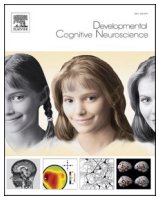
Developmental Cognitive Neuroscience 62 (2023) 101262

Contents lists available at ScienceDirect

Developmental Cognitive Neuroscience

journal homepage: www.elsevier.com/locate/dcn



Peer facilitation of emotion regulation in adolescence

Razia S. Sahi, Naomi I. Eisenberger, Jennifer A. Silvers *

Department of Psychology, University of California Los Angeles, Los Angeles, CA, USA

ARTICLE INFO

Keywords:
Emotion regulation
Adolescence
Peer influence
Friendships
Reappraisal

ABSTRACT

Emotion regulation is particularly important for adolescents as they undergo normative developmental changes in affective systems and experience heightened risk for psychopathology. Despite a high need for emotion regulation during adolescence, commonly studied emotion regulation strategies like cognitive reappraisal are less beneficial for adolescents than adults because they rely on neural regions that are still developing during this period (i.e., lateral prefrontal cortex). However, adolescence is also marked by increased valuation of peer relationships and sensitivity to social information and cues. In the present review, we synthesize research examining emotion regulation and peer influence across development to suggest that sensitivity to peers during adolescence could be leveraged to improve emotion regulation for this population. We first discuss developmental trends related to emotion regulation at the level of behavior and brain in adolescents, using cognitive reappraisal as an exemplar emotion regulation strategy. Next, we discuss social influences on adolescent brain development, describing caregiver influence and increasing susceptibility to peer influence, to describe how adolescent sensitivity to social inputs represents both a window of vulnerability and opportunity. Finally, we conclude by describing the promise of social (i.e., peer-based) interventions for enhancing emotion regulation in adolescence.

1. Introduction

Emotion regulation, the collection of strategies that are used to manage the experience and expression of emotional states (Gross, 2014), is particularly important during adolescence. Adolescents experience emotions with greater frequency and intensity than adults (Larson et al., 1980), and emotion dysregulation in adolescence has been linked to emerging or worsening internalizing symptoms (Casey et al., 2011; Kessler et al., 2005). Given that adolescence is a pivotal period for establishing emotional health (Lee et al., 2014; Paus et al., 2008; Suhrcke et al., 2008), and that anxiety and depression rates among adolescents have doubled in recent decades (Calling et al., 2017; Twenge et al., 2019), it is critical to identify novel mechanisms for improving emotion regulation outcomes for this age group.

One understudied mechanism for interventions that could promote adaptive regulatory processing and well-being in adolescents is peers, and particularly friendships (i.e., close peer relationships). Given the tremendous importance of social relationships and interactions in physical and mental health (Uchino et al., 2018), affective scientists have increasingly begun to look beyond the individual to examine how people help regulate each other's emotions, a process called interpersonal or social emotion regulation (Zaki and Williams, 2013; Niven, 2017; Reeck et al., 2016). Such research has shown that feedback from friends can boost emotion regulation outcomes in healthy adults (Sahi et al., 2021). Adolescence is characterized by enhanced sensitivity to the beliefs and behaviors of peers (Somerville et al., 2013; Andrews et al., 2021; Albert et al., 2013; van Hoorn et al., 2016, 2016). Thus, we propose that friendships might be a particularly powerful source of regulatory support that can be leveraged to improve emotion regulation outcomes in adolescence.

In the present review, we outline three lines of evidence that collectively provide support for this promising possibility. First, we identify adolescence as a period of emotional vulnerability by describing how the biobehavioral systems involved in top-down emotion regulation and self-control are still maturing during adolescence, limiting the efficacy of "gold standard" emotion regulation strategies like cognitive reappraisal during this age range (e.g., Silvers et al., 2015; McRae et al., 2012). Concurrently, however, we characterize this developmental period in terms of its heightened plasticity and sensitivity to environmental inputs, providing a window of opportunity for positive emotional development (Silvers, 2022; Sisk and Gee, 2022). Next, we review behavioral and neurobiological evidence that the adolescent brain is

* Correspondence to: Department of Psychology, University of California, Los Angeles, 1285 Franz Hall, Box 951563, Los Angeles, CA 90095-1563, USA.
E-mail address: silvers@ucla.edu (J.A. Silvers).

https://doi.org/10.1016/j.dcn.2023.101262
Received 13 October 2022; Received in revised form 2 June 2023; Accepted 4 June 2023
Available online 7 June 2023

uniquely tuned to social information — particularly from peers — and thus may be especially responsive to peer input during emotion regulation (e.g., Somerville et al., 2013; Pfeifer et al., 2011). Finally, we present findings demonstrating how friends can reduce stress and negative affect in adolescents and young adults (e.g., Scheuplein and Van Harmelen, 2021; Sahi et al., 2021), and highlight critical future directions for uncovering how such relationships could effectively facilitate emotion regulation in adolescents. We propose that "social reappraisal" wherein individuals receive help from others in changing their perspective on emotional events (Sahi et al., 2021; Sahi et al., 2023; 2022) might be especially beneficial in adolescent friendships as they continue to develop their capacities to reappraise independently.

2. Emotion regulation development during adolescence

Adolescence is defined as the developmental period that begins with the onset of puberty and ends when individuals start to plateau in terms of neural and biological maturation and achieve "independence" from caregivers (Dahl, 2004). This transition from childhood to adulthood is thus marked by a cascade of hormonal changes, neural plasticity, and increasing autonomy (Jaworska and MacQueen, 2015; Pfeifer and Allen, 2021). At the same time, adolescence is a period of high emotional reactivity and susceptibility to the environment (Somerville et al., 2010; Blakemore and Mills, 2014). In this section, we expand on how such features of adolescence establish a pivotal period for emotion regulation development (Silvers, 2022).

2.1. Development of emotion regulation skills during adolescence

The ability to effectively regulate emotions develops throughout childhood and adolescence (Silvers, 2022), and lays the foundation for health and well-being across the lifespan (Lee et al., 2014; Zeman et al., 2006; Moffitt et al., 2011). Thus, it is unsurprising that emotion dysregulation (i.e., diminished or maladaptive use of regulatory strategies) during adolescence intensifies the risk for psychopathology (Silvers, 2020; McLaughlin, Garrad, & Somerville, 2022). Internalizing symptoms like depression and anxiety are heightened during adolescence, and while most adolescents emerge from this tumultuous developmental stage with the skills necessary to effectively navigate emotional events, some experience worsening difficulties with emotion regulation and persisting mental health challenges (Casey et al., 2011; Kessler et al., 2007; Aldao et al., 2016). Thus, this period of adolescence marks a critical period for developing adaptive regulatory skills.

While emotion regulation can refer to a broad set of strategies for managing emotional experiences that develop across the lifespan (Cole and Hollenstein, 2018), we focus much of this review on cognitive reappraisal, a widely-studied regulatory strategy that involves changing how one thinks to change how one feels about an emotional stimulus. Our motivation for focusing on reappraisal is due in large part to the substantial changes that occur in the ability to use cognitive strategies like reappraisal across adolescence (reviewed in Silvers, 2022). Additionally, reappraisal usage is positively associated with good mental health (Aldao et al., 2010; Linehan, 2014; Milne and Reiser, 2017), highlighting this strategy as a possible intervention point for wellbeing across the lifespan.

Behavioral findings on adolescents' ability to reappraise is complex and nuanced, with questionnaire data providing null or mixed findings regarding age-related changes in reappraisal tendency (i.e., how often reappraisal is used) during adolescence (Chervonsky and Hunt, 2019; Gullone et al., 2010; Gullone and Taffe, 2012). Meanwhile, task-based data have more consistently demonstrated age-related improvements in reappraisal capacity (i.e., how effectively reappraisal is used) from childhood through late adolescence (Silvers et al., 2017; Silvers et al., 2012; Theurel and Gentaz, 2018). While age-related differences in reappraisal capacity appear weaker for appetitive stimuli (Giuliani and Pfeifer, 2015; Silvers et al., 2014) and in narrower age bands (Van Cauwenberge et al., 2017; Ahmed et al., 2018), on whole there is evidence for linear age-related improvements in regulatory ability. These distinctions in cross-modality observations regarding emotion regulation are consistent with current empirical and theoretical findings suggesting an underappreciated distinction between individuals' regulatory "tendency" and "capacity" (Guassi Moreira et al., 2022; Silvers & Guassi Moreira, 2019; Gruber et al., 2023). Furthermore, research suggests that while adolescents are typically able to reappraise, they show smaller and less enduring reappraisal-related reductions in negative affect relative to adults (Silvers et al., 2012; McRae et al., 2012; Silvers et al., 2015; 2017). Importantly, some neuroimaging work suggests that reappraisal can be counterproductive when attempted without parental support in children, but not in adolescence (Silvers et al., 2017; Dougherty et al., 2015), highlighting the tremendous growth in emotion regulation abilities that occurs during this age, despite adolescents not yet reaching adult-levels of ability.

2.2. Neurodevelopment of emotion regulation during adolescence

Decades of research in adults has demonstrated that reappraisal use in adults involves recruitment of dorsal and lateral prefrontal regions involved in cognitive control and attenuation of subcortical structures, like the amygdala, involved in responding to and interpreting affective stimuli (Buhle, Silvers et al., 2014; Picó-Pérez et al., 2019; Morawetz et al., 2017). While ventromedial prefrontal cortex (VMPFC) has been implicated in regulating negative affect in certain contexts – for example, fear extinction (Quirk et al., 2003; Rosenkranz et al., 2003; Phelps et al., 2004; Roy et al., 2012; Sescousse et al., 2013) – it is not consistently recruited during reappraisal in adults (Buhle et al., 2014).

An emerging neuroimaging literature on reappraisal in youth has suggested that reappraisal is relatively ineffective at regulating amygdala responses in childhood (Silvers et al., 2016; Dougherty et al., 2015), and that reappraisal-related attenuation of the amygdala improves steadily across adolescence (Stephanou et al., 2016; Belden et al., 2014; Silvers et al., 2015, Silvers et al., 2016). These age-related changes in amygdala modulation coincide with adolescents beginning to show recruitment of similar lateral and dorsal prefrontal regions to adults, though perhaps with less intensity (Silvers et al., 2015; Silvers et al., 2016). Research examining developmental differences in uninstructed emotional processing (i.e., participants view affective stimuli without being instructed to regulate their emotions) has demonstrated a shift from excitatory to inhibitory patterns in prefrontal brain regions across adolescence (Hensch, 2004; Hensch, 2005; Reh et al., 2020; Takesian et al., 2018), with some evidence that functional connectivity between the amygdala and VMPFC switches from a positive to negative association across development (Gee et al., 2013). Intriguingly, while VMPFC is not implicated in reappraisal in adults, one study examining developmental differences in reappraisal observed that recruitment of the lateral prefrontal cortex (LPFC) during cognitive reappraisal was associated with attenuated amygdala activity only for adolescents who also exhibited negative VMPFC-amygdala connectivity (Silvers et al., 2017). This finding suggests that reappraisal in adolescence may recruit neural circuitry that partially overlaps (i.e., LPFC) and is partially distinct (i.e., VMPFC) from the circuitry engaged in this process for adults.

Research increasingly describes adolescence as a period of adaptability and opportunity rather than deficiency, with a greater interest in understanding and capitalizing on the plasticity of adolescent neurobiology to establish lasting well-being (Crone and Dahl, 2012; Gee et al., 2022; Lee et al., 2014). As such, adolescence may be conceptualized as a pivotal period for practicing and strengthening emotion regulation skills to support lifelong mental health. Adolescents experience emotions with greater frequency and intensity than adults (Larson et al., 1980), making their regulatory needs quite steep. Developing a rich regulatory toolkit – including the ability to effectively use reappraisal – may be an important part of addressing these needs – especially given that reappraisal use is associated with positive mental health outcomes beginning in

adolescence (i.e., after childhood) (Compas et al., 2017). The developing state of the adolescent brain makes it exquisitely sensitive to external inputs (Luby et al., 2020; Galván, 2010; Nelson and Gabard-Durnam, 2020), and thus it may be particularly responsive to interventions aimed at enhancing emotion regulation.

3. Social influence and the adolescent brain

While adolescence is characterized by increasing autonomy from caregiver support, it is also a period of high susceptibility to cues and feedback from peers (Somerville et al., 2013). In this section, we first describe how caregivers sculpt neurodevelopment related to emotion regulation. The role of caregivers in emotion regulation has been studied far more extensively in developmental research than that of peers, providing a foundational understanding of how social influences can shape emotion regulation processes across development. Next, we discuss the shift away from parental influence towards heightened peer influence in adolescence. We discuss how peers shape adolescent decision-making and behavior in both negative (e.g., risky) and positive (e.g., prosocial) ways. Finally, we highlight the neural regions involved in processing peer feedback, and suggest neural pathways that can be explored in developing peer-focused interventions for aiding emotion regulation in adolescence.

3.1. Caregiving as a form of social influence on emotion regulation development

Before children can develop the ability to regulate their emotions independently using reappraisal and other regulatory strategies, they rely heavily on caregivers to manage their emotions. Considering how caregivers sculpt emotion regulation early in life may elucidate ways in which social inputs can shape emotion regulation more broadly across development. Early in life, children often derive immense comfort from their parents, such that simply being in the presence of their parents can powerfully down-regulate negative emotion, as captured by behavior, physiology, and neurobiology (Gee et al., 2014; Hostinar et al., 2015; Myruski and Dennis-Tiwary, 2021; Tottenham et al., 2019). However, children also learn when, why, and how to regulate their own emotions by watching and learning from their caregivers — a process described as "emotion socialization behaviors" (Eisenberg et al., 1998). In addition to modeling how to express and modulate emotions through their own emotional behavior, adults teach children how to think about and cope with their emotional experiences through direct feedback (e.g., emotional coaching) as well as their receptivity to children's emotions (e.g., warmth and sensitivity) (Morris et al., 2007; Morris et al., 2017). Thus, children that grow up in more positive caregiving environments begin demonstrating the ability to regulate their own emotions through more frequent use of adaptive regulatory strategies, laying the foundation for greater socioemotional adjustment and autonomy in self-regulation during adolescence (Morris et al., 2017; Gunzenhauser et al., 2014).

While far more research has examined correlational and causal links between caregiving practices and behavioral indices of emotional development, there is compelling evidence that caregiving also organizes neural circuits involved in emotion regulation. One line of evidence comes from research on childhood adversity, and particularly caregiving adversity (i.e., deprivation, abuse, or neglect at the hands of a caregiver), and its effects on brain structure and function. Results from a recent systematic review of 109 MRI studies found that exposure to threat in childhood (e.g., abuse at the hands of a caregiver) elicits greater reactivity in the amygdala – a brain region known to support detection and encoding of motivationally salient stimuli – whereas exposure to deprivation (e.g., caregiver neglect) is linked to altered function in frontoparietal regions commonly implicated in self-control and decision making (McLaughlin et al., 2019). Beyond these general findings, there is growing evidence that emotion regulation may promote resilience among some adolescents exposed to early caregiving adversity, such that those who develop emotion regulation skills are more likely to be buffered against mental health disorders (Weissman et al., 2019; Rodman et al., 2019) – underscoring the value of regulatory skills in overall mental health. Other research has demonstrated that variations in normative caregiving behaviors in childhood predict emotion regulatory activity (VMPFC-amygdala connectivity) during adolescence in response to emotional stimuli (Chen et al., 2020). Together, these data indicate that caregiving experiences shape the development of neural circuitry involved in self-regulation (e.g., prefrontal-amygdala circuitry) and emotional well-being (Kerr et al., 2019; Callaghan and Tottenham, 2016a; Callaghan andTottenham, 2016b; Tan et al., 2020).

Such research on caregiving influences point to how close others, broadly construed, can shape emotional behavior and neural development in early life. As children transition into adolescence, they start to rely less on caregiver support. Interestingly, while warmth and acceptance from parents continues to positively impact adolescents, hands-on parental support during emotion regulation seems to only benefit younger adolescents, signifying a critical shift in emotional autonomy across this age group (Criss et al., 2016). Relatedly, parents who engage in overzealous attempts to downregulate their children's emotions (i.e., "accommodation") can unintentionally exacerbate anxiety in youth (Norman et al., 2015; Iniesta-Sepulveda et al., 2021), demonstrating the importance of developing more autonomy from caregivers in emotion regulation processes across development. Relative to children, adolescents regulate their emotions using top-down self-regulatory strategies with greater efficacy, frequency, and flexibility (Compas et al., 2017; Fields and Prinz, 1997). Thus, it is important to interrogate how youth increasingly self-regulate and potentially rely on different types of close relationships, including close peer relationships (i.e., friendships), for regulatory support.

3.2. The shift away from parental influence during adolescence

Adolescents need and increasingly want less hands-on support from caregivers as they transition into greater independence and exploration of their other social relationships. Indeed, several studies have shown that parental availability has diminishing effects as children transition into middle and late adolescence (Hostinar et al., 2015; Gee et al., 2014). One study in low-income families found that emotion coaching from a parent decreased anger and sadness to a greater extent in younger versus older adolescents (Criss et al., 2016). Another study — also in a low-income population exposed to various degrees of early life trauma — found that maternal availability buffered against fear in children but not adolescents (Rooij et al., 2017). This change in how individuals respond to their parents over the course of development is likely rooted in their changing needs and capacities (i.e., they are more capable of dealing with their own emotions as they get older) as well their perceptions of parental authority (i.e., desire to exhibit greater autonomy and independence from caregivers) (Steinberg and Morris, 2001).

Parents continue to maintain an important protective role throughout adolescence, such that supportive caregiving is associated with heightened reward responsivity, better mental health, and less stress following peer victimization during this age (Colich et al., 2021; Jones et al., 2014; Rudolph et al., 2020). As frontolimbic circuitry, including networks of brain regions involved in emotion regulation, become more mature, the social relationship between caregivers and their children also changes, with caregivers typically providing less scaffolding for emotion regulation (Callaghan, Tottenham, 2016b; Gee at al., 2014; Hostinar et al., 2015). These concurrent changes in social relationships and neural circuitry in adolescence promote greater independence, self-regulation abilities, and investment in non-familial relationships, including peer relationships (Orben, Tomova, & Blakemore, 2020; Somerville, 2013; Silvers, 2022). Adolescents are often more open about their emotional experiences with their peers than their

parents (Sullivan, 2014), and are more attentive to feedback from their peers (Somerville, Jones, and Casey, 2010), such that peers begin to take on a more central role in providing emotional support (Gee et al., 2022). Importantly, this susceptibility to peers can also amplify negative emotions in adolescence through negative experiences such as peer rejection (Andrews et al., 2020) or even simply peer presence during a stressful situation (Doom et al., 2017). Thus, it is important to consider both negative and positive influences of peer relationships on mental health and emotional wellbeing.

3.3. Peer influence during adolescence

Adolescence is marked by increased valuation of peer relationships and increased sensitivity to social information and cues (Somerville et al., 2013; Stephanou et al., 2016). Thus, it is possible that peers are particularly influential for emotion regulation processes during adolescence. To date, little work has directly examined this proposition, though substantial work has examined how peers broadly shape emotion and cognition during adolescence. Peer relationships in adolescence have been well-documented as a source of negative influence in the form of peer pressure and the consequences associated with rejection or disapproval by peers. For example, excessive sensitivity to peer feedback or even mere peer presence has been implicated in risky decision making and substance use in adolescents (Chein et al., 2011; Albert and Steinberg, 2011; Allen et al., 2006; Galvan et al., 2007; Spear, 2011; Doremus-Fitzwater et al., 2010). Such effects have been attributed to increased engagement of brain regions involved in reward processing, including the ventral striatum (VS) and VMPFC (Garris et al., 1993; Robbins and Everitt, 1992; Schultz, 1997), in the presence of peers, resulting in greater likelihood to conform to real or perceived peer pressure. In certain contexts, peer presence can also enhance self-consciousness (Somerville et al., 2013) and amplify physiological stress responses (e.g., cortisol) (Gunnar et al., 2019; Rodman et al., 2021). Importantly, individual differences (e.g., rejection sensitivity) and relationship characteristics (e.g., propensity to engage in co-rumination) can fuel such adverse responses to peer presence in adolescence (Andrews et al., 2020; Prinstein et al., 2005; Rose, 2021; Purdie and Downey, 2000; Silvers et al., 2012).

While most research on peer influence has focused on the dangerous or maladaptive effects of peer influence, there is a growing interest in characterizing the positive effects of peer influence (Foulkes and Blakemore, 2016; Blakemore and Mills, 2014). If the core goals of adolescence are to explore one's environment and establish independence from the family, it makes sense that adolescents increasingly follow and learn from their peers. Thus, just as peer pressure can encourage risky behavior, it can also promote prosocial behavior, learning, and motivation in adolescence (Carden Smith and Fowler, 1984; van Hoorn et al., 2016; Rosenblau et al., 2018; Braams et al., 2014; Telzer et al., 2010; Warnell et al., 2018; Sharp et al., 2022; Rodman et al., 2023). For example, one compelling experimental study found that adolescents were more likely to conform to their peers' safe choices on a decision-making task than their risky choices (Braams et al., 2019; Davidow et al., 2016), illustrating the bright side of peer pressure. Another experimental study found that when adolescents believed that high status peers engaged in prosocial behavior (i.e., volunteering), it made them more likely to behave in a prosocial way as well (Choukas-Bradley et al., 2015). Other observational longitudinal work has suggested that changing peer groups (after relocating) and harmonious romantic relationships during adolescence can have lasting stabilizing effects on youth with a history of delinquency (Rutter, 1996). As such, peers have the potential to promote at least as much good as harm for adolescents, depending on the context and the nature of the relationship. However, surprisingly little research has examined the potential protective effects of positive peer relationships – particularly in the context of emotion regulation – from a neuroscientific perspective in adolescence.

3.4. Brain regions involved in reward processing may play a role in socially regulating emotion

Since adolescence is a time of heightened reward sensitivity (Galván, 2013), particularly in response to peers (Albert & Steinberg, 2013), reward-related neural circuitry such as VS and VMPFC may support peer-facilitated emotion regulation during adolescence. VS and VMPFC have both been implicated in regulatory processes, broadly speaking. For example, VS and VMPFC have been implicated in regulating stress and negative emotion in both adolescents and adults (Forbes et al., 2009; Masten et al., 2009; Wager et al., 2008). Although VMPFC has not been consistently implicated in regulatory strategies like cognitive reappraisal (Buhle et al., 2014; Diekhof et al., 2011), it has been shown to be critical for certain social buffering effects – such as reducing the experience of physical pain while seeing a picture of a loved one (Eisenberger et al., 2011). Meanwhile the VS has been implicated in positive reappraisal, wherein individuals try to see negative events in a more positive light (Wager et al., 2008; Doré et al., 2017). Work examining how positive reappraisal regulates how people recall distressing memories over time has also shown greater neural dissimilarity in VS for memories that showed an increase in positivity across memory retrievals (Speer et al., 2021). Such findings suggest that canonical "reward" circuitry can be leveraged to effectively change the affective import of aversive events.

The association between reward circuitry and emotion regulation are particularly intriguing because the VS and VMPFC are highly responsive to peer influence in both adolescence and adulthood (Welborn et al., 2016; Campbell-Meiklejohn et al., 2010; Gee et al., 2014). VS and VMPFC undergo dramatic functional changes during adolescence that support behavioral changes in reward sensitivity (Galván, 2013; Spear, 2011; Sturman and Moghaddam, 2011). The initial data that fueled this theory came from both non-human and human neuroscientific work comparing adolescents to either children or adults in how they respond to non-social cues such as food, drugs, or monetary rewards. These studies largely had two conclusions. First, they suggested that risk-taking behavior and associated reward-related brain activity — particularly in the VS — peak in adolescence (Galván, 2013; Schreuders et al., 2018). Second, they found links between said reward sensitivity in the brain and negative behavioral outcomes, including risky decision making and substance use behavior (de Water et al., 2017; Galvan, 2007; Rao et al., 2011).

Early observations on reward responsivity during adolescence has motivated a broader conversation about whether adolescence is best characterized by sensitivity to rewards, social stimuli, or both (Foulkes and Blakemore, 2016). Across species, adolescents show potentiated VS activity in the presence of peers or in response to social stimuli (Robinson et al., 2011; Chein et el, 2011; Smith et al., 2015). Moreover, adolescents demonstrate enhanced VMPFC and VS activity in response to social rewards (e.g., positive feedback from peers) (Guyer et al., 2012), and activity in VS appears to buffer adolescents against social rejection-related distress (Masten et al., 2009). Together, these findings imply that "reward circuitry" may be co-opted to motivate social behavior in adolescence, that social contexts activate reward circuitry in adolescence, and that said circuitry plays a key role in modulating affective states during this developmental period.

3.5. Leveraging peers to promote emotion regulation via reward circuitry in adolescence

Influential theoretical models in developmental cognitive neuroscience suggest that prefrontal regions mature more slowly than subcortical structures like the VS, and that prefrontal-subcortical connectivity changes dynamically during adolescence (Casey, 2015). While VMPFC-amygdala connectivity continues to strengthen across adolescence (Gee et al., 2013; Gabard-Durnam et al., 2014), existing data suggest that the VMPFC matures prior to the LPFC (Shaw et al., 2008).

Thus, both VS and VMPFC functionally mature prior to the LPFC in adolescence (Fig. 1). Existing neuroimaging studies on age-related differences in cognitive reappraisal suggest that the neurodevelopmental trajectory of the LPFC may explain adolescents' still-immature emotion regulation ability (Silvers et al., 2015; 2016). While the LPFC is still developing, it is possible that adolescents can more reliably recruit functionally mature regions such as VMPFC and VS to regulate their emotions. For example, VMPFC-amygdala connectivity appears to support reappraisal instantiation in adolescence, despite VMPFC recruitment not being consistently observed during reappraisal in adults (Silvers et al., 2017). VS-amygdala connectivity also appears to be particularly responsive to socio-affective states during this developmental period (Pfeifer et al., 2011; Heller et al., 2016). Thus, reward-related circuitry in adolescence may provide an alternative pathway for supporting effective emotion regulation during adolescence. Specifically, peers might be able to facilitate emotion regulation by engaging VMPFC and VS to help modify amygdala-based representations of negative stimuli.

4. Promise of social interventions for emotion dysregulation in adolescence

Thus far, we have shown how adolescence is a period of both vulnerability and opportunity in terms of emotion regulation development and peer influence on behavior and cognition. In this final section, we discuss existing research exploring how peer relationships can be leveraged to enhance emotion regulation efficacy. Limited research has explicitly examined how individuals help each other regulate emotions (i.e., social emotion regulation), much less its neural bases (Zaki and Williams, 2013; Reeck et al., 2016). This process may be particularly important to study during adolescence when peer relationships and social information are especially potent. As described in the next section, research on social buffering in adolescents and social emotion regulation in adults strongly suggest that adolescents may uniquely benefit from social emotion regulation, in part because of the state of their developing brains. After summarizing this research, this paper will conclude with a description of recommended next steps for this line of inquiry.

4.1. Social support and emotion regulation mechanisms from adolescence into adulthood

There is ample evidence that peers – and especially friends – play a critical role in shaping emotional states during adolescence. Friendships are defined as voluntary and reciprocal peer relationships (Hartup, 1996; Reindl et al., 2016) characterized by high intimacy and trust (Parker & Asher, 1993) often deepened over time (Ainsworth, 1989; Buhrmester and Furman, 1986). These relationships are a vital source of social support across the lifespan and particularly during adolescence, where they can modify perceptions, reactions, and physiological responses to and after stress (Gunnar et al., 2019). Adolescents who spend more time with friends, and thus ostensibly experience greater social support, demonstrate diminished cortisol responses, and lower neural activity in brain regions commonly associated with social distress following social exclusion (Eisenberger et al., 2007; Masten et al., 2009).

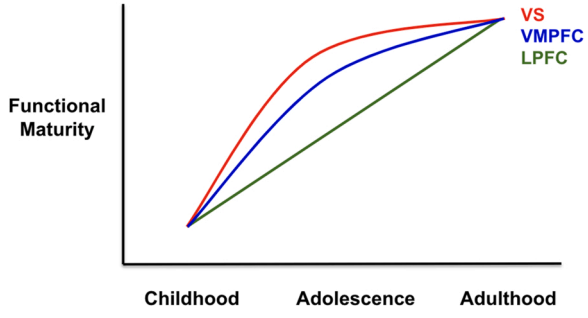


Fig. 1. Functional maturity of VS, VMPFC, and LPFC across age. The above figure builds on existing figures showing the neurodevelopmental imbalance between prefrontal and limbic functional maturity (Casey et al., 2008) to specifically highlight and include the relative functional maturity of brain regions we propose may be involved in social emotion regulation: lateral prefrontal cortex (LPFC), ventromedial prefrontal cortex (VMPFC) and ventral striatum (VS).

While such findings suggest that friends may support resilience in response to mild and acute stress, there is also evidence that friendship support may buffer against stress for individuals who have experienced more severe or chronic stress. For example, friend support has been found to improve mental well-being in young people who have faced childhood adversity (van Harmelen et al., 2014; van Harmelen et al., 2021), though the mechanisms underlying this process are not fully characterized yet (see Scheuplein and Van Harmelen, 2021 for promising future directions). Critically, these buffering effects appear to extend long after individuals have transitioned from adolescence into adulthood. For example, one study by Marion and colleagues (2013) found that a high level of peer rejection in early adolescence predicted less life satisfaction in middle adulthood, *unless* individuals had at least one friend during early adolescence – suggesting that adolescent friendships can have robust and enduring buffering effects, setting the stage for lifelong wellbeing (Marion et al., 2013).

Social support can buffer against stress and negative emotions in many ways, but limited work has examined how friends can actively help each other regulate their emotions through social emotion regulation mechanisms. In studies of healthy young adults, our group has demonstrated that listening to a friend reinterpret the content of negative stimuli (i.e., social reappraisal; for example by describing a resolution to the negative event) was more effective at down-regulating negative affect than reinterpreting the stimuli on one's own (Sahi et al., 2021; Sahi et al., 2023; see Fig. 2 for task details) — a finding replicated by another group (Morawetz et al., 2021). Importantly, we showed that these effects were not attributable to differences in the types of reinterpretations provided (i.e., the reinterpretations used during social reappraisal were qualitatively similar to those that participants used when reappraising alone), nor were they attributable to social buffering (i.e., simply hearing a friend's voice was not as effective as hearing them reappraise), suggesting that social reappraisal selectively regulated emotion (Sahi et al., 2021). Finally, this work also showed that the effects of social reappraisal can last to promote future self-regulation, suggesting that this type of social support might facilitate lasting shifts in how emotional stimuli are perceived (Sahi et al., 2023).

Given that adolescents are generally more sensitive than adults to peer influence, there is good reason to believe that social emotion regulation strategies like social reappraisal may be even more effective in adolescents than young adults. In line with this idea, observational studies have shown that social context (i.e., presence of parents or peers) influences the efficacy of emotion regulation (Stone et al., 2019) and that peer influence can shape emotion regulation strategy use in adolescents (Reindl, Gniewosz, & Reinders, 2016). Just as supportive caregivers are thought to scaffold the development of fledgling emotion regulation mechanisms in childhood, positive peer relationships may be particularly important for supporting emotion regulation development in adolescence. While no neuroimaging work has yet formally tested this hypothesis, the research we have summarized supports a possible role of VS and VMPFC in the social modulation of emotion (e.g., Chein et al., 2011; Somerville et al., 2013). As such, a critical next step in unpacking peer influences on emotion regulation in adolescence will be to experimentally interrogate how such relationships may directly support social emotion regulation, as well as the neural mechanisms implicated in such processes.

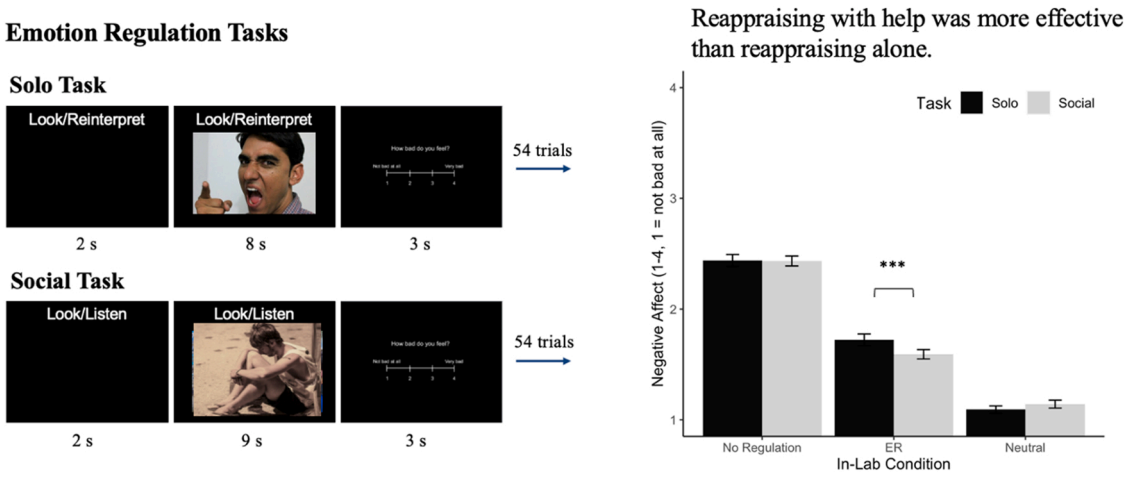


Fig. 2. ***Reappraising with help from a friend was more effective than reappraising alone in adults.*** The above figure exhibits the "solo" and "social" emotion regulation (ER) tasks conducted in studies of healthy adult friend pairs (Sahi et al., 2021; 2023). The solo task began with a 2 s cue to "look" or "reinterpret" followed by an image presentation for 8 s, and a rating screen for 3 s. The social task followed a similar procedure, except that instead of seeing a cue to "reinterpret" they saw a cue to "listen" to their friend reinterpret the image. The image was presented for 1 s before the audio clip played (9 s total). Across three studies (figure pictured here is from study presented in Sahi et al., 2023), reappraising with help from a friend was associated with lower negative affect than reappraising independently. * ** $= p < .001$.

4.2. Next steps in evaluating social emotion regulation efficacy in adolescents

Peer relationships have the potential to exert powerful and varied influences over multiple dimensions of emotion regulation during adolescence (King et al., 2018). We suggest that examining social influences on cognitive reappraisal may be particularly useful as a starting point because: (a) reappraisal is modifiable by intervention (Denny, 2020), (b) it has been studied from neuroscientific and developmental perspectives (Silvers, 2020; 2021), and (c) it has been closely tied to mental health and well-being (Aldao et al., 2010). A first step in future work will be to test whether social reappraisal is more effective than cognitive reappraisal in adolescence, as well as whether the magnitude of this difference is larger in adolescents than in adults.

To better understand the potential benefits of social reappraisal or similar social emotion regulation processes, especially for developmental populations, future work can explicitly examine how social reappraisal, especially in early life, relates to learning or contagion mechanisms (e.g., how social reappraisals might become internalized; Denny, 2020; Oveis et al., 2020). Although existing work has shown that social reappraisal can have enduring effects on how individuals independently respond to previously reappraised stimuli (Sahi et al., 2023), future work can test whether friend-supported social reappraisal during adolescence facilitates better independent cognitive reappraisal in the future, and whether this effect extends to novel stimuli. In addition to potentially facilitating emotion regulation learning, it is possible that social reappraisal enhances regulatory outcomes by capitalizing on reward. Reframing negative events in a positive light (i.e., positive reappraisal) can be rewarding in and of itself (Speer et al., 2021), but the reward of feeling socially connected (Morelli et al., 2014) might also make reappraisals more cognitively accessible by buffering against negative affect or enhancing feelings of trust and belongingness. Research on such social emotion regulation mechanisms is still in its early stages, but unpacking these processes across development can shed light on potentially underrated social support mechanisms that can facilitate positive mental health and wellbeing across the lifespan.

In this vein, brain imaging might be used to interrogate neurodevelopmental mechanisms and test whether successful implementation of social reappraisal in adolescence is supported by engagement of reward circuitry that matures earlier in development (e.g., VMPFC-amygdala and VS-amygdala connectivity) rather than recruitment of lateral prefrontal regions that are typically observed during cognitive reappraisal. While it is possible that LPFC is also recruited during social reappraisal, as has been shown in one study in adults (Morawetz et al., 2021), it will be useful to examine how such patterns of activation vary across networks (i.e., LPFC-amygdala, VMPFC-amygdala, VS-amygdala) as well as possible age-related differences in these neural patterns. If social reappraisal can enhance emotion regulation in adolescence, it may be possible to use social influence to develop emotion regulation training interventions for this age group (Denny, 2020), and particularly adolescents at risk for challenges with emotion regulation — for example, youth who have experienced early life adversity (van Hoorn et al., 2016).

While existing research comparing social reappraisal to cognitive reappraisal was done in close friend pairs, it will be informative for future work across age groups to assess the role of relationship type (e.g., parents, siblings, teachers, strangers) and quality on social emotion regulation outcomes, as it is possible that certain relationships lead to maladaptive outcomes (e.g., co-rumination; Rose, 2021). Relatedly, care must be taken to consider contexts in which peers might amplify stress or negative emotion (Gunnar et al., 2019; Rodman et al., 2021), as well as individual differences such as social anxiety that may shape social emotion regulation outcomes (Sahi et al., 2022). Additionally, one study investigating potential gender differences in social versus cognitive reappraisal in healthy adults found that social reappraisal effectively regulated emotion for both genders, but on average it was only more effective than reappraising independently for women (Sahi et al., 2023). Thus, future work in adolescents should consider how gender differences in emotion socialization or other developmental differences might shape social emotion regulation outcomes. Finally, given that the most vulnerable youth may also be less likely to have deep and supportive peer relationships, it will be imperative for future work to study whether appropriate substitutes might be leveraged, as well as how to target loneliness as an impediment for social emotion regulation strategies.

5. Conclusion

Adolescents often derive limited benefits from top-down forms of emotion regulation like cognitive reappraisal (Lewis and Stieben, 2004; Barnea-Goraly et al., 2005; Bunge and Wright, 2007; Silvers et al., 2017). At the same time, adolescents are exquisitely sensitive to feedback and support from their peers (Somerville et al., 2013; Chein et al.,

2011; Albert and Steinberg, 2011; Allen et al., 2006; van Hoorn et al., 2016). These two findings stem from the neurodevelopmental trajectory of brain regions involved in emotion regulation and reward processing: while cognitive control systems show a protracted pattern of development, reward circuitry that is responsive to peer feedback develops rapidly during adolescence (Spear, 2011). Thus, adolescents are uniquely poised to benefit from a social intervention designed to appropriate peer influence mechanisms towards enhancing emotion regulation efficacy. Peer interventions for emotion dysregulation in adolescence can work *with* the developing brain rather than against it to utilize reward circuitry that is relatively mature in adolescents (i.e., VS, VMPFC) instead of prefrontal systems (i.e., LPFC), which are still developing, to regulate emotion. Research testing whether peer-facilitated activation of reward circuitry effectively regulates negative emotion in adolescence can help demonstrate how peer-focused interventions could be utilized to support positive emotional development in this age group, ultimately promoting well-being across the lifespan.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This work was supported by grants from the American Psychological Foundation to Dr. Jennifer Silvers (Sparks Early Career Grant) and Razia Sahi (COGDOP Graduate Student Scholarship), as well as funds from the UCLA Academic Senate and the Bernice Wenzel and Wendell Jeffrey Term Chair in Developmental Neuroscience at UCLA to Dr. Jennifer Silvers.

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