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The Effect of Visual Stressors on Adolescents' Neural Response: A Review of Laboratory Research

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Abstract

Laboratory models that help us understand the neural mechanisms associated with how stress, particularly interpersonal stress, affects children's and adolescents' emotions are paramount but are limited if that understanding lacks validity in adolescents' daily lives. There is a lack of research that addresses the ecological validity of visual stimuli to induce stress in participants while measuring participants' neural response to that stimuli. This approach is needed if we are to identify the neural mechanisms that underlie the effect of stressful events on individuals' emotional functioning. The current study conducted a systematic literature review to identify visual tasks that have been used in laboratory settings to induce stress in participants. The most frequent tasks identified were developed to induce peer rejection/exclusion in youth (e.g., Chatroom and Cyberball). These tasks were generally effective at bringing about a neural response in areas of the brain traditionally associated with social cognitive processing, such as the cingulate cortex, prefrontal cortex, insula, and striatum. In particular, the cingulate cortex and prefrontal cortex are associated with the Social Information Processing Network. Almost entirely absent from the literature are systematic evaluations of ecological validity and parent-child based visual stimuli that approximate the stress that adolescents might experience in their relationships with parents. The present article highlights trends and gaps in the current research, and examines the ecological validity of current stimuli used as laboratory based stressors, which can be used to fuel further investigation into adolescent neural response to stimuli, and further evaluation of the ecological validity of tasks.

Keywords

Emotions; Ecological Validity; Neural Response; Stress; Visual Stimuli

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Introduction

Adolescence represents a critical juncture to understand the effect of stressful experiences on emotional adjustment (Dahl 2004; Spear 2010). Specifically, during adolescence areas associated with emotion processing such as the limbic system (involving regions such as the cingulate cortex, stria terminalis, amygdala, and insula; Breedlove and Watson 2017; Craig, 2009) predominate; while areas associated with top-down regulatory capacity (e.g., the prefrontal cortex) develop more slowly. This may result in adolescents making decisions with areas in the brain that are more emotional as opposed to areas that are more rational. In addition to normative developmental changes within the prefrontal cortex and limbic system, these systems also appear particularly vulnerable to stress and there is some evidence that adolescents may show an increased response to stressors in the environment when compared to other ages (Gunnar and Quevedo 2007; Stroud et al. 2009). Researchers have recognized the importance of understanding the neural mechanisms that help explain how stress affects adolescents' emotion regulation and the negative consequences that stressful experiences and problems regulating emotions in the face of stress may have on development (Romeo and Karatsoreos 2011; Spear 2000), yet our understanding of these mechanisms is still limited.

To fully understand the mechanisms that might explain how stressful experiences affect emotions and development during adolescence, researchers must utilize laboratory techniques that identify the neural mechanisms associated with how adolescents handle emotions in the face of stressful experiences and assure that these laboratory paradigms are representative of youth's everyday lived experiences with stress. This is to say that in order to fully understand how neural mechanisms may explain associations between stressful experiences and emotions, laboratory paradigms used to induce stress must be both ecologically valid and use biomarkers (e.g., fMRI, eye tracking) that allow us to assess neural activity in response to laboratory stimuli. Surprisingly, very few laboratory paradigms exist that utilize visual stimuli in order to examine neural mechanisms associated with stress and emotions. Thus, the purpose of this review was to identify what visual tasks are currently being used that help identify neural responses associated with stressful experiences and to discuss the ecological validity of these tasks.

Laboratory Paradigms and Emotional Response to Stress

A large body of research has demonstrated that exposure to stressors in laboratory settings is associated with increased emotional responses to stress as measured by biobehavioral measures (e.g., cortisol), observations, and self-report (e.g. Allwood et al. 2011; Kemeny 2003; Kudielka and Kirschbaum 2005; Robles et al. 2011). This research has generally demonstrated that presentation of a laboratory stimulus that is designed to be stressful is associated with an emotional response to that stimuli as measured by self-report of emotions (e.g., increase in negative affect as indicated by anxiety) or biomarkers such as changes in heart rate, cortisol, and alpha amylase as markers of activation of underlying biological response systems associated with stress (Foley and Kirschbaum 2010; Maruyama et al. 2012). Generally, it is the contention that this stress response in the laboratory setting is indicative of how individuals would respond to stress in their daily lives and that these

responses follow a typical pattern that is normative and less typical patterns that may be associated with poor functioning (Kidd et al. 2014). Several reviews have been published on the effect of different laboratory stress paradigms on stress response; with these reviews focusing predominately on physiological response and adults (See Chida and Hamer 2008; Dickerson and Kemeny 2004; Steptoe et al. 2007). Surprisingly though, few review articles have specifically examined the effect of visual stress paradigms on neural response to stressors. Yet, we know that individuals' responses to stressful experiences also may impact neural regions associated with cognitive control and decision-making, causing difficulties in de-escalating emotional response to future stressors and adjustment problems more generally (Ochsner and Gross 2005; Sheeber et al. 2000).

Laboratory paradigms and neural response—To induce and assess responses to stressful situations, the process that laboratory paradigms try and capture is one in which participants are exposed to a standardized stressful stimulus, cognitively evaluate that stressor in terms of the risk it may pose to them, and then respond to that stressor with some emotional response captured with different biological and behavioral measurements. When assessing neural response to a stimulus, the stimulus that participants are exposed to is most effective when visual in nature so that researchers can record particular brain regions that are activated when viewing the particular stimulus (Chen and Glover 2015). After stimulus exposure, the thalamus must relay the sensory input to the appropriate regions of the brain (Breedlove and Watson 2017), and a cognitive appraisal of the stimulus is made in the hippocampus and prefrontal cortex, identifying it as a stressor (Calvo & Gutierréz-García, 2016). The brain then sends out signals, activating the nervous system, provoking the physiological and neural response, eventually resulting in some sort of behavioral resolution (Everly and Lating 2012). More specifically, the cognitive appraisal of a stressor triggers a neurological response, beginning in the locus ceruleus, limbic system, and hypothalamus, which cause reactions in multiple axes (neural, neuroendocrine, and endocrine), enabling the body to respond appropriately to the stressor. The main regions of the brain implicated in producing the physiological stress response are the hypothalamus, amygdala, and pituitary. These parts of the brain send signals elsewhere around the body to enable it to respond to a stressor as best it can, for example by secreting noradrenaline, commonly associated with arousal (Everly and Lating 2013).

Laboratory paradigms and Social Information Processing Network—Of particular interest in the current review are laboratory paradigms that induce neural responses that are associated with stress. Several such paradigms try and induce interpersonal stress by using a socially based stimulus to bring about a response. Interpersonally based stimuli may be particularly effective with adolescents, as this is a time of life when the peer context becomes more and more salient (Bokhorst, Sumter, & Westenberg, 2009). The social stress response, while mirroring the typical stress response, has a more specific path that it follows in the brain. This particular response has been illustrated by Nelson, Leibenluft, McClure, and Pine (2005) using the Social Information Processing Network (SIPN), suggesting that there are three specific areas in the brain that are associated with certain aspects of social information processing. These areas include the detection node, the affective node, and the cognitive-regulatory node.

The detective node is comprised of regions in the occipital cortex, temporal cortex, intraparietal sulcus, fusiform gyrus, and superior temporal sulcus. These regions are associated with the detection of biological movements and faces, and because of this are more likely to be involved in social information processing. Thus, it could be expected to see activation in these areas with studies using other people as stimuli, such as in Cyberball (Williams and Jarvis 2006), or a study using photographs of faces to induce emotions (e.g. Marusak et al. 2013). The second node of the SIPN is known as the affective node, in which an affective response is associated with the stimulus that has been detected. These regions include the amygdala, ventral striatum, stria terminalis, septum, and hypothalamus, and it is worth noting that several of these areas overlap with the limbic system, which is implicated in emotion and aggression (Breedlove and Watson 2017). The final node of the SIPN is known as the cognitive-regulatory node, involved in determining others' motives, response inhibition, and finally, the carrying out of goal-directed behavior. The main region of the brain at play here is the prefrontal cortex, specifically the dorsal and ventral regions, known for its role in executive control (Breedlove and Watson 2017). While the SIPN is specific to social stimuli, it is important to consider what regions are identified for their respective roles in identifying and responding to stimuli, as many of these regions are activated in response to nonsocial stressors as well.

Methods for assessing neural response—To capture neural responses to stress, several techniques have been utilized. The method that perhaps gives researchers the most information is functional magnetic resonance imaging (fMRI). Researchers utilizing fMRI technology generally expose the participants to some visual stimuli that may be stressful (e.g., negative images) and then record changes in oxygenation levels in different areas within the brain associated with the processing of stress and emotions; specifically the areas of the hippocampus, prefrontal cortex, and amygdala have most often been examined. fMRI studies give us great insight into the underlying neural response associated with stress but tend to be limited in their sample size given the extreme cost of the technology. An alternative more cost-effective method to examine neural responses to stress is eye-tracking technology (Karatekin 2007). Eye tracking can be used to assess pupil dilation and attention as measures of emotional and cognitive processing in the prefrontal cortex and limbic system (e.g., amygdala) as the pupil becomes more dilated in response to stimuli that requires greater cognitive load and emotional processing (Gross 1998; Siegle et al. 2003). These methods, along with utilizing electroencephalography (EEG) with event related potentials (ERP), allow researchers, with varying degrees of precision, to assess neural activity in response to a stressful stimulus in a laboratory setting.

Ecological Validity

Laboratory models that help us understand how stressful experiences affect stress response are important but are limited if that understanding lacks validity in individuals' daily lives (e.g., ecological validity; Bronfenbrenner 1977). Ecological validity describes the extent to which the methods, materials and setting of an experimental study approximate the real-world phenomenon to which those findings will be generalized (Reis and Judd 2000; Schmuckler 2001). Ecological validity is highly desirable in controlled laboratory experiments as it helps ensure that results found in a lab, where extraneous variables are

easier to control, generalize to the target population outside of the lab (Street 1995). The issue of ecological validity stems from the worry that in experimental contexts psychologists only study artificial problems that are not represented in larger patterns of life. Bronfenbrenner (1977) suggests that ecological validity is essential in laboratory-based research and that to achieve ecological validity an experiment must be able to maintain the integrity of the real-life situation that it was designed to investigate, be faithful to the contexts in which the participants in a given study come from, and demonstrate that the experimental manipulations/stimuli are perceived by participants in a manner that is true to these constructs in everyday life. A concern with stimuli is at the forefront of examining ecological validity, as many have argued that experimental research relies on stimuli that are only marginally real and that this significantly hurts the application of results to making real changes in people's lives (Schmuckler 2001). Thus, a second goal of this review was to consider if the visual tasks that are being used to induce neural response present any evidence of ecological validity.

The Current Study

This article reviews the literature in order to identify visual stressors that have been used in the past with children or adolescents to induce some sort of emotional response to stress, with the focus being on stimuli that has been used to understand the neural response to visual stressors presented in a laboratory setting. A review on this topic is important given that mechanistic models identifying how the brain mediates stressful experiences are imperative for comprehensive and accurate theories on adolescent development (Guyer et al. 2009). This information could be used by practitioners in clinical practice to detect individual variability in difficulties with cognitive control and identify youth who may be vulnerable. Additionally, in the interest of identifying results in the laboratory that have been shown to have real-world meaning this review will consider the ecological validity of the tasks that have been utilized and if the experiences modeled in the laboratory approximate participants' everyday experiences.

Methods

Using online databases such as Google Scholar, Biological Sciences, JSTOR, PsycArticles, and PsycInfo, relevant studies were found based on the criteria that the study used some kind of laboratory based visual stimulus to produce an emotional response to stress, as measured by neural indices, and was used with children and/or adolescents. Articles were considered relevant as long as they included a visual stimulus that was used to produce some sort of neural stress response in typically developing, healthy children and adolescents. Search terms used included (a) types of paradigms that might be used: "Chatroom," "Cyberball," "Yale Interpersonal Stressor," "emotional tasks," "family tasks," "stress stimuli," "mood induction," "laboratory stress," "ostracism," "rejection," "exclusion," "video," "visual," "picture," and "interactive,"; (b) measures used to assess neural response: "EEG," "ERP," "MRI," "fMRI," "imaging," "eye tracking," and (c) potential outcomes of interest: "neural," "emotional reaction," "emotion." These terms were individually input, and then used in various combinations, such as "family visual stimuli," "fMRI Chatroom," "eye-tracking stress stimuli," in order to further explore potential results. Only articles that were focused

on children or adolescents were reviewed. Nineteen articles involving various visual stimuli to produce neural response associated with stress were identified.

Results

After reviewing the literature, two main types of visual stressor were identified. These included passively viewed stimuli (See Table 1, in which participants simply viewed the stimuli, and interactive stimuli (See Table 2), which required some sort of action on the participant's part. Articles have been organized below and in tables to represent these two different kinds of visual stimuli.

Passive Stimuli

Of the 19 studies found, 4 of them used a passively viewed visual stimuli (Table 1). An example of this kind of stressor would be having participants view photos of faces depicting some kind of emotional affect while undergoing an fMRI scan (Marusak et al. 2013). This kind of stimulus most commonly brought about a response in the amygdala (Furman et al. 2010; Marusak et al. 2013), which is a part of the affective node of the SIPN (Nelson et al. 2005). Furthermore, the study done by Marusak and colleagues (2013) also brought about a response in the prefrontal cortex and fusiform gyrus, known for their roles played in the cognitive-regulatory and detection nodes, respectively (Nelson et al. 2005), as well as the occipital cortex, known for visual processing (Collignon et al. 2013), inferior temporal gyrus, cerebellum, and right angular gyrus. A third study, also passive in nature, utilized participants' own mothers as visual stimuli, rather than strangers. Whittle and colleagues (2012) had participants rate how lonely they were, and then watch a video segment of their own mother's affective behavior while undergoing an fMRI scan. Results indicated that watching their own mother was associated with activation in the posterior cingulate, precuneus, and ventrolateral prefrontal cortex, which are areas of the brain associated with cognitive activity (Leech et al. 2012; McCormick et al. 2017), visuo-spatial processing, as well as self-referent processing (Cavanna and Trimble 2006), and memory (McCormick et al. 2017). This suggests that observing their own mother brought about widespread cognitive and self-referent processing.

Visual stressors are unique in that they give researchers the opportunity to examine what participants attend to, and how they naturally react to photos. One study that we reviewed took advantage of these features, recording event related potentials (ERP), essentially externally measuring electrical impulses in the brain (Latham et al. 2017). However, results indicated that there was no main effect of picture valence on ERPs suggesting that static images may not be effective at inducing changes in neural response. Interestingly, this was the only study reviewed that examined ERPs, but the lack of significant findings potentially suggest that this method of measurement is not capable of capturing activity associated with visual stressors.

Interactive Stimuli

Main effects.—Stressors that involve some sort of action on the participant's part were classified as interactive stimuli. Of the 15 interactive studies identified, 11 of them used a

stimulus known as “Cyberball”, in which participants are led to believe that they are interacting with two other people online through a ball-passing game. These other two “players” are, in reality, part of the computer simulation, and over time, they exclude the participant, leading to feelings of social exclusion (Williams and Jarvis 2006). The remaining four studies utilized a stimulus known as the “Chatroom Task” in which participants are led to believe that they are going to interact with other people via an online Chatroom. They rate pictures of people according to how interested they would be in interacting with them, and are led to believe that other people will be doing the same to them, when in reality, other people are not actually involved.

Of the 15 studies found, nine observed a response in the insular cortex (Bolling et al. 2011; Chester et al., 2014; Groschwitz et al. 2016; Guyer et al. 2009; Masten et al. 2009, Moor et al. 2012; Olino et al. 2015; Tan et al. 2014) with four of the studies specifically mentioning activation in the anterior insula (Chester et al., 2014; Groschwitz et al. 2016; Masten et al. 2009), and seven of the studies specifically involving the use of Cyberball. The insula, and in particular, the anterior insula, is known for social and emotional processing (Craig, 2009), suggesting that these studies effectively produce an emotional response that has been associated with processing social interactions, and may be involved in the SIPN despite not being directly mentioned in Nelson and colleague’s original theory.

Ten of the studies also found a response in the cingulate cortex (Bolling et al. 2011; Chester et al., 2014; Groschwitz et al. 2016; Guyer et al. 2009; Masten et al. 2009, Masten et al., 2010; Moor et al. 2012; Whittle et al. 2012; Will, van Lier, Crone, & Güro lu, 2016), eight of which utilized Cyberball. The cingulate cortex has been implicated in the regulation of affect, and has been suggested to have both cognitive as well as emotional functions due to how close it is to the limbic system (Stevens et al. 2011).

The prefrontal cortex displayed activation in 9 of the 15 studies found (Bolling et al. 2011; Groschwitz et al. 2016; Masten et al. 2009, 2010, Moor et al. 2012; Sebastian et al. 2011; Whittle et al. 2012; Will et al. 2016), seven of which used Cyberball. The prefrontal cortex is considered part of the SIPN, specifically part of the cognitive node, which organizes the response to social stimuli (Nelson et al. 2005).

Three studies indicated a response in the hippocampus (Bolling et al. 2011; Groschwitz et al. 2016; Guyer et al. 2009), two of which used Cyberball rather than the Chatroom Task. The hippocampus has been suggested to play a role in emotional responses, specifically in self-relevant processing as well as the producing and sustaining appropriate emotional responses to social stimuli (Immordino-Yang and Singh 2013). The striatum was implicated in three of the studies found (Masten et al. 2009; Olino et al. 2015; Will et al. 2016). The striatum is part of the affective node of the SIPN, which assigns emotional value to incoming social stimuli (Nelson et al. 2005).

The final regions identified in response to interactive stimuli (N = 2) included the nucleus accumbens (Tan et al. 2014; Guyer et al. 2009; Both using the Chatroom Task), and the temporal sulcus (Masten et al. 2010; Olino et al. 2015; Both using Cyberball). The nucleus accumbens is known for its involvement in reward and aversion (Costa et al. 2010), while

the temporal sulcus is part of the detection node of the SIPN, involved in the identification of stimuli as socially oriented as well as the detection of biological movement.

Individual differences in neural response: Many of the studies examined if the main effects of the stressor paradigms differed based off individual characteristics of the participants. Individual differences examined included gender (Guyer et al. 2009; Silk et al. 2012), age (Bolling et al. 2011; Guyer et al. 2009; Moor et al. 2012; Silk et al. 2012), depressive symptomology (Groschwitz et al. 2016; Whittle et al. 2012), and social competencies such as empathy or rejection sensitivity (Masten et al. 2010, Moor et al., 2009; Olino et al. 2015). Overall, women seemed to respond more emotionally to stressors when they were younger (Guyer et al. 2009), and when they were evaluated by other women (Silk et al. 2012).

Evidence of ecological validity: To assess ecological validity within the studies reviewed, we looked for evidence that either specifically referenced results that supported ecological validity or we inferred ecological validity of the task when evidence was presented that certain youth were more vulnerable (e.g., youth high in rejection sensitivity). Overall, very few studies directly mentioned ecological validity. Of those that did, one stated that only one rejection block for Cyberball was used in order to maintain ecological validity (Masten et al. 2009), one set up real email accounts for Cyberball “players” for participants to email in order to enhance ecological validity (Masten et al. 2010), one had participants meet two confederates before playing Cyberball in order to reinforce the belief that the participant was playing with other people, and one final study developed the Chatroom Task to function as an ecologically valid stressor (Silk et al., 2012).

Inferred evidence of ecological validity was determined based on the criteria that adolescents displayed increased vulnerability to a stressor. In one study, a clinical portion of the sample showed an increased response to stressors, suggesting that they were more vulnerable to stress (Groschwitz et al. 2016). In another study, activation in certain areas of the brain associated with social processing was increased for those who showed more social distress following rejection (Masten et al. 2009). In a later study by Masten and colleagues (2010), participants who reported more empathy were shown to experience more distress while watching others experience social rejection, suggesting efficacy of the stressor at producing a response mirroring what they may experience in their typical lives. One final study found that reported feelings of peer affiliation to be associated with activation in areas identified as part of the SIPN (Olinio et al. 2015).

While specific evidence of ecological validity was rarely mentioned, extant evidence was found mainly by examining interaction effects and activation associated with areas of the brain known to be part of the SIPN, suggesting that regions of the brain that would respond in real-life scenarios were responding to the laboratory-based stressors.

Discussion

To further understand adolescent development, researchers need to identify the neurobiological mechanisms that explain how stressful experiences affect emotions and

development during adolescence, and be able to generalize these laboratory findings to youth's everyday experiences with stress (Street 1995). As such, the current study reviewed previous research examining adolescent response to visually-based stimuli used to induce a neurological stress response, with a main goal of examining what kinds of stimuli were used, the effect that these stimuli had on the adolescent brain, and finally, the ecological validity of these stimuli. To date, only 19 studies have been published that utilize a visual stimulus to assess neural response to a stressful experience within the laboratory setting. The majority of the studies involved the use of Cyberball, a task that was designed to induce feelings of ostracism and rejection. The kinds of stimuli used were broken into two main classifications (Passive versus Interactive), and their observed effects were found to support the SIPN (Nelson et al. 2005), as many of them were social in nature. Finally, few studies assessed ecological validity, suggesting that this should be further emphasized in future research.

Effectiveness of Visual Stimuli

Results indicated that the stimuli generally induced neural responses in the areas of the prefrontal cortex, cingulate cortex, insula, striatum, hippocampus, and temporal sulcus. The areas in which the most activation was seen was the prefrontal cortex, known for its role in cognitive processes (Nelson et al. 2005), and the cingulate cortex, known for its proximity to the limbic system, and involvement in cognitive processing (Stevens et al. 2011). Nine studies found activation in the insula, implicated in social processing (Craig, 2009). Thus, most of the activation that occurred in response to the visual stressors involved cognitive and social processing regions.

It is difficult to draw conclusions about the relative effectiveness of different types of stimuli that were presented across the studies. Due to the limited variability in the types of visual stimuli that have been used to produce an emotional response, it is difficult to truly determine if one type of stimuli is more effective than others, as this would require comparing different stimuli within one study. Cyberball was the most frequently utilized stimulus, and it produced the greatest response in areas associated with social information processing, however, it is important to consider that while Cyberball was the most frequently used, it was also developed before the Chatroom Task. Additionally, it is important to note that the passively viewed stimuli ranged in nature of task, whereas the Chatroom Task and Cyberball both had to do with social interaction, which may account for the fact that there were no commonalities in activation of regions of the brain within studies using passively viewed stimuli. Many of the passively viewed stimuli did not specifically look at areas that are activated by social stimuli, with some even using alternative methods of measurement that would not be able to observe areas associated with the neurological response to such stimuli in the same manner, such as by looking at ERPs (Latham et al. 2017).

Cyberball was more frequently associated with activation in the SIPN regions, suggesting that it was particularly effective at eliciting a neural response associated with processing of interpersonal stimuli. Specifically, when Cyberball was used, 82% of the studies indicated activation in areas associated with SIPN (Bolling et al. 2011; Masten et al. 2009, 2010, Moor et al. 2012; Olino et al. 2015; Sebastian et al. 2011; Will et al. 2016). In contrast, none of the

Chatroom Task studies yielded activation in regions of the SIPN, and only 50% of the passively viewed stimuli were found to induce activation of regions associated with the SIPN (Furman et al. 2010; Marusak et al. 2013). These findings suggest that Cyberball may be a particularly effective task at inducing neural responses associated with social processing, while the efficiency of the Chatroom Task and Passive Stimuli remains ambiguous.

Interaction effects—The interaction effects observed in the studies did not evidence consistency within effects observed. Surprisingly, only one study out of all the reviewed studies found evidence for gender differences, reporting that greater activation was seen in females in response to the Chatroom Task than males, an effect that escalated over time such that as female age increased, so did activation, while the opposite effect was seen in males, such that activation decreased as age increased (Guyer et al. 2009). Alone, this study suggests that females may be more responsive to social rejection than males as an effect of maturation. Placed in context with the volume of research that did not identify gender differences, the lack of effects suggesting that there may not be gender differences in how adolescents process visual (and especially social) stimuli. However, considering the aforementioned Guyer and colleagues (2009) study, it is possible that differences in neurological response to visual stimuli may become more pronounced as time goes on. Given that sample sizes in the research reviewed in this article tended to be smaller, it becomes clear that larger samples will be important to investigate these differences in future research.

Age differences were more frequently examined in the literature, observed in 4 of the 19 studies explored (Bolling et al. 2011; Guyer et al. 2009; Moor et al. 2012; Silk et al. 2012), yet the volume of studies not reporting age differences still greatly outnumbers those that did. This could potentially be due to limited variability of age in the samples, as most of the studies examined adolescents only, with the highest standard deviation being 2.5 years (Groschwitz et al. 2016; Silk et al. 2012). Interestingly, one study having included a group of adults in the sample, observed that younger participants evidenced more activation in response to Cyberball than adults (Moor et al., 2009), while another study suggested that older adolescents exhibited more activation to the Chatroom Task than younger adolescents (Silk et al. 2012). A third study reported that activation in response to Cyberball was found to increase with age (Bolling et al. 2011). Among the stress literature, evidence has suggested that age differences are not, in fact, based on age, but based on pubertal stage (Colich et al. 2015). Because of the stressful nature of the stimuli used, it is possible that neurological activation may mirror this effect, and future research should take this approach to determine if that is a factor in the inconsistency of age differences seen. Additional potential reasons for this inconsistency could involve differences in perception, overall emotional reactivity, or the actual photographs used could have something to do with these responses. It would also be interesting to explore the specific underlying mechanisms behind age differences that were observed, whether they had to do with maturation of neural process or emotional development. Understanding these factors could help in increasing ecological validity of future visual stimuli.

Also seen were studies impacted by indicators of interpersonal competency, indicating a degree of ecological validity such that adolescents who reported more social problems were more susceptible to the social stressors. For example, the Masten et al. (2010) study observed greater activity in anterior insula in participants that displayed more empathy when observing a fake participant experience rejection in Cyberball. This is of importance, as the anterior insula is implicated in response to social rejection, meaning this finding suggests that the empathy that participants showed could have led to them actually feeling a degree of social rejection on behalf of the “participant” that they had been observing.

Ecological Validity

One of the goals of this article was to consider the ecological validity of these stimuli. Yet ecological validity itself is rarely mentioned, let alone assessed, in the research. One could ascertain that ecological validity is suggested by the fact that many studies found changes in neural regions associated with the SIPN, but again, it is rarely directly assessed. While it may appear that interactively viewed stimuli are associated with activation in the brain in areas that are associated with social information processing, and passively viewed stimuli bring about more of an emotional response, it is unknown exactly how much these studies mirrored situations that adolescents may experience in their everyday lives. Thus, an estimation of ecological validity is missing, and conclusions about how adolescents truly respond to emotionally stressful stimuli in the real world may not be accurately drawn. However, drawing from the studies explored, those tasks designed to mimic everyday situations (i.e. Cyberball, Chatroom Task), appeared to produce a stronger neural response compared to studies that utilized more static, less ecologically valid stimuli such as affective video clips, as indicated by brain activation in more areas associated with the processing of stress and emotions (e.g., the amygdala, striatum), as well as the regulation of emotion (e.g., the prefrontal cortex). Future studies should make a concerted effort to use stimuli that mirror real life scenarios, making laboratory based stimuli more relevant to everyday life, and thus making the findings of the lab study more generalizable to the population (Street 1995).

Limitations

One of the goals of this article was to review studies in which adolescents respond to stressful visual stimuli. Accordingly, one would expect that at least some activation would be seen in areas in the brain associated with stress. However, many of the regions associated with the physiological stress response (e.g., the hypothalamus, pituitary, thalamus) were not mentioned in most of the articles examined, despite using stimuli aimed at inducing stress response. While this is likely due to the goal of the studies looking into a more specific response (for example, response to rejection) rather than looking at the stress response in general, it is also possible that these regions were not activated by the visual stressors. To address this ambiguity, future studies should take a more holistic approach to assessing response to stress by using more measures of stress, such as physiological and behavioural measures. This would more accurately capture the stress response and allow for the assessment of multiple stress response systems.

Past evidence has suggested that the physiological response to stress may be different depending upon the nature of the stressor to which a person is responding (Dickerson and Kemeny 2004; Stroud et al. 2009). The studies reviewed used different kinds of stimuli to produce feelings of stress, yet most of the studies were peer rejection based in nature, excluding other kinds of stress that may be experienced. For example, there was only one study that examined response to a family-based stressor. Although the peer context becomes increasingly salient during adolescence, family-based stressors are also important as the family is critical to mental health (Morris et al. 2007) and neurological development (Noble et al. 2015). Evidence has suggested that some biomarkers are less responsive to family-based stressors (Dickerson and Kemeny 2004; Klimes-Dougan et al. 2001), indicating that the physiological response to family stress may be unique. However, there is a lack of understanding of why this difference exists, possibly due to a lack of a standardized, empirically validated family-based stressor that could be used while undergoing fMRI to explore underlying neural mechanisms.

Lastly, the current study in and of itself is not without limitations. Because this article is a review of the present research, it is limited to what has already been put forth by other researchers, and their interpretations of their data. If other areas of the brain showed activation in response to a stressor but were not reported in the article, the present study is unable to report or examine such effects. To a similar point, the current study is limited to what has been published, which is subject to a publication bias in that studies that do not find significant effects may not be published, which may account for a lack of studies that specifically examine effects such as age or sex differences. Few of the studies examined in the present article reported such demographic effects (Bolling et al. 2011; Guyer et al. 2009; Moor et al. 2012; Silk et al. 2012), yet it remains unclear as to if this was due to true absence of age and gender differences, failure to examine such effects, or small samples that lack variability. Finally, to further the current knowledge base, a meta-analysis would be needed in order to examine aspects of previous research done, for example to address the question of efficacy across stimuli used by comparing effect sizes reported in the studies examined. This would provide more robust evidence to indicate which kind of stressor may be more effective at producing a neurological effect.

Conclusion

The present article sought to review studies that utilized a visual stressor to examine a neural response, specifically within the adolescent population. This is a time during which rates of psychological disorders and vulnerability to stress spike (Costello, Copeland, & Angold, 2011; Pryce 2008), impacting not only mental health during this developmental period, but also future mental (Thoits 2010) and physical health (Pervanidou and Chrousos 2012). Thus, it is important to understand how stressors trigger a neurological response in the brain. The results indicated a commonality in regions of the brain activated using these visual stimuli, especially those of a social orientation, providing support for the SIPN (Nelson et al. 2005). Additionally, our study examines how these studies evaluated the ecological validity of stimuli used to induce a stress response, noting that few studies explicitly examined ecological validity, leaving the potential for the findings to be the result of stressors encountered in the laboratory setting only. Furthermore, the review highlights the

importance of including specific measures of ecological validity, and also serves as a call to action, to include laboratory based paradigms that go beyond assessing peer rejection and include family related stressors, as well as examining activation in the brain specifically associated with the stress response, such as the amygdala and hypothalamus.

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Table 1

Summary of studies utilizing passive viewing of stimuli to elicit neural response

Citation	Participants	Design	Task characteristics	Outcome examined	Results: main effects	Results: interaction effects	Ecological validity
Furman et al. (2010)	N = 49 females M = 12.5, SD = 1.3 Community sample	Within subjects	Watched a sad movie clip featuring a character learning their best friend committed suicide, or finding out that their best friend was terminally ill and passed They were then asked if they have ever been in a similar or lost a loved one, how this made them feel, and then prompted to really allow them-selves to <i>feel</i> whatever they felt	fMRI	Amygdala activation increased from baseline condition	S allele participants showed earlier peak activation than /allele participants	No evidence presented
Latham et al. (2017)	N = 113, 33.6% males M = 12.68, SD = 0.43 Community sample	Within subjects	Participants looked at 18 pleasant, 18 neutral, and 18 unpleasant photos	ERP	Main effect on ERP was not significant	None examined	No evidence presented
Marusak et al. (2013)	N = 28, 64.3% females M = 12.45, SD = 2.26 Community sample	Within subjects	Had participants view adult and child faces depicting multiple expressions during fMRI scan	fMRI	Negative and neutral adult faces brought about greatest reaction within amygdala	None examined	No evidence presented
Whittle et al. (2012)	N = 30, 60% female M = 17.35, SD = 0.43 Recruited from larger longitudinal study	Within subjects	Used video segments of adolescents' mothers and an unfamiliar mother's affective behavior to elicit emotion while during fMRI task	fMRI	Exposure to their own mother's positive affective behavior was associated with activation in the anterior and posterior cingulate, precuneus, and ventrolateral prefrontal cortex	Depressive symptoms in adolescents were associated with reduced rostral anterior cingulate cortex activity during positive behavior seen from their own mother, and reduced striatal and lateral occipital activity during positive affective behavior in general	No evidence presented but actual mothers of participants were used as stimuli

Table 2

Summary of studies utilizing interactive visual stimuli to elicit neural response

Citations	Participants	Design	Task characteristics	Method of assessment	Results: Main effects	Results: interaction effects	Ecological validity
Bolling et al. (2011)	N = 40, 72.5% male M = 13.04 SD = 2.42 Community sample	Within Subjects	Cyberball and then Cybershape (passed shape to player who had a matching shape)	fMRI	Social rejection showed activation in bilateral insula, postcentral gyrus, left hippocampus, and posterior cingulate cortex, ventral anterior cingulate cortex, left ventrolateral prefrontal cortex, left middle and inferior temporal sulcus, and left superior temporal sulcus	As age increased, so did activation seen in bilateral vIPFC, dorsal and ventromedial PFC, posterior cingulate cortex, retrosplenial cortex, left anterior superior temporal sulcus, and left posterior middle temporal gyrus	No evidence presented
Chester et al. (2014)	N = 35, 45.6% female M = 19.03 SD = 1.36 Community sample	Within Subjects	Used Cyberball as rejection simulation	fMRI	Social rejection condition associated with increased activity in the dACC and the bilateral anterior insula	Found dorsal anterior cingulate cortex (dACC) activation had positive association with aggression	No evidence presented
Groschwitz et al. (2016)	N = 43, 51.2% female M = 15.45 SD = 2.5 Clinical and community sample	Between and within subjects design	Cyberball	fMRI	Main effect of ball tossing condition seen in anterior insula, ACC, parahippocampus, presupplementary motor area, and secondary visual regions	Clinical sample showed increased response in medial and ventrolateral prefrontal cortex	Clinical sample showed more of a response suggesting that more relevant for youth already evidencing problems
Guyer et al. (2009)	N = 34, 47.1% female M = 13.6 SD = 2.4 Community sample	Within subjects	Chatroom	fMRI	Few main effects seen consistently with entire sample	Greater activation seen in nucleus accumbens, hypothalamus hippocampus, and insula in females, as female age increased. Insula activation increased as age increased in females, but decreased as age increased in males	No evidence presented
Masten et al. (2009)	N = 23, 60.9% female M = 13.0, SD= (not reported) Community sample	Within-subjects design	Cyberball	fMRI	Significant activity in the insula and the right vPFC, sub-ACC, and ventral striatum	Activity in the sub-ACC, insula, anterolateral prefrontal cortex, and certain regions of right vIPFC was associated with subjective distress. Activity in two different regions of right vIPFC and dorsomedial PFC, and ventral striatum were negatively associated with subjective distress in response to rejection	Article states that used only one rejection block to maintain ecological validity Those who showed greater activity in the insula and subgenual anterior cingulate cortex reported more social distress in response to rejection
Masten et al. (2010)	N = 20, 50% female M = 13.17, SD=(not reported) Community sample	Within-subjects	Underwent scan while observing what they were led to believe were "past participants" playing Cyberball,	fMRI	Activity was seen in areas associated with mentalization (dorsomedial prefrontal cortex, medial prefrontal cortex, precuneus, and posterior superior temporal sulcus)	With greater displayed empathy/prosocial behavior saw increased activity in clusters of dmPFC and temporal pole in response to observed rejection. There was also greater activity seen in anterior	Actual email accounts were created for participants, both real and fake, to enhance ecological validity. Also, those who were

Citations	Participants	Design	Task characteristics	Method of assessment	Results: Main effects	Results: interaction effects	Ecological validity
			then were asked to send email to excluded participants			insula (related to social rejection and empathy for physical pain), less activity in posterior cingulate cortex and precuneus	more empathetic showed increased response
	N = 53, 58.5% female M = 17.77 SD = 0.43	Within and between subjects	Adolescents used a daily diary to report time spent with friends outside of school, and underwent fMRI scan 2 years later. During the scan, played Cyberball with what they were led to believe were two same-aged peers	fMRI	In response to social rejection, increased activity was seen in dACC, right and left anterior insula, as well as vIPFC and dmPFC, and the rACC	Spending more time with friends was related to less activity in dACC and anterior insula (areas associated with negative affect and pain processing)	Had participants meet "other players" before playing Cyberball to increase ecological validity of task
Moor et al. (2012)	N = 53, 58.5% female M = 15.77 SD = 0.84 Community sample	Between and within subjects	Cyberball	fMRI	Main effect found for condition such that rejection was associated with increased activity in mPFC, vACC, subgenual ACC, vIPFC. Insula appeared to be especially sensitive to rejection	Subgenual ACC more active in 10–12 year olds while adults showed more activity in right insula, right temporal pole, and dACC	
Olino et al. (2015)	N = 47, 57.4% M = 12.98 SD = 2.14 Community sample	Within and between subjects	Cyberball	fMRI	Greater activation found in ventral striatum, cuneus, insula, and superior temporal sulcus in response to rejection blocks	Affiliation (tendency to seek warmth and closeness) positively associated with activation in striatum, anterior cingulate, inferior frontal gyrus, and insula. Affiliation negatively related to activation in middle temporal gyrus and precuneus	Affiliation was associated with areas involved in the SIPN
Platt et al. (2015)	N = 30, 86.7% female M = 15.4 SD = 1.05	Within and between subjects	Chatroom	fMRI	Activation for whole sample in right frontal pole	There were no clusters of the brain showing greater connectivity in nondepressed versus depressed participants Significantly increased connectivity during reappraisal between the right frontal pole and the left superior frontal gyrus	No evidence presented
Sebastian et al. (2011)	N = 19 females M = 15.44 SD = 0.81 Community sample	Within and between subjects	Cyberball	fMRI	Significantly increased blood oxygen level dependent (BOLD) responses to rejection relative to inclusion seen in vIPFC and in large bilateral cluster with a peak in mPFC Neural responses found in large cortical midline cluster and in vIPFC	None examined	No evidence presented

Citations	Participants	Design	Task characteristics	Method of assessment	Results: Main effects	Results: interaction effects	Ecological validity
Silk et al. (2012)	N = 60, 53.3% females M = 13.2 SD = 2.5 Community sampling	Within subjects	Chatroom	Eye tracking	More pupil dilation in response to social rejection	Older participants showed stronger reactions than younger participants Same gender judges generated stronger pupillary responses to acceptance than for different gender judges	Increased pupil response to rejection was associated with decreased feelings of real-world connectedness in peer interactions
Tan et al. (2014)	N = 40, 62.5% female M = 14.75 SD = 1.63 Half clinical sample, half healthy controls	Within subjects	Chatroom	fMRI	Longer negative affect duration was associated with less activity in the bilateral insula, left anterior insula, left nucleus accumbens, and subgenual anterior cingulate cortex in acceptance conditions		No evidence presented
White et al. (2013)	N = 19, 78.9% males M = 12.86 SD = 1.30 Community sample	Within subjects	Cyberball	ERP	No main effects observed	3-way interaction between region, condition, and attachment classification, securely and dismissingly attached children's N2 wave amplitude did not differ when controlling for gender. Secure children showing a greater increase in N2 reported more ostracism experienced in life, while dismissing children showing a greater N2 increase reported less ostracism	No evidence presented
Will et al. (2016)	N = 44, 59.1% boys M = 14.0 SD = 0.70 Selected for acceptance versus chronic rejection by peers	Within and between subjects	Cyberball	fMRI	Ventral anterior cingulate cortex, medial prefrontal cortex, striatum, bilateral ventral lateral prefrontal cortex and dorsomedial prefrontal cortex showed increased activation in response to social rejection	None examined	No evidence presented