were removed from analyses as they were outliers. Children were recruited from primary schools and were selected from two age groups (see Table 1) based on previous developmental research (Chronaki et al., 2015). Child assent and adult informed consent were obtained prior to participation. Data were also collected from healthy adults recruited from university undergraduates. The study was approved by the Ethics Committee, at the School of Psychology and Humanities, University of Central Lancashire.

Table 1. Participants characteristics

Age groups	Age range	Mean	SD	N
Children	7-10	9.30	.80	93 (40 males)
Adolescents	11-15	12.00	.95	51 (34 males)
Adults	18-48	23.40	7.10	50 (42 males)

Materials

Vocal stimuli

Non-word vocal stimuli (interjection 'ah') were derived from a battery of vocal emotional expressions (Maurage et al., 2007) and were normalized and standardized regarding acoustic properties including 700-ms duration, 16000 Hz recording frequency, and 70 dB intensity. The stimuli used for this study consisted of angry, happy, and neutral vocal expressions.

These vocal stimuli have already been validated in adults (Maurage et al., 2007) and children and adolescents (Chronaki et al., 2015). We used praat software (Boersma & Weenink, 1992) for the normalization and standardization of vocal emotional expressions. The average level of intensity (in dB[A]) over stimulus duration was used to calibrate the vocal stimuli to a 70 dB(A) intensity, which was measured with a Casella CEL-633B1 decibel level meter. Spectrograms for the vocal emotional stimuli are provided in Figure 1.

--Insert Figure 1 here---

Experimental task design

Participants took part in a cross-modal oddball paradigm that required them to help an animal (dog and cat) across the river to the other side using a steppingstone. Participants were asked to press one of three different coloured buttons (red, blue and green) on the keyboard that matched the colour of the steppingstone in the river. Colours were indicated using small circle stickers; red on the 'F' key, green on the 'H' and blue on the 'K'. The dimensions of the keyboard were 30 (lenght) x 10 (width) x 2 (depth) cm. Participants were instructed to press the correct button and as quickly as possible. The coloured steppingstones were preceded by emotional and neutral voices. The angry and happy voices were the oddballs, and the neutral voices were standards. Angry and happy voices had a probability of 10% each and the neutral voices had a probability of 80%. There was a practice block including 10 trials. The main experiment task included two blocks with 102 trials each. In block 1 there were 81 neutral voices, 11 happy voices and 10 angry voices in total. In block 2 there were 81 neutral voices, 10 happy voices and 11 angry voices in total. Vocal expressions were presented binaurally via Sennheiser HD 380 pro supra-aural headphones that were plugged directly into a Lenovo computer. Reaction time and accuracy of the responses were recorded and stored through E-prime software. The task lasted approximately 15 minutes. Due to having two animals in the task (dog and cat), two versions of the game were presented. In version 1, the cat appeared first in Block 1 and was followed by the dog in Block 2. In version 2, the dog appeared first in Block1 and was followed by the cat in Block 2. This design was adopted to eliminate order effects..A graphical representation of the task and equipment including the keyboard and buttons is presented in Figure 2.

--Insert Figure 2 here---

Questionnaire measures

Behavioural and emotional problems: Parents, teachers and children completed the hyperactivity, conduct problems, and emotional problems subscales of the Strengths and Difficulties Questionnaire (SDQ) screening questionnaire for 3-16-year-olds (Cronbach's alpha=.85; Goodman, 1997). The SDQ is a validated self-report measure for use in children (Curtis, et al., 2013). Each item is scored on a scale from 0 (not true) to 2 (certainly true). The five items for each sub-scale generate a score of 0-10. The hyperactivity sub-scale includes inattention (3 items) and hyperactivity (2 items) symptoms. Reliability in the current study was high with Cronbach's alpha =.74, .67 and .70 for the parent, teacher, and self-report version respectively.

Adult inattention and hyperactivity-impulsivity: Adults completed the Current Behaviour Scale measuring inattention, and hyperactivity/impulsivity (i.e., 'I am easily distracted' Barkley & Murphy, 1998). The ADHD-CBS is a self-report scale consisting of 18 items derived from the 18 ADHD symptom criteria for adults reported in the DSM-IV. Nine items measure inattention, and 9 items measure Hyperactivity and Impulsivity. Each of the 18 items is rated on a 4-point Likert scale (never, sometimes, often, very often). Scores range from 0–27 for each scale. Items were added to create a total score of combined inattention, and hyperactivity/impulsivity. Reliability in the current study was high with Cronbach's alpha =.70.

Procedure

Children and adolescents were tested individually in a quiet room in their school and adults at the University. The task was introduced to the participants as a game. Participants were instructed to ‘help the animal across the river to its babies’. Following the instructions, each participant completed 10 practice trials before continuing onto the main task. All participants were successful in completing the trials in the practice block and proceeded into the main experiment when ready. After the first block, the researcher offered an opportunity for a short break. Children were prompted to remain on task and pay attention during the task. After completing the task, participants were asked to complete the questionnaires. Teachers and parents completed the SDQs after the child completed the task. At the end of the task children were rewarded with a certificate of participation as a small thank you gift.

Data Processing

Raw data from the auditory oddball task were transformed into measures of accuracy and reaction time. Accuracy was computed for each target using ‘hits’ (e.g., stone colour identified correctly). Accuracy scores took values of 1 for correct responses and 0 for incorrect responses. Reaction times for correct responses were calculated in milliseconds. We also created a separate mean value for the accuracy and reaction time for neutral voice trials that directly followed the happy deviants and the angry deviants. This is because the accuracy, but most often the reaction time, for neutral voice trials that follows a deviant are less accurate and slower due to postdeviant distraction (Berti, 2008; Pacheco-Unguetti & Parmentier, 2014).

Data analysis

Preliminary analyses: Kolmogorov-Smirnov tests indicated that values for reaction time did not differ significantly from normality ($p > .05$). Values of accuracy were significantly different from normality ($p <. 001$).

Main analyses: Scores of reaction time were entered into a mixed design ANOVA with Emotion (Angry, Happy, Neutral) as the within-participant factor and Age group (Child, Adolescent, Adult) as the between-participants factor to examine the effect of emotion, group, and emotion × group interaction effect on reaction time. These analyses compared the angry deviant against the neutral and the happy deviant against the neutral (standard). We used partial eta-squared (Cohen, 1973) estimates of effect sizes for the ANOVAs. Because accuracy values were not normally distributed due to ceiling effects, non-parametric tests were used. Values of accuracy were entered in repeated measures non-parametric Kruskal-Wallis H test with Emotion (Angry, Happy, Neutral) as the within-participant factor and Age group as the between-participants factor, to examine the effect of emotion, age group, and emotion × group interaction effect on accuracy. Pearson's correlations examined the relationship between reaction time, and child behaviour problems and adult inattention/hyperactivity. Non-parametric Spearman's correlations examined the relationship between accuracy, and child behaviour problems and adult inattention/hyperactivity.

Results

Accuracy

Tables 2-3 display means and standard deviations for accuracy by emotion and age. Non-parametric Kruskal-Wallis H tests showed a statistically significant difference in accuracy between the age groups for targets preceded by happy ($\chi2(2) = 13.28$, $p = 0.001$), and neutral

($\chi 2(2) = 18.00$, $p < 0.001$) but not angry (*p*s >.05) voices. For neutral voices, there was a mean rank accuracy of 83.80 for Children, 125 for Adolescents, and 94.80 for Adults. For happy voices, there was a mean rank accuracy of 92.05 for Children, 120.18 for Adolescents, and 84.50 for Adults. These results indicate that accuracy for targets preceded by happy and neutral voices significantly increased from childhood to adolescence, suggesting a steep developmental trajectory for accuracy following happy and neutral voices (see Figure 3). Although, accuracy following happy and neutral voices declined from adolescence to adulthood this difference was not statistically significant (*p*s > .05). For happy voices, there was a mean rank accuracy of 116.10 for Adolescents, and 95.60 for Adults. For neutral voices, there was a mean rank accuracy of 125.10 for Adolescents, and 94.80 for Adults. The results did not change when analyses were repeated with the postdeviance distraction accuracy scores.

--Insert Tables 2-3 and Figure 3 here--

Reaction time

Tables 4-5 display means and standard deviations for reaction time by emotion and age. There was a significant main effect of age on reaction time, F (2, 191) = 37.44, $p < .001$, $\eta 2 = .28$. Post-hoc pairwise comparisons showed that overall, children and adolescents were slower than adults, and children were slower than adolescents (all *p*s' < .001). No other effects were significant (all *p*s > .05). A deviance distraction effect was not evident. When analyses were repeated for the postdeviance distraction scores, in addition to the significant main effect of age on reaction time ($p <. 001$), there was a main effect of emotion on reaction time, F (2, 191) = 12.60, $p < .001$, $\eta 2 = .06$. Participants were slower to respond to targets on neutral trials that had been preceded by angry (*M* = 717 ms, *SD* = 137) compared to neutral (*M* = 697 ms, *SD* = 130) voices ($p < .001$). There was a significant emotion × age interaction effect on reaction time F (4, 191) = 2.90, $p < .05$, $\eta 2 = .03$. To explore this, we ran additional analyses in which reaction time scores per emotion were entered in one-way ANOVA examining the effect of emotion on reaction time for the age groups separately. There were significant differences in reaction times between the age groups for targets on neutral trials preceded by angry, happy, and neutral voices, F (2, 92) > 4.90, ps <.02. Children were slower to respond to targets after neutral trials preceded by emotional (angry and happy) compared to neutral voices (ps < .001), while adults were slower to respond to targets on neutral trials preceded by angry compared to neutral (p = .010) and happy (p = .025) voices (see Figure 4). These results suggest that adults' performance is slowed by threat-related (e.g., anger) voices. There was no statistically significant difference in reaction times for the different emotion conditions in adolescents (p >.11).

--Insert Tables 4-5 and Figure 4 here—

Distraction by vocal anger and behaviour problems

Pearson's correlations were employed to explore the relationships between behavioural and emotional problems and reaction time. Because age was negatively correlated with reaction time (ps <.001), it was controlled for in this analysis. Results showed that higher parent-rated hyperactivity scores were positively associated with reaction times to targets preceded by angry (r = .26, p = .007), happy (r = .24, p = .014), and neutral (r =.26, p = .006) voices. No significant associations emerged between conduct problems, emotional problems, and reaction time scores after correcting for multiple testing (ps >.04). Pearson's correlations explored the relationship between adult inattention and hyperactivity and reaction time scores. Results showed no significant associations (ps > .05). Non-parametric Spearman's correlations showed no significant associations between child behaviour problems or adult inattention/hyperactivity and accuracy scores (all *p*s > .05). Results did not change when analyses were repeated for the post-deviant distraction reaction time and accuracy scores.

Multiple regression analyses examined the independent contribution of child behavioural and emotional problems to reaction time scores. In this analysis, reaction time was the dependent variable and age, and child behaviour problems (hyperactivity, conduct problems and emotional problems) were the independent variables. Parent-rated hyperactivity was significantly positively associated with reaction time to targets preceded by angry voices ($p < .05$; see Table 6) but not happy or neutral voices (*p*s > .05). Neither conduct problems nor emotional symptoms were significantly associated with reaction times. These results indicate that the positive association between behaviour problems and reaction time scores reflected individual differences in hyperactivity specifically. Results suggest that hyperactivity predicts slower performance via distraction by threat-related (e.g., angry) stimuli.

When analyses were repeated for reaction time and accuracy scores for postdeviant distraction, parent-rated hyperactivity was significantly positively associated with reaction time to targets after neutral trials preceded by angry and happy ($p < .05$) but not neutral voices. Neither conduct problems nor emotional symptoms were significantly associated with reaction times. These results indicate that hyperactivity predicted longer reaction times to targets after neutral trials preceded by emotional (angry and happy) compared to neutral voices. This suggests that hyperactivity predicted slower performance via postdeviant distraction attributable to emotion. No other effects were significant (ps >.05).

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Discussion

The present study adopted a novel cross-modal oddball task requiring attention-independent processing of vocal emotion in children, adolescents, and adults. First, the task produced the expected developmental effects on accuracy and reaction time. Our study did not show a cross-modal deviance distraction effect but did show a postdeviance distraction effect. Second, childhood hyperactivity predicted slower performance via distraction by threat-related stimuli.

First, our study showed age-related effects on accuracy. Accuracy for targets preceded by happy and neutral voices improved from childhood to adolescence. These results suggest a steep developmental trajectory for accuracy following happy and neutral but not angry voices. These findings extend previous research showing that 10-year-old children are equally as accurate as adults in recognising angry voices in vocal emotion recognition tasks (Chronaki, et al., 2015). A developmental pattern in reaction time was also evident. As expected, speed improved from childhood to adolescence and adulthood. The findings converge with developmental research showing an improvement in processing speed with age (Hale, 1990; Kail, 1991; Śmigasiewicz, et al., 2021).

Contrary to our prediction, we did not find a deviance distraction effect wherein the deviant stimuli (angry, happy) caused prolonged reaction times in the task compared to the standard (neutral) stimuli (Escera, et al., 2002; Parmentier et al., 2008). The lack of a deviance distraction effect in our study contradicts the results of previous investigations (Parmentier et al. 2008; Schröger & Wolff, 1998; Parmentier et al., 2008; Schröger & Wolff, 1998; Weise, et al., 2023). Here we discuss possible explanations for this. First, some investigations have shown reduced distraction effects or even improved performance with task-irrelevant emotional information (Lorenzino & Caudek, 2015; Max, et al., 2015), suggested to reflect an increased level of arousal caused by the emotional nature of distractors

(Max et al., 2015). For example, a recent study in adults found that emotional novel sounds decreased attention distraction effects compared to neutral novel sounds. It also found a larger pupil dilation (reflecting increased arousal) to novel compared to standard sounds, and a direct relation between reduced distraction effects and increased arousal (Bonmassar, et al., 2023). The emotional content of novel sounds has been shown to increase arousal also in 7-10-year-old children (Bonmassar et al., 2020). These findings demonstrate that task-irrelevant emotional stimuli may facilitate processing and improve performance. Second, sensory stimuli presented in different modalities may interfere less with each other than stimuli in the same modality (Schupp et al., 2008). Research has shown that presenting task-irrelevant emotional stimuli in a different modality compared to the target reduced distraction effects (De Houwer et al., 2002). Third, our task required participants to make one of three responses as compared to a binary response in previous studies. This may have led to slower reaction times in our task and possibly explain the lack of distraction effects, although problematic for that account is that we did find postdeviance distraction effects. Fourth, individual differences in hyperactivity may play a role in deviance distraction effects related to threat-related stimuli in children. We discuss this possible explanation in more detail below.

As predicted, when examining the accuracy and reaction time for neutral trials that directly followed the happy deviants and the angry deviants, we found prolonged reaction times on the next trial wherein a standard is presented (e.g., postdeviance distraction effect). Parmentier and Andres (2010) argue that postdeviance distraction represents the completion of a reconfiguration of the task set after the switch of attention toward the deviant on the preceding trial. While the completion of task-set reconfiguration explanation would seem on the face of it unsatisfactory, due to the lack of evidence of attentional capture on the previous trial, it is possible that the lack of evidence of an attentional switch is produced by two countervailing forces – on the one hand a speed-up effect produced by the emotionality of the to-be-ignored stimulus and on the other hand distraction produced by the deviant nature of that stimulus. Thus, task-set reconfiguration could still occur and explain the postdeviance distraction effect.

Age-related effects on reaction time varied by emotion when examining postdeviance distraction. We found that children's performance was slowed by the presence of a deviant in general, while adults' performance was slowed by threat-related stimuli specifically (e.g., the difference between angry and happy deviants). The fact that adults' but not children's performance was impacted under conditions of distraction by vocal anger may suggest that attentional control abilities in an emotional (e.g., threatening) context mature later in development. Although we cannot assess the effect of emotionality on reaction time in the absence of a neutral deviant, we can speculate that adults' attentional control abilities may counteract the post deviance distraction caused by the happy deviants. Previous studies have not examined the effect of age on post-deviant distraction using vocal emotional stimuli. Research using related paradigms (e.g. visual or auditory selective attention tasks) has shown that distractability is higher in children compared to adults (Robinson, et al., 2018). This pattern of results is compatible with research using auditory distraction paradigms. For example, children aged 7-9 years were more susceptible to disruption by a deviant sound compared to adults in an auditory distraction task (Joseph, et al., 2018). Some studies have found a reduction in auditory (Wetzel & Schröger, 2007) and audiovisual (Gumenyuk et al., 2001) distraction as children grow older. For instance, research using a duration categorization task has found greater distraction by deviant sounds in children aged 6-8 compared to young adults, but no difference between children aged 10-12 and young adults (Wetzel et al., 2016). EEG and MEG data indicate that mismatch responses, thought to reflect deviance detection, are delayed in 9-10-year-old children compared to adults, suggesting that not all neurophysiological aspects of deviance processing are mature by 10 years (Ruhnau, et al., 2017). Other studies using auditory and audio-visual tasks, however, have found no effect of age on deviance distraction in childhood (Horváth, et al., 2009; Roer, et al., 2018). At the other end of the age spectrum, older adults (55-72 years) have been shown to be more distracted by a deviant than younger adults (19-32 years) and take longer to overcome a distracting event on a subsequent standard trial (Getzmann & Wascher, 2016; see also Getzmann et al., 2014). Through analyses of EEG components, research has shown that older compared to younger participants demonstrate a reduction and delay in attentional control following a deviant (i.e., postdeviance distraction) and a decrement in processing of stimuli following an attentional switch (Getzmann & Wascher, 2016). Getzmann et al. (2014) argue that the increased postdeviance distraction observed in elderly participants may reflect a delay in orienting-reorienting mechanisms.

Parent-rated hyperactivity significantly predicted reaction time to targets preceded by angry voices, but not happy and neutral voices. It is possible that individual differences in hyperactivity can shed light on the specific disruption produced by threat-related stimuli. In other words, although, vocal anger may not preattentively capture attention in children, it may be preattentively processed in children with high levels of hyperactivity. Our findings suggest that the involuntary processing of threat-related (e.g., angry) stimuli can slow down performance in children with hyperactivity. Our study extends previous research in this area which has relied on explicit emotion recognition (Chronaki et al., 2013), by investigating the pre-attentive processing of vocal emotion using a cross-modal oddball paradigm. Our study shows that when vocal emotional cues are processed pre-attentively, performance is slowed in children with hyperactivity. It is possible that when attention is directed to vocal emotions, children with hyperactivity demonstrate less sensitive emotion recognition (Chronaki et al., 2013), however, at a pre-attentive level children with hyperactivity are sensitive to emotion, especially anger. There is some evidence in the ADHD literature which suggests that processing biases in emotion perception may be a marker of “cognitive distortion”, reflecting misinterpretation at a perceptual level of emotion recognition, whereas processing deficits, may be a marker of attention deviancies (Cadesky, et al., 2000). If children with hyperactivity are slower to respond to a target following a deviant distractor, as in our study, one could argue that this may indicate attention deviance.

Our findings suggest sensitivity to signals of social punishment (i.e., anger) in some children with hyperactivity, when these signals are processed outside conscious awareness. This is consistent with research showing that target processing was disrupted in the context of angry, but not happy, faces in a Go/No-Go task in children with ADHD symptoms (Manoli et al., 2021). Our findings extend existing literature showing impairments in auditory processing of non-emotional stimuli at the early sensory stages in ADHD (Loiselle et al., 1980; Zambelli et al., 1977) and add to the growing literature implicating early sensory (e.g., preattentive) emotion processes in ADHD (Chronaki et al., 2015a). However, the finding of a slower performance under conditions of distraction by vocal anger is not entirely consistent with our previous finding of an enhanced N100 component to vocal anger, possibly suggesting hyper-vigilance towards vocal anger in ADHD (Chronaki et al., 2015a), and findings from the face processing literature showing exaggerated early perceptual face-specific components (i.e., N170) to anger (Williams et al., 2008). Future research should explore the hypothesis of a rapid initial hyper-orientation to threatening (angry) stimuli followed by deficits in later, cognitive evaluation of the emotional significance of these stimuli.

In addition, hyperactivity predicted slower performance via postdeviance distraction following an emotive stimulus, as children with hyperactivity were slower to respond to targets after neutral trials preceded by emotional (happy, angry) vocal expressions. Our findings suggest that distraction by vocal emotion can be robust enough to interfere with task performance perhaps through delaying task-set reconfiguration. The residual distraction on the subsequent trial (postdeviance distraction) is hypothesized to reflect bottom-up, stimulus-driven rather than top-down processes (Parmentier & Andrés, 2010). It is possible that emotion in general may be encoded automatically and slows down performance in children with hyperactivity via postdeviance distraction. Previous research has shown increased early, 'bottom-up' attention capture, as reflected by increased P1 to emotional (fear and happy) faces, in adolescents with ADHD (Karalunas, et al., 2020). Collectively, existing literature supports the idea of limbic dysfunction which may impact cognitive control in emotional contexts and contribute to the social and emotional problems typically associated with ADHD (Schulz et al., 2014). Postdeviance distraction effects found in this study may be driven by individual differences in emotional self-regulation skills. Previous research has shown that emotion dysregulation can be a core feature of childhood ADHD (Sjowall et al.,2013). Research in adults has found independent effects of executive deficits and emotion dysregulation (Sjöwall & Thorell, 2019) in relation to symptoms of hyperactivity/impulsivity, in line with the dual pathway model (Sonuga-Barke, 2003). There is debate in the literature as to whether emotion dysregulation in ADHD reflects deviant attentional mechanisms (Barkley, 2015) or atypical perceptual emotion processing (Chronaki et al., 2015a). Future research should aim to systematically investigate the determinants of the postdeviance distraction effect reported.

While we provide the first evidence of the involuntary capture of attention by vocal anger in children with hyperactivity, further study is required in several areas. First, future research should aim to replicate our findings in clinical samples of children with ADHD. Second, the ecological validity of the stimuli could be improved by using cross-modal presentation of emotion (faces and voices), as in real life situations. Third, in the present study we did not include a neutral deviant to keep the experiment duration in reasonable bounds for the children. To further examine the effects of emotionality on reaction time, future studies should include a neutral deviant distracter. Fourth, future studies should also employ Event-Related Potential methods to examine the neural correlates of the pre-attentive processing of vocal anger in children with hyperactivity. These methods offer higher resolution to measure 'how early' distraction occurs. In addition, these methods can disentangle early, sensory components (e.g., N1) from later cognitive components (e.g., P3) implicated in emotion processing. Finally, future research should aim to include separate measures of cognitive abilities (e.g., processing speed, working memory) as well as arousal in children. For example, previous research has shown that relative to controls, young adults with ADHD had difficulty attenuating auditory cortical responses to task-irrelevant sounds when working memory task demands were high, suggesting that ability to cope with auditory distraction may be related to working memory and cognitive control (Blomberg et al., 2021).

The finding of implicit processing of negative vocal emotional stimuli in children with hyperactivity has important implications for clinical practice. Distraction and the drawing of attention away from threat can serve as an important target of cognitive therapy treatments of ADHD where patients have difficulties in blocking rumination and diverting their attention to other (e.g., positive, neutral) stimuli or situations (McRae et al., 2010). Treatments for ADHD may need to consider an individual's tendency to distract oneself from a potentially threatening situation as a coping mechanism to establish a sense of control over the situation (Bodenhausen, et al., 2000).

In summary, we have validated a novel experimental task that can reliably measure distraction by emotional vocal stimuli in children and adolescents. In addition, we have shown preattentive processing of vocal anger using this oddball task in children with hyperactivity. Our findings have important implications for programs which aim to help children with hyperactivity develop better attention control skills under emotional contexts.

Appendix

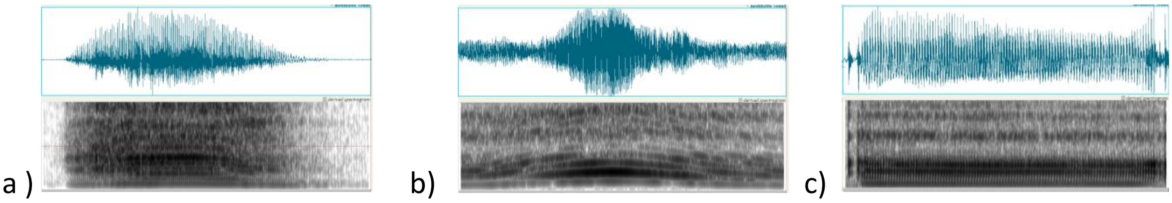

Figure 1. Spectrograms for angry (panel a), happy (panel b) and neutral (panel c) vocal stimuli.

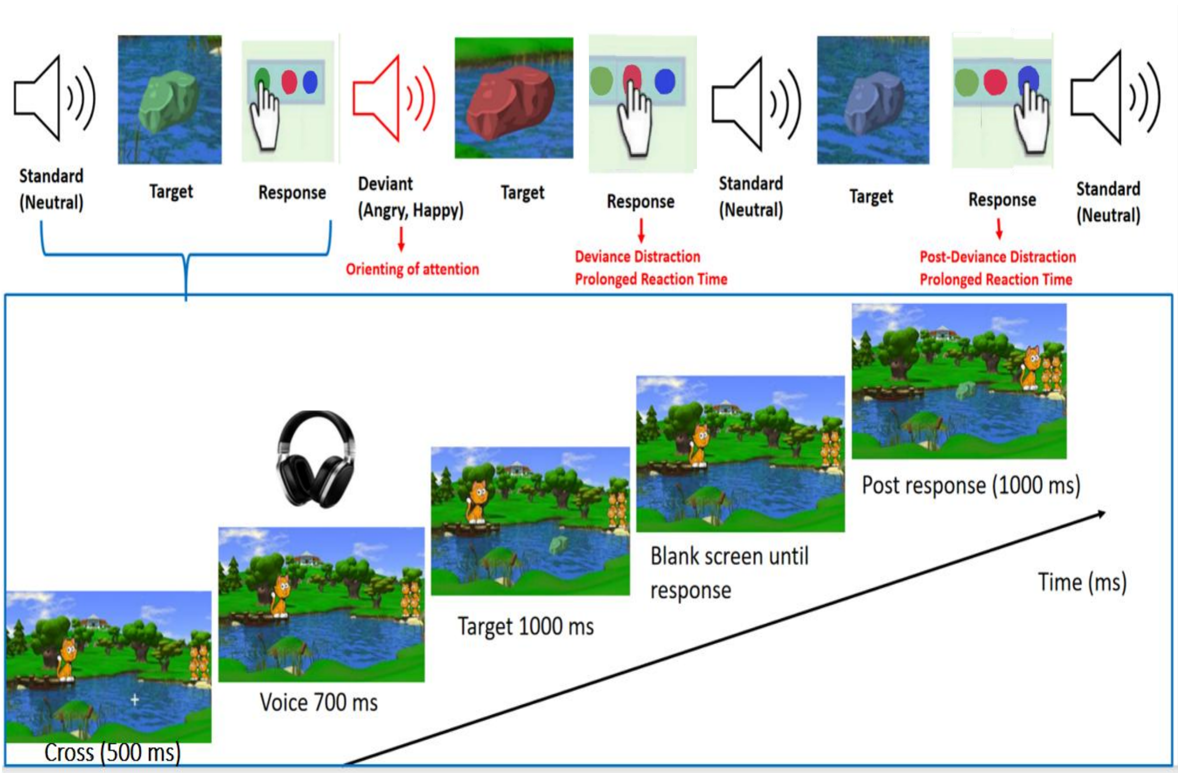

Figure 2. Task design. Participants received the following instructions: A mummy or daddy animal (cat and dog) have been separated from their baby animals. In this game you need to help the cat and dog to get back to their baby animals on the other side of the river. Stones will appear in the middle of the stream. The cat and dog will need to step on the stones to cross the river. The stones have three different colours: red, green, and blue. You need to press the key on the keyboard that matches the colour of the stones. You need to press the key as quickly as you can because the stones appear quickly! You will hear some sounds while you do the task. Try to ignore the sounds as they are not related to your task to press the right key. Instructions were presented in a child-friendly way to the

child group. This consisted of slower pace, more explanation when needed, more time for questions and frequently checking the children had understood the instructions.

Table 2.

Mean (SD) of accuracy scores (deviance distraction) to visual targets per age group and emotion.

	Vocal Emotional Expression		
Age group	Angry	Happy	Neutral
Children	.94(.07)	.93(.08)	.93(.07)
Adolescents	.96 (.05)	.97(.06)	.96(.04)
Adults	.94 (.12)	.94(.12)	.93(.13)

Table 3.

Mean (SD) of accuracy scores (post deviance distraction) to visual targets per age group and emotion.

	Vocal Emotional Expression		
Age group	Angry	Happy	Neutral
Children	.92 (.09)	.93(.08)	.92 (.07)
Adolescents	.94(.07)	.97(.04)	.97(.04)
Adults	.92(.14)	.92(.12)	.93(.12)

Table 4.

Mean (SD) of reaction time scores (deviance distraction) to visual targets per age group and emotion.

	Vocal Emotional Expression		
Age group	Angry	Happy	Neutral
Children	759.50(124)	761.90(117)	760.08(105)
Adolescents	704.77(132)	706.90(123)	692.23(104)
Adults	581.89 (128)	584.70(130)	584.90(120)

Table 5.

Mean (SD) of reaction time scores (postdeviance distraction) to visual targets per age group and emotion.

	Vocal Emotional Expression		
Age group	Angry	Happy	Neutral
Children	787.98(118)	778.30(118)	760.00(105)
Adolescents	700.50(107)	703.70(120.80)	692.20(104)
Adults	602.14(112)	582.90(122)	584.90(120)

Table 6. Hierarchical multiple regression examining the independent contribution of behaviour problems on the reaction time scores to targets following angry voices.

	Reaction time following angry voices			
	b	*SEB*	β	*p*
Model 1				
Age	-22.04	9.43	-.22	**.020**
Model 2				
Hyperactivity	11.34	5.60	.24	**.046**
Conduct problems	.48	9.40	.00	.960
Emotional problems	4.44	5.78	.07	.444

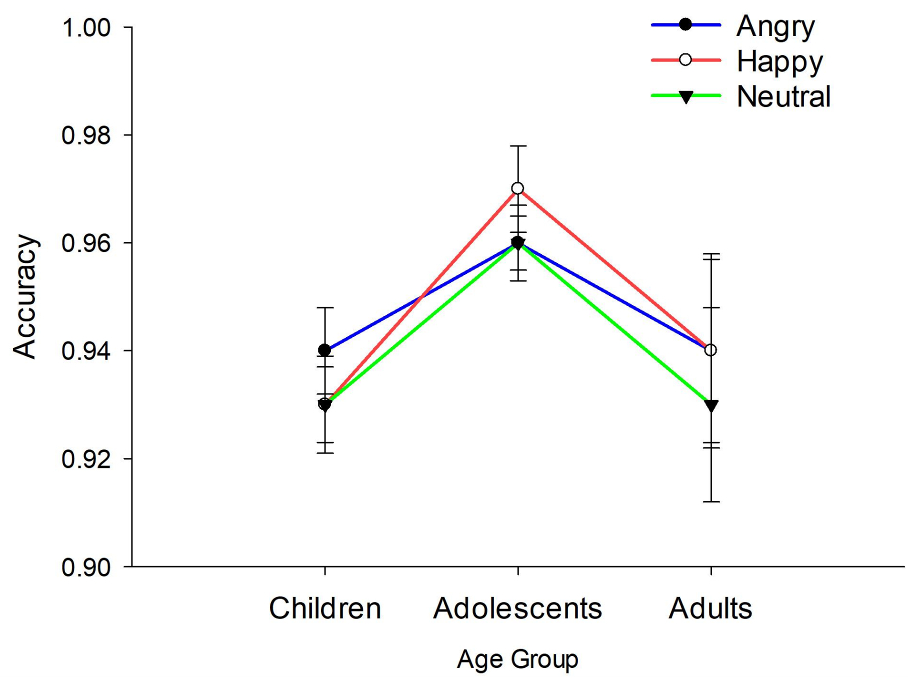

Figure 3. Line graph with error bars showing the accuracy scores for angry, happy and neutral voices for each age group separately.

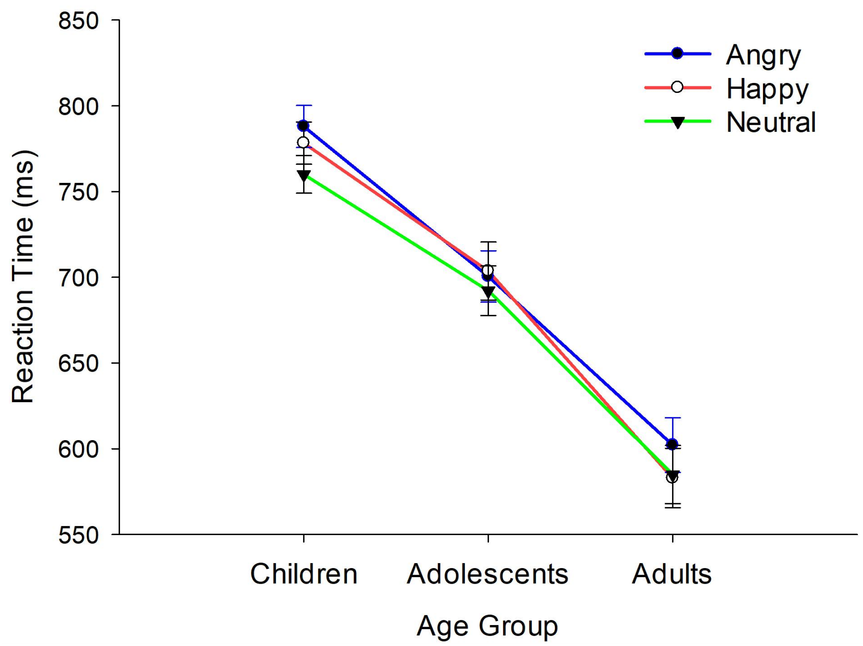

Figure 4. Line graph with error bars showing the emotion x age interaction effect on post deviance distraction reaction time scores. Children were slower to respond to targets after neutral trials

preceded by emotional (angry and happy) compared to neutral voices, while adults were slower to respond to targets on neutral trials preceded by angry compared to neutral and happy voices.

Data Availability Statement

The data that support the findings of this study are openly available from the first author.

References

American Psychiatric Association (2000). Diagnostic and statistical manual of mental disorders (5th Ed.). Washington, DC: American Psychiatric Association.

Arango-Tobón, O. E., Guevara Solórzano, A., Orejarena Serrano, S. J., & Olivera-La Rosa, A. (2023). Social Cognition and Prosocial Behavior in Children with Attention Deficit Hyperactivity Disorder: A Systematic Review. *Healthcare, 11*(10), 1366.

Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin*, *121*(1), 65–94. https://doi.org/10.1037/0033-2909.121.1.6

Barkley, R., & Murphy, K. (1998). *Attention-Deficit Hyperactivity Disorder: A Clinical Workbook (2nd ed.).* New York: Guilford Publications.

Beaman, C. P., & Jones, D. M. (1998). Irrelevant Sound Disrupts Order Information in Free Recall as in Serial Recall. *The Quarterly Journal of Experimental Psychology Section A, 51*(3), 615-636. doi:10.1080/713755774

Bendixen, A., Prinz, W., Horváth, J., Trujillo-Barreto, N. J., & Schröger, E. (2008). Rapid extraction of auditory feature contingencies. *NeuroImage, 41*(3), 1111-1119.

Berti, S. (2008). Cognitive control after distraction: Event-related brain potentials (ERPs) dissociate between different processes of attentional allocation. *Psychophysiology, 45*(4), 608-620. doi:https://doi.org/10.1111/j.1469-8986.2008.00660.x

Blomberg, R., Johansson Capusan, A., Signoret, C., Danielsson, H., & Rönnberg, J. (2021). The Effects of Working Memory Load on Auditory Distraction in Adults With Attention Deficit Hyperactivity Disorder. *Frontiers in Human Neuroscience, 15*. https://doi.org/10.3389/fnhum.2021.771711

Bodenhausen, G. V., Gabriel, S., & Lineberger, M. (2000). Sadness and susceptibility to judgmental bias: The case of anchoring. *Psychological Science,, 11*, 320-323. doi:doi:10.1111/1467-9280.00263

Boersma, P. & Weekink (1992-2022: **Praat: doing phonetics by computer [Computer program].**Version 6.2.06, retrieved 20 Feruary 2022 from https://www.praat.org.

Bonmassar, C., Scharf, F., Widmann, A., & Wetzel, N. (2023). On the relationship of arousal and attentional distraction by emotional novel sounds. *Cognition, 237*(1), 1-13. doi:https://doi.org/10.1016/j.cognition.2023.105470

Bonmassar, C., Widmann, A., & Wetzel, N. (2020). The impact of novelty and emotion on attention-related neuronal and pupil responses in children. *Developmental Cognitive Neuroscience, 42*, 1-13. doi:https://doi.org/10.1016/j.dcn.2020.100766

Buchner, A., Rothermund, K., Wentura, D., & Mehl, B. (2004). Valence of distractor words increases the effects of irrelevant speech on serial recall. *Memory and Cognition, 32*(5), 722-731.

Cadesky, E. B., Mota, V. L., Mota, V. L., & Schachar, R. J. (2000). Beyond words: How do children with ADHD and/or conduct problems process nonverbal information about affect?. *Journal of the American Academy of Child & Adolescent Psychiatry, 39*(9), 1160–1167. https://doi.org/10. 1097/00004583-200009000-00016

Chronaki, G., Benikos, N., Fairchild, G., & Sonuga-Barke, E. J. (2015a). Atypical neural responses to vocal anger in attention-deficit/hyperactivity disorder. *Journal of Child Psychology and Psychiatry, 56*(4), 477-487. doi:doi:10.1111/jcpp.12312

Chronaki, G., Benikos, N., Soltesz, F., & Sonuga-Barke, E. J. S. (2019). The reinforcing value of delay escape in attention deficit/hyperactivity disorder: An electrophysiological study. *Neuroimage Clinical, 23*, 101917. doi:10.1016/j.nicl.2019.101917

Chronaki, G., Garner, M., Hadwin, J., Thompson, M., Chin, C., & Sonuga-Barke, E. J. (2013). Emotion-recognition abilities and behavior problem dimensions in preschoolers: evidence for a specific role for childhood hyperactivity. *Child Neuropsychology, 21*(1), 25-40.

Chronaki, G., Hadwin, J. A., Garner, M., Maurage, P., & Sonuga-Barke, E. J. (2015). The development of emotion recognition from facial expressions and non-linguistic vocalizations during childhood. *Br J Dev Psychol, 33*(2), 218-236.

Chronaki, G., Soltesz, F., Benikos, N., & Sonuga-Barke, E. J. S. (2017). An electrophysiological investigation of reinforcement effects in attention deficit/hyperactivity disorder: Dissociating cue sensitivity from down-stream effects on target engagement and performance. *Dev Cogn Neurosci, 28*, 12-20. doi:10.1016/j.dcn.2017.10.003

Connor, D. F., & Doerfler, L. A. (2008). ADHD With Comorbid Oppositional Defiant Disorder or Conduct Disorder:Discrete or Nondistinct Disruptive Behavior Disorders? *Journal of Attention Disorders, 12*(2), 126-134. doi:10.1177/1087054707308486

Corbett, B., & Glidden, H. (2000). Processing affective stimuli in children with attention-deficit hyperactivity disorder. *Child Neuropsychol, 6*(2), 144-155. doi:10.1076/chin.6.2.144.7056

Curtis, W., Susannah, M., & Qualter, P. (2013). The validation of the self-report Strengths and Difficulties Questionnaire for use by 6- to 10-year-old children in the UK. *British Journal of Clinical Psychology, 53*(1), 131-137.

De Houwer, J., Hermans, D., Rothermund, K., & Wentura, D. (2002). Affective priming of semantic categorisation responses. . *Cognition and Emotion, 16*(5), 643-666. doi:https:// doi.org/10.1080/02699930143000419

Duchesne, S., Larose, S., Vitaro, F., & Tremblay, R. E. (2010). Trajectories of anxiety in a population sample of children: clarifying the role of children's behavioral characteristics and maternal parenting. *Dev Psychopathol, 22*(2), 361-373. doi:doi:10.1017/s0954579410000118

Eimer, M. (1996). The N2pc component as an indicator of attentional selectivity. *Electroencephalography and Clinical Neurophysiology, 99*(3), 225-234.

Escera, C., Corral, M. J., & Yago, E. (2002). An electrophysiological and behavioral investigation of involuntary attention towards auditory frequency, duration and intensity changes. *Brain Res Cogn Brain Res, 14*(3), 325-332. doi:10.1016/s0926-6410(02)00135-0

Getzmann, S., & Wascher, E. (2016). Postdeviance distraction in younger and older adults: Neuro-behavioral evidence from speech perception. *Psychology and Aging, 31*(8), 943–957. https://doi.org/10.1037/pag0000121

Getzmann, S., Falkenstein, M., & Gajewski, P. D. (2014). Neuro-behavioral correlates of post-deviance distraction in middle-aged and old adults. *Journal of Psychophysiology, 28(3),* 178–186. https://doi.org/10.1027/0269-8803/a000124

Goodman, R. (1997). The Strengths and Difficulties Questionnaire: a research note. *J Child Psychol Psychiatry, 38*(5), 581-586. doi:10.1111/j.1469-7610.1997.tb01545.x

Gumenyuk,V., Korzyukov, O., Alho, K ., Escera, C., Schröger, E., Ilmoniemi, R.J. & Näätänen, R. (2001). Brain activity index of distractibility in normal school-age children. *Neurosci. Lett.*, 314 (3), pp. 147-150

Hale, S. (1990). A Global Developmental Trend in Cognitive Processing Speed. *Child Development, 61*(3), 653-663.

Hargrove, P. M. (1997). Prosodic Aspects of Language Impairment in children. *Topics in Language Disorders, 17*(4), 76-83.

Horváth, J., Czigler, I., Birkás, E., Winkler, I., & Gervai, J. (2009). Age-related differences in distraction and reorientation in an auditory task. *Neurobiology of Aging, 30*(7), 1157–1172. https://doi.org/10.1016/j.neurobiolaging.2007.10.003

Hughes, R. W., Vachon, F., & Jones, D. M. (2007). Disruption of short-term memory by changing and deviant sounds: Support for a duplex-mechanism account of auditory distraction. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*(6), 1050–1061. doi:https://doi.org/10.1037/0278-7393.33.6.1050

Jääskeläinen, I. P., Ojanen, V., Ahveninen, J., Auranen, T., Levänen, S., Möttönen, R., . . . Sams, M. (2004). Adaptation of neuromagnetic N1 responses to phonetic stimuli by visual speech in humans. *NeuroReport, 15*(18), 2741-2744.

Jensen, P. S., Hinshaw, S. P., Swanson, J. M., Greenhill, L. L., Conners, C. K., Arnold, L. E., & . . . Wigal, T. (2001). Findings from the NIMH Multimodal Treatment Study of ADHD (MTA): Implications and Applications for Primary Care Providers. *Journal of Developmental & Behavioral Pediatrics, 22*(1), 60-73.

Johnston, C., & Jassy, J. S. (2007). Attention-deficit/hyperactivity disorder and oppositional/conduct problems:Links to parent-child interactions. Journal of the Canadian. *Academy of Child and Adolescent Psychiatry, 16*, 74–79.

Johnston, W. A., & Strayer, D. L. (2001). A dynamic, evolutionary perspective on attentional capture. . In C. Folk & B. Gibson (Eds.), *Attraction, distraction, and action: Multiple perspectives on attentional capture* (pp. 375-397). Amsterdam, the Netherlands: Elsevier Science.

Jones, D. M., & Macken, W. J. (1993). Irrelevant tones produce an irrelevant speech effect: Implications for phonological coding in working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*(2), 369-381. doi:https://doi.org/10.1037/0278-7393.19.2.369

Jones, D. M., Williams, L. M., & Murray, A. C. (1992). Disruption of visual short-term memory by changing-state auditory stimuli: The role of segmentation. *Memory and Cognition 21*(3), 318-328.

Joseph, T. N., Hughes, R. W., Sörqvist, P., & Marsh, J. E. (2018). Differences in Auditory Distraction between Adults and Children: A Duplex-mechanism Approach. *Journal of Cognition, 1*.

Kail, R. (1991). Developmental change in speed of processing during childhood and adolescence. *Psychological Bulletin, 109*(3), 490–501. doi:https://doi.org/10.1037/0033-2909.109.3.490

Karalunas, S. L., Weigard, A., & Alperin, B. (2020). Emotion-Cognition Interactions in Attention-Deficit/Hyperactivity Disorder: Increased Early Attention Capture and

Weakened Attentional Control in Emotional Contexts. *Biol Psychiatry Cogn Neurosci Neuroimaging, 5*(5), 520-529. doi:10.1016/j.bpsc.2019.12.021

Kats-Gold, I., Besser, A., & Priel, B. (2007). The role of simple emotion recognition skills among school aged boys at risk of ADHD. *J Abnorm Child Psychol, 35*(3), 363-378. doi:10.1007/s10802-006-9096-x

Kattner, F., & Ellermeier, W. (2018). Emotional prosody of task-irrelevant speech interferes with the retention of serial order. *J Exp Psychol Hum Percept Perform, 44*(8), 1303-1312. doi:10.1037/xhp0000537

Kattner, F., Fischer, M., Caling, A. L., Cremona, S., Ihle, A., Hodgson, T., & Föcker, J. (2023). The disruptive effects of changing-state sound and emotional prosody on verbal short-term memory in blind, visually impaired, and sighted listeners. *Journal of Cognitive Psychology, 35*(3), 1-14. doi:doi: 10.1080/20445911.2023.2186771

Konrad, K., Neufang, S., Hanisch, C., Fink, G. R., & Herpertz-Dahlmann, B. (2006). Dysfunctional attentional networks in children with attention deficit/hyperactivity disorder: Evidence from an event-related functional magnetic resonance imaging study. *Biological Psychiatry, 59*, 643–651.

Lima, C. F., Anikin, A., Monteiro, A. C., Scott, S. K., & Castro, S. L. (2019). Automaticity in the recognition of nonverbal emotional vocalizations. *Emotion, 19*(2), 219-233. doi:https://doi.org/10.1037/emo0000429

Loiselle, D. L., Stamm, J. S., Maitinsky, S., & Whipple, S. C. (1980). Evoked potential and behavioral signs of attentive dysfunctions in hyperactive boys. *Psychophysiology, 17*(2), 193-201. doi:10.1111/j.1469-8986.1980.tb00134.x

Lorenzino, M., & Caudek, C. (2015). Task-irrelevant emotion facilitates face discrimination learning. *Vision Research, 108*, 56-66. doi:10.1016/j.visres.2015.01.007

Maurage, P., Joassin, F., Philippot, P., & Campanella, S. (2007). A validated battery of vocal emotional expressions. *Neuropsychological Trends*(2), 63-74.

Manoli, A., Liversedge, S. P., Sonuga-Barke, E. J. S., & Hadwin, J. A. (2021). The Differential Effect of Anxiety and ADHD Symptoms on Inhibitory Control and Sustained Attention for Threat Stimuli: A Go/No-Go Eye-Movement Study. *Journal of Attention Disorders, 25*(13), 1919-1930. doi:10.1177/1087054720930809

Marsh, J. E., Kattner, F., & Ruhnau, P. (2021). Research Collection: On Theoretical Advancement in Auditory Distraction Research. *Auditory Perception & Cognition, 4*, 133-138. doi:DOI: 10.1080/25742442.2022.2036524

Marsh, J. E., Yang, J., Qualter, P., Richardson, C., Perham, N., Vachon, F., & Hughes, R. W. (2018). Postcategorical auditory distraction in short-term memory: Insights from increased task load and task type. *J Exp Psychol Learn Mem Cogn, 44*(6), 882-897. doi:10.1037/xlm0000492

Max, C., Widmann, A., Kotz, S. A., Schröger, E., & Wetzel, N. (2015). Distraction by emotional sounds: Disentangling arousal benefits and orienting costs. *Emotion, 15*(4), 428-437. doi:10.1037/a0039041

McRae, K., Hughes, B., Chopra, S., Gabrieli, J. D., Gross, J. J., & Ochsner, K. N. (2010). The neural bases of distraction and reappraisal. *Journal of Cognitive Neuroscience, 22*, 248-262. doi:doi:10.1162/jocn.2009.21243

Näätänen, R. (1990). The role of attention in auditory information processing as revealed by event-related potentials and other brain measures of cognitive function. *Behavioral and Brain Sciences, 13*(2), 201–288. doi:https://doi.org/10.1017/S0140525X00078407

Nock, M. K., Kazdin, A. E., Hiripi, E., & Kessler, R. C. (2007). Lifetime prevalence, correlates, and persistence of oppositional defiant disorder: results from the National Comorbidity Survey Replication. *Journal of Child Psychology and Psychiatry, 48*(7), 703-713. doi:https://doi.org/10.1111/j.1469-7610.2007.01733.x

Pacheco-Unguetti, A. P., & Parmentier, F. B. R. (2014). Sadness increases distraction by auditory deviant stimuli. *Emotion, 14*(1), 203-213. doi:https://doi.org/10.1037/a0034289

Parmentier, F. B., & Andrés, P. (2010). The involuntary capture of attention by sound: novelty and postnovelty distraction in young and older adults. *Exp Psychol, 57*(1), 68-76. doi:10.1027/1618-3169/a000009

Parmentier, F. B. R., Elford, G., Escera, C., Andrés, P., & Miguel, I. S. (2008). The cognitive locus of distraction by acoustic novelty in the cross-modal oddball task. *Cognition, 106*(1). doi:https://doi.org/10.1016/j.cognition.2007.03.008

Parmentier, F. B. R., Elsley, J. V., Andrés, P., & Barceló, F. (2011). Why are auditory novels distracting? Contrasting the roles of novelty, violation of expectation and stimulus change. *Cognition 119*(3), 374-380.

Parmentier, F. B. R., Pacheco-Unguetti, A. P., & Valero, S. (2018). Food words distract the hungry: Evidence of involuntary semantic processing of task-irrelevant but biologically-relevant unexpected auditory words. *PLoS ONE, 13*(1 e0190644). doi:https://doi.org/10.1371/journal.pone.0190644

Pessoa, L., & Adolphs, R. (2010). Emotion processing and the amygdala: from a 'low road' to 'many roads' of evaluating biological significance. *Nat Rev Neurosci, 11*(11), 773-783. doi:10.1038/nrn2920

Robinson, C. W., Hawthorn, A. M., & Rahman, A. N. (2018). Developmental Differences in Filtering Auditory and Visual Distractors During Visual Selective Attention. *Frontiers in Psychology, 9*. https://doi.org/10.3389/fpsyg.2018.02564

Röer, J. P., Bell, R., Körner, U., & Buchner, A. (2018). Equivalent auditory distraction in children and adults. *J Exp Child Psychol, 172*, 41-58. https://doi.org/10.1016/j.jecp.2018.02.005

Ruhnau, P., Herrmann, B., Maess, B., Brauer, J., Friederici, A., & Schröger, E. (2013). Processing of complex distracting sounds in school-aged children and adults: evidence from EEG and MEG data. *Frontiers in Psychology, 4*. https://doi.org/10.3389/fpsyg.2013.00717

Sayal, K., Prasad, V., Daley, D., Ford, T., & Coghill, D. (2017). ADHD in children and young people: prevalence, care pathways, and service provision. *Lancet Psychiatry, 5*(2), 175-186.

Schirmer, A., & Adolphs, R. (2017). Emotion Perception from Face, Voice, and Touch: Comparisons and Convergence. *Trends Cogn Sci, 21*(3), 216-228. doi:10.1016/j.tics.2017.01.001

Schröger, E., & Wolff, C. (1998). Attentional orienting and reorienting is indicated by human event-related brain potentials. *NeuroReport, 9*(15), 3355-3358.

Schulz, K. P., Bédard, A. C., Fan, J., Clerkin, S. M., Dima, D., Newcorn, J. H., & Halperin, J. M. (2014). Emotional bias of cognitive control in adults with childhood attention-deficit/hyperactivity disorder. *Neuroimage Clin, 5*, 1-9. doi:10.1016/j.nicl.2014.05.016

Schupp, H. T., Stockburger, J., Bublatzky, F., Jungh¨ofer, M., Weike, A. I., & Hamm, A. O. (2008). The selective processing of emotional visual stimuli while detecting auditory targets: An ERP analysis. *Brain Research, 1230*, 168-176. doi:https://doi.org/10.1016/j.

Sells, R., Liversedge, S. P., & Chronaki, G. (2023). Vocal Emotion Recognition in Attention-Deficit Hyperactivity Disorder: A Meta-Analysis. *Cognition and Emotion* doi: 10.1080/02699931.2023.2258590

Shaw, P., Stringaris, A., Nigg, J., & Leibenluft, E. (2014). Emotion dysregulation in ADHD. *American Journal of Psychiatry, 171*, 276–293.

Sjöwall, D., Roth, L., Lindqvist, S., & Thorell, L. B. (2013). Multiple deficits in ADHD: executive dysfunction, delay aversion, reaction time variability, and emotional deficits. *J Child Psychol Psychiatry, 54*(6), 619-627. https://doi.org/10.1111/jcpp.12006

Sjöwall, D., & Thorell, L. B. (2022). Neuropsychological deficits in relation to ADHD symptoms, quality of life, and daily life functioning in young adulthood. *Appl Neuropsychol Adult, 29*(1), 32-40. https://doi.org/10.1080/23279095.2019.1704287

Śmigasiewicz, K., Servant, M., Ambrosi, S., Blaye, A., & Burle, B. (2021). Speeding-up while growing-up: Synchronous functional development of motor and nonmotor processes across childhood and adolescence. *PLoS ONE, 16*(9).

Sonuga-Barke, E.J. (2003). The dual pathway model of AD/HD: an elaboration of neuro-developmental characteristics. *Neurosci Biobehav Review, 27*(7):593-604. doi: 10.1016/j.neubiorev.2003.08.005. PMID: 14624804.

Sonuga-Barke, E. J. S., & Fairchild, G. (2012). Neuroeconomics of attention-deficit/hyperactivity disorder: Differential influences of medial, dorsal, and ventral prefrontal brain networks on suboptimal decision making? *Biological Psychiatry, 72*, 126–133.

Squires, N. K., Squires, K. C., & Hillyard, S. A. (1975). Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. *Electroencephalogr Clin Neurophysiol, 38*(4), 387-401. doi:10.1016/0013-4694(75)90263-1

Vachon, C. M., Modchalingam, S., Hart, B. M., & Henriques, D. Y. P. (2020). The effect of age on visuomotor learning processes. *PLoS ONE, 15*(9), e0239032. doi:10.1371/journal.pone.0239032

Vachon, F., Labonté, K., & Marsh, J. E. (2017). Attentional capture by deviant sounds: A noncontingent form of auditory distraction? *J Exp Psychol Learn Mem Cogn, 43*(4), 622-634. doi:10.1037/xlm0000330

Vuilleumier, P., & Pourtois, G. (2007). Distributed and interactive brain mechanisms during emotion face perception: evidence from functional neuroimaging. *Neuropsychologia, 45*(1), 174-194. doi:10.1016/j.neuropsychologia.2006.06.003

Weise, A., Hartmann, T., Parmentier, F., Weisz, N., & Ruhnau, P. (2023). Involuntary shifts of spatial attention contribute to distraction—Evidence from oscillatory alpha power and reaction time data. *Psychophysiology, n/a*(n/a), e14353. doi:https://doi.org/10.1111/psyp.14353

Wetzel, N., & Schröger, E. (2007). Cognitive control of involuntary attention and distraction in children and adolescents. *Brain Research, 1155,* 134–146. https://doi.org/10.1016/j.brainres.2007.04.022

Wetzel, N., Widmann, A., Berti, S., & Schröger, E. (2006). The development of involuntary and voluntary attention from childhood to adulthood: a combined behavioral and event-related potential study. *Clin Neurophysiol, 117*(10), 2191-2203. https://doi.org/10.1016/j.clinph.2006.06.717

Williams, L. M., Hermens, D. F., Palmer, D., Kohn, M., Clarke, S., Keage, H., . . . Gordon, E. (2008). Misinterpreting emotional expressions in attention-deficit/hyperactivity disorder: evidence for a neural marker and stimulant effects. *Biol Psychiatry, 63*(10), 917-926. doi:10.1016/j.biopsych.2007.11.022

Woldorff, M. G., Gallen, C. C., Hampson, S. A., Hillyard, S. A., Pantev, C., Sobel, D., & Bloom, F. E. (1993). Modulation of early sensory processing in human auditory cortex during auditory selective attention. *Proceedings of the National Academy of Sciences, 90*, 8722–8726.

Zambelli, A. J., Stamm, J. S., Maitinsky, S., & Loiselle, D. L. (1977). Auditory evoked potentials and selective attention in formerly hyperactive adolescent boys. *Am J Psychiatry, 134*(7), 742-747. doi:10.1176/ajp.134.7.742