The development, expression and neural basis of frustration in adolescence

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Thesis submitted in fulfilment of the degree of

Doctor of Philosophy

January 2020

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Declaration of Authorship

I, Rachael Anne Lickley, hereby declare that this work was carried out in accordance with the Regulations of the University of London. I declare that this submission is my own work, and to the best of my knowledge does not represent the work of others, published or unpublished, except where duly acknowledged in the text. No part of this thesis has been submitted for a higher degree at another university or institution.

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Abstract

Frustration is the affective response to the thwarting of one's goals and is one of the antecedent processes to reactive aggression. Yet, little is known about how frustration develops, is expressed or its neural bases. This is particularly lacking in relation to adolescence, a period of ongoing affective and neural development characterised by comparatively high levels of reactive aggression. This thesis therefore aimed to a) understand the development of the frustration response across adolescence at behavioural and neural levels, and b) explore whether individual differences in the frustration response are related to individual differences in reactive aggression during adolescence. In Chapter 2 an age-appropriate frustration paradigm was developed and validated that induced and parametrically modulated the frustration response. In Chapter 3, individual differences in overt reactive aggression (measured via grip force) and the frustration response in adults was explored. Aggressive responding parametrically increased in the same direction as the frustration response, but the two were not significantly correlated. In Chapter 4, age and trait-like reactive aggression was investigated in a sample of 11-16 year- olds. The frustration response did not vary with age but was positively related to trait-like reactive aggression. In Chapter 5, the neural bases of frustration were explored in a sample of 11-18 year olds. The frustration response was characterised by increased activation in regions associated with emotional reactivity, modulation of emotional responses and reactive aggression, including the cingulate cortex and anterior insula. Further, amygdala activation was negatively related to age, while anterior cingulate cortex activation was positively related to trait-like reactive aggression in response to increasing frustration. Results

are discussed in terms of current theories of adolescent neurocognitive development, with findings across the thesis suggesting that individual differences in the frustration response vary only marginally with age, but more strongly with trait-like reactive aggression.

Acknowledgements

First and foremost, I want to thank my two wonderful supervisors, Dr. Catherine Sebastian and Dr. Gary Lewis. To Cat, I would not have gone on this journey with anybody else, and I thank you for believing in me to be part of this wonderful project. To Gary, I will always be grateful for your excellent advice and your fascinating tangents. My thanks go to you both for the endless support and opportunities you have given me throughout this process.

I also want to thank my cohort of PhD students – it has been hard work but was made so much easier having such an amazing group of people around to support (and moan to) each other. In particular, I want to thank David Morgan for lifting me out of myself and getting me to that office in those first 6 months when I thought I would never make it through. You genuinely changed my life for the better and I'll be forever grateful you spoke to me in those first few months. I am so proud of you and everything you achieved, and that I can call you one of my dearest friends. I also want to thank Craig Arnold for being such a huge help and having such patience in teaching me to code my experiments and talking through statistics. This PhD would have lasted a lot longer if you weren't around to share your infinite wisdom, time and kindness.

Finally, I want to thank my family from the bottom of my heart for supporting me along this journey. Devin, you have been my rock and I don't think I would be where I am today without you always being there to encourage me and hold me up when I couldn't hold myself any longer. And to my two beautiful parents, of whom I am so immensely proud. For your unconditional love, for always encouraging me to be curious, and for always making sure myself and my brother could chase our dreams, I love you.

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Glossary and Abbreviations

Brain Regions	
PAG	Periaqueductal gray
PFC	Prefrontal cortex
OFC	Orbitofrontal cortex
vmPFC	Ventromedial prefrontal cortex
dlPFC	Dorsolateral prefrontal cortex
ACC	Anterior cingulate cortex
rACC	Rostral anterior cingulate cortex
mPFC	Medial prefrontal cortex
vlPFC	Ventrolateral prefrontal cortex
dACC	Dorsal anterior cingulate cortex
PCC	Posterior cingulate cortex
vPFC	Ventral prefrontal cortex
MCC	Mid cingulate cortex
Clinical Groups	
DBD	Disruptive behaviour disorders
CP	Conduct problems
CD	Conduct disorder
CU	Callous-unemotional traits
CP/HCU	Conduct problems with high levels of callous unemotional traits
CP/LCU	Conduct problems with low levels of callous unemotional traits

Questionnaire Measures	
FDS	Frustration Discomfort Scale
RPQ	Reactive Proactive Aggression
STARS	Situational Triggers of Aggressive Responses Scale
PDS	Pubertal Development Scale
FNR	Frustrative Non-Reward
Other	
SVC	Small volume corrected
FWE	Family wise error corrected
ROI	Region of interest
RT	Reaction time

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Chapter 1: Introduction: Reactive aggression, frustration and adolescence

1.1 General introduction

Reactive aggression refers to aggressive behaviours in response to real or perceived threat, provocation or frustration, and is typically impulsive, immediate and directed toward the perceived perpetrator (Berkowitz, 1993). In line with the emergence of externalising and internalising behaviours (Kessler et al. 2005; NHS, 2017), reactive aggressive behaviours typically emerge for the first time or escalate during adolescence (developmentally normative early childhood aggression notwithstanding; Moffitt, 1993; Raine et al. 2006). Notably, reactive aggressive behaviours have significant potential for long-term socio-legal consequences for both perpetrator and victims (Erskine et al., 2014). Interestingly, reactive aggressive behaviours also desist in early adulthood, suggesting there may be something special about the adolescent developmental period that confers a risk to developing these maladaptive behaviours. Yet, there is a paucity of research into the antecedent processes of reactive aggression, such as frustration, and how the frustration process may interact with adolescence, to explain why some individuals are more vulnerable to developing problematic externalising behaviours such as reactive aggression. This thesis aims to address these questions.

This literature review will provide an overview of existing research in reactive aggression, including current theories of aggression, the neural bases of reactive aggression and adolescent vulnerability to clinically relevant reactive aggression. It will then explore the extant research on frustration, starting with key definitions and conceptualisations, followed by a review of the human behavioural research on frustration and the likelihood of frustration resulting in reactive aggression. It will then explore the neuroimaging data relating to frustration in adult, developmental and clinical populations to try and identify a neural basis of the frustration process, and why this may present a precursor to reactive aggression. Based on the literature presented, this review will also identify key questions that will be addressed in the thesis and provide a summary of the methodological approaches undertaken.

1.2 Reactive aggression

1.2.1 Theoretical frameworks

Reactive aggression occurs, by definition, in the absence of pre-planned intention. This is in contrast to proactive aggression, which is typically goal-directed or instrumental in nature (Dodge & Coie, 1987). The key difference between these two functions of aggression are the underlying motivations (Card & Little, 2006). Reactive aggression is primarily defensive or 'hot-headed' whereas proactive aggression is often used as a means to an end. This defensive aggression is thought to rely on a separable neural network from that of predatory aggression, which has been more strongly associated with proactive aggression (Haller, 2017). There are also key differences in the cognitive processes underpinning reactive and proactive aggression; reactive aggression is notably characterised by emotional hyper-reactivity, emotional dysregulation and poor executive control (Atkins, Stoff, Osborne & Brown, 1993; Raine et al. 2006), whereas proactive aggression is more strongly associated with callous-unemotional traits characterised by lack of empathy, guilt, and shallow affect (Frick & Viding, 2009). In individuals displaying high levels of aggression, a significant proportion display primarily reactive aggression. However, for individuals who display high levels of proactive aggression this usually co-occurs with high levels of reactive aggression and this subset of individuals typically displays more severe levels of aggression overall than the reactive aggression only subset (Marsee et al. 2014).

Typically, reactive aggression is referred to as a maladaptive behaviour but it is worth noting that it could at times be adaptive, e.g. for defence, the preservation of resources or in response to attacks on social status when mate selection is particularly important (Bennet, 2017). From this perspective, reactive aggression may have evolved as an adaptive response to threats. On the other hand, research suggests that humans have evolved with a relatively low propensity for reactive aggression similar to Bonobos, but a high propensity for proactive aggression compared to Bonobos (Wrangham, 2018). As humans evolved as a social group, high levels of reactive aggression may have been less preferable as it signals low co-operation, whereas high levels of proactive aggression may signal successful negotiation and societal gains when proactive aggression is combined with social competence. This would be consistent with the theory that human evolution was based on a 'selection of the friendliest', where mates were chosen for their prosociality (Hare, 2017) and high status mates were defined by their social prestige and ability to negotiate and form coalitions (Wrangham, 2018). As such, for the purposes of the thesis reactive aggression will be referred to as a maladaptive behaviour. Specifically, this thesis will focus on physical forms of reactive aggression, though social/relational forms do exist, e.g. harming one's relationships through spreading rumours.

Several theoretical models have been put forward to explain reactive aggression. Behavioural models of aggression such as the General Aggression Model (Anderson & Bushman, 2002; see also Allen, Anderson, & Bushman, 2018) and the I³ ('I-cubed') model (Finkel & Hall, 2018; Finkel & Slotter, 2009; Slotter & Finkel, 2011) provide theoretical frameworks for studying aggression and can be used as a guide to interpret the literature, test specific models of aggression, and allow for research into the antecedent processes of reactive aggression. These models aim to account for individual differences in susceptibility to reactive aggression by taking into account a multitude of different factors which may increase or decrease the likelihood of a reactive aggressive response.

The General Aggression Model (Allen, Anderson & Bushman, 2018; Anderson & Bushman, 2002; see Figure 1), for example, considers the roles of both proximal factors, e.g. person-related and situational factors that may influence single episodes of aggression, and distal factors, e.g. environmental or biological factors working in the background to influence personality. Proximal factors include social, cognitive, biological, developmental and environmental factors. Person-related factors refer to individual differences in traits, e.g. trait anger, cognitive biases such as the hostile attribution bias, and impaired executive functions such as inhibitory control. Situational factors on the other hand refer mostly to environmental factors and include components such as frustration, provocation, social stress and social rejection. Each of these component factors are considered *modifiers* of the likelihood of an aggressive response, as they interact with cognitive and affective processes such as affect appraisal and decision-making. The disruption to one's cognition and affect by proximal factors influences whether the outcome is aggressive or non-aggressive. Through repeated exposure, these factors begin to form knowledge structures of situation-responses, which in turn build aggressive (or non-aggressive) 'personalities'. The formed knowledge structures, aggressive personalities and related schema then become the distal factors that work in the background of each episode of aggression, providing a distal influence. For example, consider a situation where individual A is purposefully bumped by individual B walking down the street (provoking situational factor). Individual A has high trait anger (proximal person-related factor) which, combined with the provocation, leads to an affectively charged internal state. Thus, individual A responds aggressively. A few weeks later, individual A is bumped by individual C, but this time it is apparent that this was accidental. However, individual A's previous experience that this was done intentionally (distal factor) and their high trait anger (proximal person-related factor) interact to influence the way individual A interprets the new bump to be negatively intended (cognition and appraisal), therefore individual A again responds aggressively.

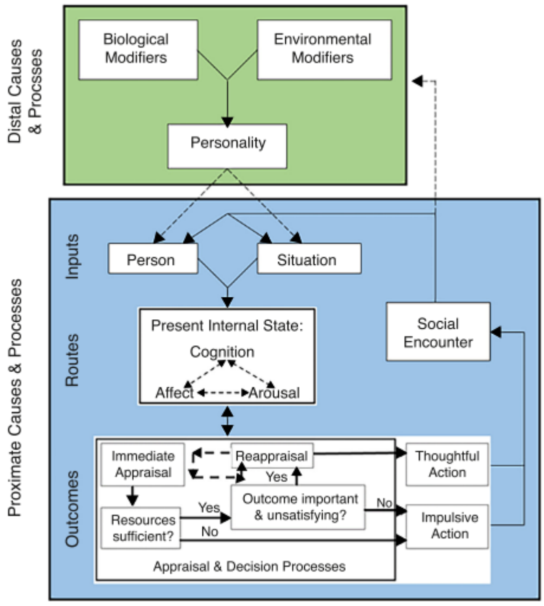


Figure 1. General Aggression Model displaying the interaction between proximal and distal factors and how they interact with cognition, affect and appraisal to result in an aggressive or non-aggressive outcome. From Allen, Anderson & Bushman (2018). *With permission for reuse from Elsevier.*

Similarly, the I³ theory (Finkel & Hall, 2018; Slotter & Finkel, 2011) does not focus on one 'root' cause of aggression but on the interaction of a number of influencing factors. The I³ theory provides an organisational model of aggression whereby the likelihood of an aggressive response is determined by the net value of three interacting stages: Instigation, Impellence and Inhibition. The first and only necessary stage is Instigation, and this refers to situations or circumstances which may trigger an aggressive *impulse*, e.g. goal-obstruction or peer-rejection. Once an aggressive impulse has been instantiated, the strength of one's proclivity to aggress may be increased by Impellence factors or decreased by Inhibition factors. Impellence factors include both person-related and situational factors much the same at the GAM, such as personality, attitudes, beliefs, temperature and pain. Inhibition factors on the other hand include executive functioning such as inhibitory control and frontal lobe function, as well as social norms, which may serve to override the proclivity to aggress. The I^3 model posits that the balance of these three factors determines whether or not an aggressive act will occur (Figure 2; see also the highly-related Perfect Storm Theory, Finkel, 2014).

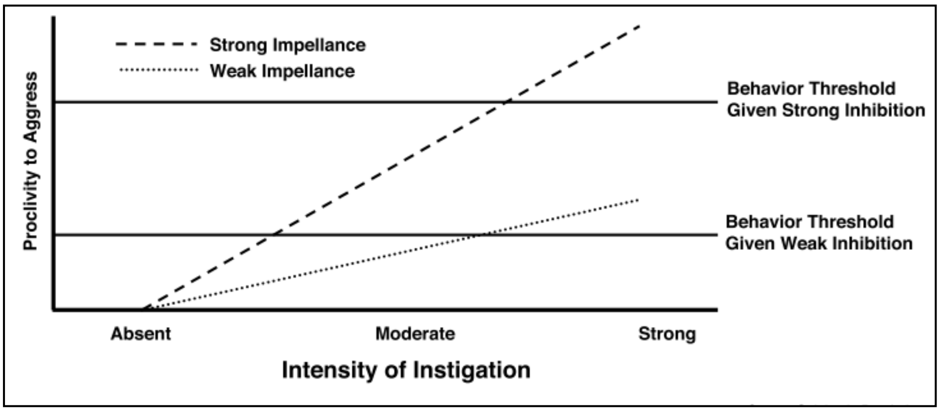


Figure 2. I^3 Model of aggression: Proclivity to aggress (y-axis) is determined by the net strength of the interaction between Instigating (x-axis) and Impellence factors. Aggressive behaviour only manifests when the strength of proclivity to aggress exceeds the strength of Inhibition factors, shown here as the behaviour thresholds. From Finkel & Hall (2018). *With permission for reuse from Elsevier.*

Both models provide a detailed framework of factors at multiple levels of analysis (e.g. social, cognitive, and biological) which may interact to culminate in an aggressive response. In addition, the I^3 model makes an important distinction between factors related to *risk* for an aggressive response (e.g. trait narcissism or hostile rumination) and those related to *resilience* (e.g. inhibitory control ability). However, as noted by the authors (e.g. Finkel & Hall, 2018), these models of aggression currently constitute 'meta-theories', i.e. general-purpose frameworks laying down a foundation of 'true assumptions' as opposed to falsifiable propositions. Moreover, while these theories acknowledge the importance of both development and the neurobiological underpinnings of aggressive behaviour, specific models incorporating the development of reactive aggression over time are currently lacking. According to the prominent neuroconstructivist approach to developmental disorders (Dekker & Karmiloff-Smith, 2011; Karmiloff-Smith, 1998) and the related 'causal model' of developmental disorders (Morton & Frith, 1995), atypical behaviour should be understood as arising from an interplay between genes, environment, brain, cognition and behaviour over developmental time. Applied to reactive aggression, it could be argued that it is important to understand the context in which aggression-relevant cognitive processes, e.g. emotional reactivity and (dys)regulation, are developing. As such, these models cannot currently comprehensively account for the emergence of reactive aggressive behaviours over development in young people at risk of anti-social outcomes. In the next section, the neural circuitry involved in the elicitation and regulation of reactive aggressive responding will be reviewed, before discussing this circuitry in relation to typical and atypical development of reactive aggression.

1.2.2 Neural bases of reactive aggression

Animal studies have provided a useful basis for studying the neural underpinnings of reactive aggression and have converged to identify a network of brain regions implicated in aggression known as the 'aggression network' (Panksepp, 2005). The aggression network is primarily located in the limbic system, one of the oldest brain systems evolutionarily, and prefrontal cortex areas. Much of this research has been done using lesion studies in rodents and non-human primates (see Bartholow, 2018; Nelson & Trainor, 2007 for comprehensive reviews). In adult male rodents, lesions to the anterior hypothalamus (Kruk, 1991) and medial amygdala (Vochteloo & Koolhaas, 1987) resulted in reduced aggression, with similar effects also found in non-human primates (e.g. hypothalamus lesions, Lloyd & Dixson, 1988). In contrast, electrical stimulation of the anterior hypothalamus (Kruk, 1991; Kruk et al., 1984) and amygdala (Potegal, Hebert, DeCoster, & Meyerhoff, 1996) in male rodents, and of the ventromedial hypothalamus in non-human primates (Lipp & Hunsperger, 1978), resulted in an increase in the number of species-specific aggressive behaviours, e.g. vocal displays of dominance in primates. Furthermore, electrical stimulation of the anterior hypothalamus or periaqueductal gray (PAG) in cats induced defensive rage behaviours that mirrored naturally elicited behaviours exhibited in response to threat (Siegal, Roeling, Gregg, & Kruk, 1999). This suggests that these regions are crucial for the aggression response.

Animal studies have also implicated regions of the prefrontal (PFC) and orbitofrontal (OFC) cortex in the aggression network, largely in a regulatory capacity. For example, lesions to the OFC in male rats and dominant rhesus monkeys resulted in increased aggression (De Bruin, Van Oyen, & Van De Poll, 1983; Machado & Bachevalier, 2006), suggesting these regions may regulate aggression via inhibitory control function.

Human lesion and brain injury studies have found largely similar results to those in the animal literature. For example, a study of temporal lobe epilepsy within a focal region of the amygdala/peri-amygdala, and associated with aggressive outbursts during seizures, found a decrease in aggressive symptoms following an amygdalectomy (removal of the amygdala) in three out of four cases (Hood, Siegfried & Wieser, 1983; see Siegal & Victoroff, 2009 for a review on the neuroscience of aggression). Lesions to the OFC in humans have been associated with high levels of reactive aggression in individuals identified as having 'acquired sociopathy' (e.g. Blair, 2001). Case studies of patients with OFC lesions have also reported explosive and impulsive aggressive outbursts (Anderson, Bechara, Damasio, Tranel & Damasio, 1999; Blair & Cipolotti, 2000). Likewise, a review of the frontal brain injury literature found that brain injury to focal OFC was specifically associated with increased levels of aggression compared to other areas of frontal brain injury (Brower & Price, 2001). Additionally, lesions to the adjacent ventromedial prefrontal cortex (vmPFC) was associated with increased aggressive behaviours in veterans compared to veterans with lesions to other regions and healthy controls (Grafman et al., 1996). Increased aggression occurring post-removal or following damage to the OFC and vmPFC therefore suggests these areas regulate aggressive responding, such that greater activation in areas such as the OFC and vmPFC would more strongly suppress an aggressive response (Davidson, Putnam & Larson, 2000).

Within functional human neuroimaging there has been some converging evidence to that found across animal models of aggression and human lesion studies. In line with the animal literature on threat and reactive aggression (e.g. Potegal et al., 1996), threat paradigms used in human neuroimaging, e.g. viewing of stimuli signalling threat such as fearful faces, or threat-induction via fear-conditioning, have found increased activity in the amygdala (Morris et al., 1996; Whalen et al., 1998; Buchel, Morris, Dolan & Friston, 1998). For example, adults display hyper-responsivity of the amygdala when viewing negatively valenced or threatening images, e.g. angry faces compared to neutral faces (Nomura et al., 2004), and this hyper-responsivity is exaggerated in individuals with clinical diagnoses characterised by heightened levels of dispositional reactive aggression, for example in individuals with Intermittent Explosive Disorder compared to healthy controls when viewing angry faces compared to rest (Coccaro, McCloskey, Fitzgerald & Phan, 2007). In contrast, a meta-analysis of fMRI studies using emotional face viewing paradigms in typical individuals found that angry faces compared to a baseline fixation cross had no significant effect on the amygdala (Fusar-Poli et al., 2009). Though not strongly implicated in animal models of aggression, human neuroimaging studies have also found increased responsivity of the insula when viewing angry faces compared to a baseline fixation cross (Fusar-Poli et al., 2009), suggesting the insula may also play a role in reactive aggression.

The amygdala (implicated in animal and human studies) and the insula (implicated in human imaging studies) both form part of the limbic system. The limbic system has been heavily implicated in emotion processing (Rajagopalan et al. 2017; Rolls, 2015), with the amygdala particularly responsible for threat and salience processing (Adolphs, 2008), while the insula has been implicated in emotional responding via, for example, managing the cognitive resources needed to effectively respond to salient events (Fanning, Keedy, Berman, Lee & Coccaro, 2017; Menon & Uddin, 2010). Both salience processing and emotional responding are processes involved during instances of reactive aggression, e.g. evaluating threat, provocation or frustration and responding accordingly.

In addition, neuroimaging studies within typically developing adults find increased activity in the dorsolateral PFC during threat (dlPFC; viewing fearful faces compared to neutral faces; Schienle et al., 2002), but that recruitment of the OFC is attenuated in individuals with high levels of dispositional reactive aggression compared to healthy controls (Coccaro et al., 2007). These results suggest that both the dlPFC and OFC regions of the PFC are relevant for modulating emotional responding, e.g. by downregulating the reactivity of the amygdala and other limbic areas (Blair, 2004).

Aggressive responding therefore appears to depend on limbic areas, namely the amygdala, hypothalamus, PAG and insula (e.g. Panksepp, 2005), with prefrontal regions (primarily OFC and vmPFC) playing a largely regulatory role. The 'fight' response is thought to be in part mediated by the brainstem threat system (Bartholow, 2018; Blair, 2001) interacting with top-down control mediated by prefrontal cortex (Davidson et al., 2000). Relatedly, the PAG may act as a possible interface between the emotional reactivity (limbic) and emotion regulation (PFC) regions via functional and structural connections (Benarroch, 2012).

However, human reactive aggression is a complex phenomenon that can be elicited by several antecedent triggers, broadly conceptualised as threat, provocation and frustration (Gilam & Hendler, 2015). While the behaviour elicited (e.g. hitting) may appear similar across contexts, the underlying neurocognitive processes and subjective experiences likely differ. Indeed, constructionist conceptions of emotion (e.g. Lindquist & Feldman Barrett 2012; Feldman Barrett, 2017) posit that specific emotional experiences are constructed from brain networks that encode a set of more basic operations, e.g. internal and external sensations, knowledge based on past experience, and understanding of the current context. It therefore makes sense to consider how superficially similar reactive aggressive responses can arise as a consequence of differing triggers and underlying networks.

While the studies above have largely focused on threat as the trigger for aggression, provocation refers to the incitement of an individual to aggress, and is usually tested in experimental tasks through unfair treatment such as opponents 'stealing' earned points from the participant (e.g. point-subtraction aggression paradigm, Cherek, Moeller, Schnapp & Dougherty, 1997) or unfair monetary 'punishments' from opponents (e.g. Taylor Aggression Paradigm, Taylor, 1967). For example, the Taylor Aggression Paradigm is disguised as a reaction time competition between the participant and a virtual opponent. In each trial, the participant sets the level of punishment to be delivered to the opponent should they win, i.e. have a quicker reaction time than their opponent. However, should they lose, i.e. their reaction times be slower than their opponent, the participant would receive the punishment at the threshold set by their opponent. In reality, the punishment delivered by the 'opponent' is pre-determined to manipulate the level of provocation induced by altering the degree of unfairness in the opponent's punishments; high provocation opponents will consistently apply very unfair punishments while low provocation opponents will consistently apply less unfair punishments. The advantage of using these paradigms in studying reactive aggression is that they allow participants to make a measurable aggressive response, operationalised as the severity of the punishment delivered by the participant to the opponent. As such, both the antecedent provocation phase and the resulting aggressive response can be measured independently of each other.

Neuroimaging studies of adult samples have found both overlapping and distinct neural activations during the provocation and aggression segments of the paradigms (Krämer, Jansma, Tempelmann & Münte, 2008; Pincham, Wu, Killikelly, Vuillier & Fearon, 2015; Repple et al., 2017), suggesting the neural activation of the antecedent process (provocation) may be preparing the individual for an aggressive response (Repple et al., 2017). For example, Repple et al., (2017) used the Taylor Aggression Paradigm in healthy adults, with participants able to take anything from 10 to 100 cents from their opponent as a punishment. Behaviourally, participants chose a more severe punishment for the high-provocation opponent compared to the low-provocation opponent. During the provocation stage, high compared to low provocations revealed increased activation in the rostral anterior cingulate cortex (rACC), medial PFC (mPFC) and thalamus. During the aggression stage however, high versus low provocation comparisons revealed increased activity in rACC, mPFC and OFC, insular cortex, dorsolateral PFC and ventrolateral PFC (vlPFC). The ACC may serve as an 'alarm system' that will recruit self-control areas of the PFC including the OFC and dlPFC (Denson et al. 2012). Both dlPFC and vlPFC are associated with control and management of cognitive processes, (Levy & Wagner, 2011; Elliot, 2003), suggesting an increased recruitment of regulatory regions during the aggression stage, although this was not tested directly. Similarly, in a version of the point-subtraction aggression paradigm, violent-offenders compared to non-offending controls chose an aggressive response (stealing an opponent's point) twice as often (da Cunha-Bang et al., 2017). At the neural level, violent offenders compared to non-offending controls showed increased activation in the amygdala and striatum (salience and reward areas) and decreased amygdala-prefrontal and striatal-prefrontal connectivity during provocation (when they had points stolen from them). The authors conclude that violent offenders had greater behavioural and neural sensitivity to provocation. That individuals with clinically significant levels of reactive aggression, i.e. offenders, show diminished prefrontal engagement during aggression extends previous findings (e.g. Repple et al. 2017) of the engagement of prefrontal regions to exert regulatory control in response to provocation.

Together, these studies provide the basis for a neural model of reactive aggression, encompassing both the antecedent (trigger) processes and the resulting aggressive response. Research identifies an 'aggression network' comprising limbic (amygdala, hypothalamus, insula, ACC and periaqueductal gray; e.g. Panksepp, 2005) and PFC regions (e.g. OFC and vmPFC; Davidson et al., 2000). However, this 'aggression network' is based on adult studies so may not be representative of the functioning of the developing adolescent brain. As such, the neural model of aggression shares the same limitations as the behavioural models, i.e. not accounting for the neural bases of reactive aggression studied over developmental time. The following section will highlight the typical developmental trajectories of reactive aggression, focusing on adolescence, and discuss the structural and functional maturation of the neural circuitry underpinning these processes during adolescence.

1.2.3 Typical development of reactive aggression

Epidemiological and developmental data show a peak in antisocial behaviours during adolescence, such as is demonstrated by the age-crime curve (Blumstein, Cohen, Roth & Visher, 1986). The age-crime curve maps the incidence of crime and shows onset to be typically around 10 years of age, peaking between 15-20 years before decreasing in a stepwise manner from then on. As data also suggest that the majority of these behaviours are impulsive or reactive in nature (Raine et al., 2006), this provides a useful avenue to explore the development of reactive aggressive behaviours from a related prospective.

Longitudinal data suggest that antisocial behaviours are carried out by a minority of individuals (Barker, Tremblay, Nagin, Vitaro, & Lacourse, 2006; Moffitt, 1993; Moffit, Caspi, Dickson, Silva & Stanton, 1996). In a longitudinal sample of boys followed from 13-17 years, Barker et al. found that the majority showed infrequent and desisting levels of reactive aggression, but a significant proportion were found to have peaking levels of reactive aggression around mid-adolescence, and this pattern was observed at both moderate (40.8%) and severe (6.6%) levels of reactive aggression. Additionally, in the influential dual taxonomy model, Moffitt (1993; Moffitt et al., 1996) found that around ~25-32% of all adolescents engage in antisocial behaviours. Of this group, Moffitt reported an average age of onset of aggression between 11-14 years, with aggressive behaviours peaking between 15-19 years and finally decreasing between 20-29 years (1993, 2018), demonstrating the increased prevalence of antisocial behaviours during adolescence, subsequently labelling these individuals the adolescent-onset or adolescent-limited group. Notably, individuals on this trajectory were primarily engaged in reactive aggressive behaviours (Frick, Kimonis, Dandreaux & Farrell, 2003). In comparison, ~5-10% of all children engaged in antisocial behaviours were subsequently labelled as the child-onset or life-course persistent groups, as these individuals show high levels of antisocial behaviour and both reactive and proactive aggression that remains stable across the lifespan. One factor that is consistent across these studies is that the adolescent period seems to be important for increasing levels of externalising behaviours.

Other longitudinal studies have since replicated similar patterns of increase across several antisocial behaviour domains. For example, Martino, Ellickson, Klein, McCaffrey and Edelen (2008) investigated trajectories of physical aggression across 7th – 11th Graders (~12-17 years) and found ~40% of their sample followed this adolescent peaking trajectory (23.15% adolescent-onset & 17.23% high persisters; note the probability of engaging in physical aggression was lower at all time points for the adolescent-onset group than the high persisters, and the high persisters group showed generally high levels of antisocial behaviour but these also peaked during mid-late adolescence). The remaining sample were categorised as low/non-aggressors (37.33%) and desisting aggressors (22.29%; see Figure 4). Similarly, a meta-review of 105 studies exploring the developmental trajectories of violence, aggression and/or delinquency found that every study reviewed identified at least one trajectory demonstrating an adolescent-onset trajectory characterised by an increase in aggressive/antisocial behaviours during adolescence which desisted in early adulthood (Jennings & Reingle, 2012). However, not all studies have found an increase in physical aggression during adolescence. For example, a longitudinal study by van Lier et al. (2009) found that across a sample of 10-15 year olds there was a general decline in physical aggression occurring in parallel with an increase in other types of aggression, specifically theft and alcohol-drug use, and an increase in vandalism for individuals on the high profile trajectory. This may be for a number of reasons, including increasing cognitive and verbal abilities (Bjoerkqvist, Lagerspetz, & Kaukiainen, 1992) and peer pressure to inhibit aggressive responding or tantrum like behaviours (Vitaro, Brendgen & Barker, 2006).

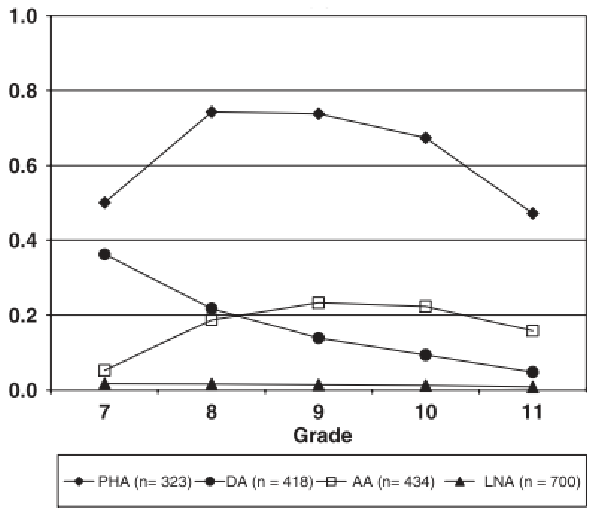


Figure 4. Model-predicted trajectories of physical aggression from Grade 7 through Grade 11 showing estimated probability of both familial and non-familial physical aggression in the past year for each trajectory class (PHA=persistent high aggressor; DA=desisting aggressor; AA=adolescent aggression; LNA=low/no aggression). From Martino et al. 2008. *Permission for reuse from Wiley*.

Together these studies highlight a consistent pattern of increasing reactive aggression in a significant minority of adolescents that returns to 'baseline' or normative levels towards early adulthood. This pattern has been found across various sample compositions and geographical locations (though physical aggression appears to decrease in some adolescents for a number of reasons). Despite age-related general cognitive development perhaps pushing towards a desistence in reactive aggression, that there remains a significant subset of adolescents robustly displaying increasing patterns of physical reactive aggression (at often clinically or legally relevant levels), suggests that the adolescent developmental period may be a particularly interesting time to study reactive aggression. Could there be developmental mechanisms operating across the entire spectrum of adolescence that could be contributing to this pattern? This next section explores the adolescent developmental period in more detail and how it may contribute to our understanding of the concentration of aggression during adolescence.

1.2.4 Adolescence

Adolescence refers to a specific period of development between childhood and adulthood roughly spanning the ages of 11-24 (Sawyer, Azzopardi, Wickremarathne & Patton, 2018), beginning with the onset of puberty until the adoption of a consistent and stable adult role (Damon, 2004). Stereotypically, adolescence is referred to as a time of 'storm and stress' characterised by increased mood volatility (e.g. Larson, Moneta, Richards, & Wilson, 2002), sensation seeking and risk-taking (Romer & Hennessy, 2007; Steinberg, 2008). Adolescence is also characterised by behavioural, cognitive and physical change; shifting social focus from family to peers, a greater need for independence, and increased social pressures (Spear, 2000). For example, adolescents in comparison to adults and children appear to be hypersensitive to peer-pressure and peer-rejection (Sebastian, Viding, Williams & Blakemore, 2010; Kloep, 1999).

Evidence from structural and functional neuroimaging also suggests that adolescence might be a key time for neurocognitive maturation of circuitry relevant for reactive aggression, for example regions underlying emotional reactivity, emotion regulation, decision-making and social cognition (e.g. Blakemore & Mills, 2014; Crone & Dahl, 2012). The identification of distinct developmental trajectories of brain regions underlying 'reactivity' and 'regulation' (broadly defined) has led some researchers to conclude that adolescence represents a period of 'developmental mismatch' or 'imbalance' (e.g. Steinberg, 2008; Casey, Getz & Galvan, 2008). While evolutionarily older regions of the brain such as those in the limbic system (e.g. amygdala, striatum) undergo rapid, broadly linear development and are thought to reach maturity during adolescence (Romer, Renya & Satterthwaite, 2017), some regions within prefrontal and temporal cortices do not fully mature until late adolescence or early twenties (Gogtay et al., 2004). As such, increases in emotional reactivity, sensation-seeking and emotional lability driven by the maturation of limbic regions and the concomitant remodelling of dopaminergic circuitry (Nelson, Jarcho, & Guyer, 2016; Nelson, Leibenluft, McClure, & Pine, 2005; Telzer, 2016) may not yet be paralleled by efficient regulatory circuitry. Complementing this theory, amygdala volume increases across adolescence (Schumann et al., 2004), and Scherf et al. (2013) suggest that maturation of the amygdala and its connections drives a reorganisation of neural networks involved in social processing. Tracing studies in rats, for example, have found bottom-up amygdala-PFC projections to emerge earlier than the inverse top-down PFC-amygdala projections (Bouwmeester, Smits & van Ree, 2002a; Bouwmeester, Wolterink & Ree, 2000b). Therefore, adolescence could be considered a time of risk for reactive aggression due to the overall state of flux in the developing brain, e.g. both poor regulation of negative emotion in response to perceived threat or frustration and a lower threshold for impulsive aggression in the context of peer group influence. On the other hand, adolescence is also a time of increasing maturity, e.g. age-related improvements in self-regulation, emotion regulation and peer pressure to inhibit aggressive responding or tantrum-like behaviours in line with social norms (Vitaro et al. 2006), as evidenced by the decreasing levels of reactive aggression in late adolescence/early adulthood (e.g. Moffitt, 1993; Jennings & Reingle, 2012).

While the majority of typically developing adolescents do not exhibit clinically meaningful aggression (see Vitaro et al., 2006 for a review of normative trajectories of aggression; see also Barker et al., 2006), one interpretation in line with mismatch and related theories of adolescent brain development is that the increase in reactive aggressive behaviours seen during adolescence in some individuals reflects a phase of normative neurocognitive development and social maturation. Moffitt (2018) suggests that the increasing need for autonomy during adolescence, while not being afforded it by people in authority, e.g. parents, creates a maturity gap in which adolescents turn to older peers and emulate peer behaviours to attain independent social status, often characterised by risky or delinquent behaviours. As such, developmental shifts in typical adolescent behaviours reflecting these processes might be expected across the full spectrum of individual differences, i.e. some behavioural or affective change would be measurable even in temperamentally calm individuals. Clinically significant reactive aggression would therefore reflect an exaggeration of normative neurocognitive development and behaviours (Moffitt, 2003). Alternatively, (though these models are not entirely mutually exclusive), normative maturational processes may confer a window of increased vulnerability (Steinberg, 2005), that would only have overt behavioural or affective consequences for a minority depending on interaction with the presence of additional risk and resilience factors. Either way, it is important to consider both normative neurocognitive developmental trajectories and individual differences that might confer clinical risk in order to formulate a model of adolescent reactive aggression.

Indeed, most theories of clinically significant reactive aggression implicate processes that overlap with those still developing in adolescence. It has been suggested, for example, to result from: heightened reactivity to frustration (Hubbard et al., 2002); hypersensitivity to affective arousal (Gatzke-Kopp et al., 2015); and/or impaired emotion regulation capacities, particularly when dealing with negative or aversive emotions (Shields & Cicchetti, 1998). Relatedly, Gatzke-Kopp et al. (2015) suggest this hypersensitivity to affective arousal may directly compete with resources allocated to emotion regulation, inhibiting successful regulation of this heightened state and making an aggressive response more likely. The following sections will review the typical development of key neurocognitive processes subserving reactive aggression, specifically emotional reactivity and regulation.

1.2.4.1 Emotional reactivity

Emotional reactivity has been shown to increase during adolescence across multiple paradigms and brain regions (see Guyer, Silk & Nelson, 2016; Scherf et al., 2013 for comprehensive reviews). Of particular relevance to threat-related reactive aggression, Stroud et al. (2009) found increased reactivity in systems implicated in the fight, flight or freeze response (sympathetic system and hypothalamic-pituitary-amygdala axis) during a stressful task in 13-17 years olds compared with 9-12 year olds. This suggests a peak in reactivity of these systems during mid-adolescence (Dahl & Gunnar, 2009), although it should be noted that an adult comparison group was not available. Self-report and experience-sampling studies have also shown a peak in frequency, volatility and intensity of emotional experiences during adolescence relative to childhood or adulthood (Guyer et al., 2016; Casey et al., 2010; Larson et al., 2002). At the neural level, fMRI studies have demonstrated that adolescents show greater amygdala activity in response to emotional stimuli, e.g. fearful, happy and calm faces, relative to both children and adults (Hare et al., 2008). Similarly, increased reactivity to emotional faces has been demonstrated longitudinally at age 13 compared to age 10 in amygdala and ventral striatum (Pfeifer et al., 2011), with the magnitude of increased reactivity between age 10 and 13 found to positively correlate with pubertal status (Moore et al., 2012). Given the amygdala's role in processing socially and emotionally salient information (Adolphs, 2008), increased activity implies greater sensitivity or reactivity to emotional stimuli.

The ventral striatum is also implicated in heightened emotional reactivity in adolescence, with this brain region considered a key node in reward-related circuitry.

Hyper-reactivity in this area during adolescence may therefore contribute to increased risk-taking and sensation-seeking behaviours during this time (Luciana, Wahlstrom, Porter & Collins, 2012). For example, several fMRI studies have shown increased ventral striatum response in adolescents in risky but rewarding contexts such as during risky gambling, for example selecting high-risk rewards of a large value but small attainment probability (van Leijenhorst et al., 2010), and risk-taking in the presence of peers (Chein, Albert, O'Brien, Uckert & Steinberg, 2011). One interpretation of these data are in terms of mismatch theories, i.e. the increase in ventral striatum activity during adolescence coupled with poor regulatory control, drives the increase in risk-taking behaviours. However, alternative models have recently been proposed that allow for the impact of social factors (e.g. peer influence) and individual differences (e.g. in proclivity towards sensation-seeking, see Foulkes & Blakemore, 2018).

During adolescence, there is a greater emphasis on peer group interaction than at other points in the lifespan (Steinberg & Silverberg, 1986) and social rewards such as peer approval are particularly potent (Davey, Yücel & Allen, 2008). Similarly, social punishment such as rejection can have a profound negative effect in adolescents compared to adults, whereby adolescents displayed greater negative mood after social rejection (Sebastian et al., 2010) and showed attenuated activity within the vlPFC during exclusion (cyberball task; Sebastian, Tan, Roiser, Viding, Dumontheil & Blakemore, 2011). Increased sensitivity of ventral striatum and amygdala to social reward in adolescence (e.g. peer approval) may mean that the potential for social reward plays a disproportionate role when weighing up the costs and benefits of risk behaviours that typically play out in a social context (e.g. whether to drive recklessly, experiment with drugs, or take part in a fight; Blakemore & Mills, 2014). This idea of a cost-benefit analysis forms the basis of the Seesaw model (Blakemore & Mills, 2014) to understanding risky behaviours during adolescence. The Seesaw model posits that the evidenced increased sensitivity to peer rejection and peer approval during adolescence may 'reweight' or bias the weightings in favour of engaging in risky behaviours. That is, the potential social reward of peer approval and the aversion to peer rejection may disproportionately outweigh the potential costs of a risky behaviour during adolescence compared to other age groups, possibly as a result of the increased social and neurobiological changes during adolescence detailed above.

Another model, the Life-Span Wisdom Model (Romer et al., 2017) suggests that peaks in adolescent risk-taking occur predominantly in the context of sensation-seeking, i.e. exploration of novel stimuli where risk is ambiguous, as opposed to contexts where risk are fully known. For example, adolescents compared to adults engaged in more risky behaviours (gambling) only when under conditions of ambiguity (van den Bos & Hertwig, 2017; Lloyd and Döring, 2019) or uncertainty (van den Bos & Hertwig, 2017), but not when the risk is known. Under this model, the peak in sensation-seeking found across cultures in late adolescence (Steinberg et al., 2018) could be adaptive, driving adolescents to gain necessary life experience.

Irrespective of the prevailing model, the findings reviewed thus far with regard to emotional reactivity (increased reactivity on behavioural and self-report measures; increased amygdala and ventral striatum activity in response to socio-affective stimuli with age) have clear implications for the reactive aggression literature. Firstly, reactive aggression has been associated with greater emotional reactivity (Hubbard et al., 2002), e.g. greater skin conductance and heart rate responses to stressful stimuli in participants (7-8 year olds) with higher levels of teacher-reported reactive aggression (Hubbard et al., 2004). Secondly, striatal activity and the role of peer pressure seems particularly relevant; most antisocial behaviours and law-violating behaviours occur in groups for adolescent offenders, but not for adults (Sickmund, & Puzzanchera, 2014; Zimring et al., 1998).

1.2.4.2 Emotion regulation

Research also suggests an improvement in emotion regulation abilities during adolescence (see Ahmed et al., 2015 for a review). Behavioural studies have found increased ability to manage emotional experiences by selecting and implementing effective regulation strategies (Silvers et al., 2012), and to express emotions in socially appropriate ways (Cole, Michel & Teti, 1994). The neural underpinnings of emotion regulation also continue to develop during adolescence, in particular prefrontal engagement during regulation and connectivity with limbic regions (Sebastian et al., 2011; Gee et al., 2013). For example, using fMRI, Gee et al. (2013) found that mPFC-amygdala connectivity during an emotional face processing task became more strongly negative across ages 4-22 years, suggesting age-related improvement in prefrontal 'top-down' regulation, paralleled by improvements in task performance. Importantly, the authors found the connectivity between mPFC and amygdala switched around the onset of puberty, whereby connectivity was more strongly positive at 9 years and younger, suggesting bottom-up amygdala driven connectivity, but at 10 years and older connectivity was more strongly negative, suggesting top-down mPFC driven connectivity. Similar results have been found when participants are instructed to use a deliberate strategy such as cognitive reappraisal to downregulate negative affect in response to aversive images. For example, in a sample of 6-23 year olds, Silvers et al. (2017) found increasingly negative connectivity between amygdala and ventromedial PFC with age during reappraisal, as well as decreased negative affect. The relationship between age and amygdala response was additionally found to be mediated by left ventrolateral PFC response. These findings suggest that tighter negative coupling between prefrontal and limbic regions across the course of childhood and adolescence may serve to underpin improving emotion regulation abilities.

Looking more specifically at emotional reactivity and emotion regulation in reactive aggression in adolescents, existing studies using provocation paradigms suggest functional development in the ability to manage provocation, a known precursor to reactive aggression. Using a provocation paradigm with EEG in younger (10-12 years) and older (14-16 years) adolescent participants, Pincham et al. (2015) looked particularly at N2 (inhibitory control) and late positive potential (LLP) signals. LLP has been associated with limbic areas such as amygdala, as well as cingulate cortex and insula, and is thought to reflect emotional evaluations and the processing of arousing stimuli, e.g. larger amplitudes in response to more arousing stimuli (Bradley, Hamby, Löw & Lang, 2007). Behavioural results showed that both younger and older adolescents selected more severe punishments for the high-provocation opponent, i.e. the opponent who consistently 'punished' with the more severe aversive noise, than the low-provocation opponent. However, younger adolescents on average selected more severe punishments than the older adolescents, despite the level of unprovoked aggression being similar across ages, i.e. punishment selected prior to facing an opponent. During both the provocation and aggression phase, LLP activation was greater for the younger participants during high provocation only. Increased activity during high provocation for the younger participants could therefore indicate greater emotional reactivity in response to the provocation, consistent with more severe punishments selected by this group. Furthermore, LLP difference scores (difference in activation between low- and high-provocation opponents) were positively correlated with average punishment selection, suggesting a potential association between sensitivity to provocation and proclivity to aggress. N2 activity was also stronger for younger participants than older participants, but there were no effects of level of provocation found. N2 activity is associated with inhibitory control, suggesting potentially more inefficient recruitment of inhibitory mechanisms in the younger adolescents than the older adolescents.

Together, these findings suggest that regulatory control of provocation-induced negative affect is still developing during the adolescent period, with young and mid-adolescents requiring greater recruitment of regulatory mechanisms when they were provoked than older adolescents. However, individual differences in the LLP difference scores (Pincham et al., 2015) further suggest an important role for individual variability in the aggressive response chosen.

Overall, studies in typically developing adolescents suggest that the neurocognitive underpinnings of reactive aggression and its component processes continue to develop during this time. In line with developmental models (e.g. mismatch model and seesaw model), evidence suggests that increases in age-related cognitive functioning, such as emotion regulation and increasing peer pressure to inhibit reactive aggression, may explain the declining prevalence of reactive aggression over the course of adolescence (in all but a subset; Vitaro et al., 2006). In the following section, studies that seek to understand the neural underpinnings of adolescent reactive aggression by focusing on the extreme tail of the distribution, i.e. individuals exhibiting clinically significant levels of antisocial behaviour, such as Conduct Disorder (CD), Conduct Problems (CP) and Disruptive Behaviour Disorders (DBD) will be reviewed.

1.2.5 Atypical development

Conduct Disorder refers to a persistent pattern of antisocial and aggressive behaviours that violate social norms and the rights of others (DSM-5), and falls within the broader category of Disruptive Behavioural Disorders. Conduct disorders peak during adolescence (Frick and Viding, 2009), predominantly affect males (Maughan, Rowe, Messer, Goodman & Meltzer, 2004; Bongers, Koot, van der Ende & Verhulst, 2004) and entail a significant cost to public health and wider society (Romeo, Knapp & Scott, 2006). Prevalence is estimated at approximately ~4% of males globally (Global Burden of Disease Study 2010 sample; Erskine et al., 2013) and has been estimated to account for 5.75 million years living with disability globally (Erskine et al., 2014). Additionally, externalising behaviours (dominated by reactive, as opposed to proactive, aggression) feature transdiagnostically across conditions as diverse as ADHD, ODD, Borderline

Personality Disorder, Intermittent Explosive Disorder, anxiety and depression (Haller, 2017; Card & Little, 2006), and as such represent a significant public health concern.

Previous research investigating the neural bases of reactive aggression have found abnormal activations in regions subserving emotional reactivity and emotion regulation in adolescents with CP/CD/DBD relative to typically developing adolescents. However, contradictory findings have often been reported. For example, studies demonstrating abnormal emotional reactivity processing in CP youth compared to typically developing youth have found both hypo-activation (Passamonti et al., 2010) and hyper-activation (Herpertz et al., 2008; Sterzer, Stadler, Krebs, Kleinschmidt & Poustka, 2005) of the amygdala in response to threat such as fearful or angry faces. Regarding emotion regulation, Herpertz et al. (2008) found no differences in neural response to emotional faces between CD and control participants in regulatory regions of interest including OFC and ACC, suggesting no regulatory deficit. In comparison, relative to typically developing children, children with CP showed reduced P3b amplitude (reflecting inhibition) during a frustrating go/no-go task (Gatzke-Kopp et al., 2013). In addition, a recent meta-analysis (Alegria, Radua & Rubia, 2016) found CP individuals showed reduced activation within dmPFC during hot executive functioning tasks, e.g. decision-making in the presence of potential rewards; and within dlPFC during emotion processing tasks, e.g. viewing affective stimuli. These latter results suggest impaired emotion regulation, not consistent with the findings from Herpertz and colleagues (2008).

This mixed picture seen with regard to atypical affective processing in young people with conduct problems is likely at least in part driven by heterogeneity within the Conduct Disorder diagnostic category, which encompasses the full spectrum of aggressive behaviours (e.g. from reactive to proactive) and multiple aetiologies (Moffitt, Caspi, Harrington & Milne, 2002; Frick & Viding, 2009). To date very few studies have investigated the neural bases of affective processing specifically in young people with CP exhibiting primarily reactive aggressive behaviour. One approach to shedding light on this issue is to subtype adolescents with CP on the basis of callous-unemotional (CU) traits. CU traits are characterised by a lack of guilt and empathy, and a profile of shallow affect (Essau, Sasagawa & Frick, 2006). Children with CP and high levels of CU traits (CP/HCU) typically display high levels of proactive aggression (plus co-occurring reactive aggression; Card & Little, 2006), and exhibit hypo-reactive behavioural (Sharp, van Goozen & Goodyer, 2006) and neural (Lockwood et al., 2013) responses to affective stimuli. In contrast, those with CP and low levels of CU traits (CP/LCU) typically exhibit mainly reactive aggressive behaviour (Frick & Viding, 2009) coupled with behavioural and neural hyper-reactivity to affective stimuli (Sebastian et al., 2014) and impaired emotion regulation abilities (Frick & Morris, 2004). Understanding the neural bases of reactive aggression within this latter group therefore may shed light on the underlying causes of developing harmful reactive aggression.

Studies that have differentiated subgroups of adolescents with CP based on CU traits have found a more consistent pattern of results in CP/LCU (reactive) individuals, with heightened emotional reactivity in limbic regions, and impairments in PFC-mediated emotion regulation performance. For example, Sebastian et al. (2014) found increased responses in amygdala, subgenual ACC and OFC in CP/LCU relative to typically developing youth aged 10-16 when attention was specifically drawn to the most salient eye region of a fearful face by a requirement to locate a target stimulus. Reaction times to locate the target were also slower in this condition for CP/LCU youth, and the size of this RT interference was positively correlated with increased activation in the amygdala. This suggests amygdala hyper-reactivity to affective information may have functional relevance for behavioural performance. Amygdala hyper-reactivity in this group, relative to both control and CP/HCU groups, has also been found when fearful faces are presented 'pre-attentively' for only 17-ms and below the level of conscious awareness (Viding et al., 2012). This finding suggests that increased threat reactivity in adolescents with Conduct Problems and low levels of CU traits extends to the very earliest levels of threat processing. Moreover, these findings cannot be attributed to Conduct Problems per se, since a very different pattern of results was seen in CP/HCU. Comorbid ADHD and anxiety symptoms also could not explain the findings. Together, these studies suggest that hyper-reactivity of limbic regions in response to threat characterises adolescents exhibiting primarily reactive aggressive conduct problems.

Extending this approach beyond simple threat processing, White et al. (2016) compared groups of youth with DBD and either low or high CU traits and typically developing controls (10-18 years) using a provocation paradigm (Social Fairness Game). Participants were offered either a fair (i.e. equal) or varying levels of unfair (i.e. unequal) split of a $20 reward which they could either accept or reject. The most unfair splits of the reward represented high-provocation trials. Participants could also punish their opponent at a cost to the participant. Behaviourally, both fair (e.g. $10/$10) and extremely unfair offers (e.g. $18 to partner/$2 to participant) were equally as likely to be accepted or rejected respectively by all groups. However, DBD participants responded more severely to slightly unfair offers (e.g. $14/$6). fMRI results showed greater amygdala and PAG activity in DBD/LCU youth relative to controls, as well as reduced attenuation of vmPFC activity (i.e. less reduction in activity) and reduced amygdala-vmPFC functional connectivity specifically during high-provocation trials. Notably, both reduced vmPFC attenuation and reduced amygdala-vmPFC connectivity were negatively correlated with level of punishment selected. Therefore, both hypo-activation and decreased functional connectivity between PFC and limbic areas may result in impaired emotion regulation in clinical groups characterised by high levels of reactive aggression.

Insight into reactive aggression can also be gained by exploring the neural bases of related phenotypes, such as irritability (see Leibenluft, 2017; Brotman, Kircanski & Leibenluft, 2017 for comprehensive reviews). Clinical irritability has been defined as ‘an increased propensity to exhibit aggression relative to one's peers' (Leibenluft, 2017, p. 277) and is thought to arise from dysfunctional threat and frustration processing (Brotman et al., 2017). Reactive aggressive behaviour is considered the extreme behavioural manifestation of irritability (Leibenluft, 2017). In line with the studies so far presented of reactive aggression in CP (Sebastian et al., 2014; Viding et al., 2012), youth with clinical or chronic irritability exhibit increased activation to threat (e.g. angry faces) in the amygdala, insula, cingulate and striatum compared to typically developing controls (Thomas et al., 2013), suggesting heightened emotional reactivity as a core component of irritability (although see Deveney et al., 2013, which found *decreased* amygdala response in this group, albeit on a non-affective task). Additionally, amygdala-mPFC functional connectivity was found to inversely correlate with irritability severity in youth viewing angry faces at 150% intensity (Stoddard et al., 2017), suggesting a failure of top-down regulation from the mPFC to amygdala. Results therefore suggest similar neural bases could underpin high irritability and threat-reactive conduct problems, though potential overlap across these groups would need to be more closely delineated.

1.2.6 Reactive aggression summary

During adolescence, ongoing functional development occurs in neural circuitry underpinning processes of key relevance to reactive aggression, including emotional reactivity, emotion regulation, decision-making and social reward, as well as in the response of the 'aggression network' itself (including amygdala, hypothalamus, insula, PAG, OFC/PFC). Increased emotional reactivity and decreased or aberrant emotion regulation can be seen in both typical and atypical manifestations of reactive aggression. As such, developmental changes during adolescence may at least in part explain the peak in reactive aggressive behaviour seen during these years. However, the biology of puberty is a constant across almost all adolescents, yet the majority of adolescents do not develop clinically significant reactive aggression. This suggests that while the neurobiological changes associated with adolescence may confer a window of vulnerability to developing aggression, it does not comprehensively account for the variability in developing aggression. It is therefore important to understand how individual differences may interact with canonical trajectories of adolescent neurocognitive trajectories to confer risk or resilience in this area. How these general developmental trends interact with individual variation in factors contributing to aggression (such as those identified by the GAM and I^3 models) is an important question for future research. Previous research into threat and provocation as antecedent processes to reactive aggression has been well documented in the literature and discussed in this introduction both generally and in relation to adolescence. However, there is a research gap when it comes to frustration. Frustrations occur on a daily basis, yet there is still a paucity in research examining how this antecedent process translates to reactive aggression. In the next section, the focus is on frustration as a factor that may help explain adolescent onset of aggression.

1.3 Frustration

1.3.1 Definition and psychometric properties

Frustration is the affective state of being upset or annoyed, arising from the perceived resistance or unfulfillment of one's goal, e.g. the prevention of progress or success (de Botton, 2011; www.en.oxforddictionaries.com). Early psychological work on frustration operationalised frustration as an external factor that interferes with the attainment of an initiated goal (Dollard, Doob, Miller, Mowrer & Sears, 1939), i.e. frustration is the *occurrence* of one's goal being blocked. Other accounts of frustration (e.g. Abler, Walter, & Erk, 2005) point to the emotional state that occurs in *response* to a goal being blocked. For example, recent studies (e.g. Deveney et al., 2013; Yu, Mobbs, Seymour, Rowe, & Calder, 2014) have used experimental paradigms that systematically block the participants' goal (typically by blocking rewards) to induce an occurrence of frustration. Using self-report ratings of frustration or similar affective states, participants report increased feelings of frustration after blocking. This suggests that the two definitions of frustration refer to different stages of the same process: *feelings* of frustration result from a frustration *occurrence*. Goal-blocking has subsequently been identified as the most effective way to induce frustration in the literature (Rich et al. 2007). As an affective state, frustration is regarded as an aversive emotion (Otis & Ley, 1993) but one that may be adaptive as it may instigate behavioural responses to overcome goal-blocking obstacles (Gatzke-Kopp et al., 2015). To avoid confusion, this review will only refer to frustration as the affective state; studies conceptualising frustration as a goal-blocking event will be referenced specifically as using a goal-blocking event.

Frustration falls under a broader umbrella term of distress. Distress *in*tolerance, i.e. the inability to withstand distressing states, has been associated with many disorders, including anti-social personality disorder (Daughters, Sargeant, Bornovalova, Gratz & Lejuez, 2008) as well as depression, anxiety and substance and alcohol abuse (Leyro, Zvolensky, & Bernstein, 2010). In a theoretical review of distress intolerance, Zvolensky et al., (2010) identified frustration tolerance as one of five facets of distress (tolerance of: uncertainty, frustration, negative emotion, ambiguity and physical discomfort), defined as the ‘individual differences in the perceived ability to withstand aggravation’ (p.408). Similarly, Bebane, Flowe & Maltby (2015) found frustration to be part of a model of distress after conducting a factor analysis on five existing measures of distress tolerance, suggesting frustration is a prevalent factor component of aversive affect.

Frustration tolerance itself has also been identified to be multifaceted construct. Harrington (2005) developed the Frustration-Discomfort Scale (FDS) and in a factor analysis of potential questionnaire items found both a four and five-factor model to be significant. The subscales of the four-factor model are: Discomfort Intolerance (e.g. ‘tasks must not be too difficult’), Entitlement (e.g. ‘must not be taken for granted’), Emotional Intolerance (e.g. ‘I must be free of distressing thoughts) and Achievement (e.g. ‘must not leave work unfinished’). For the five-factor model, the Entitlement subscale was split into two separate subscales, Gratification (e.g. ‘I can't tolerate being overlooked’) and Fairness (e.g. ‘I can't tolerate being taken for granted’), as it was unclear whether these were separate facets of Entitlement. However, the two subscales were not necessarily independent, therefore Harrington concluded the four-factor model was the best fit on the grounds of parsimony.

Together these studies suggest that frustration is a negative affective response, broadly associated with distress, but more specifically is a multidimensional construct. Understanding the properties of frustration is crucial to understand how it may be a precursor to reactive aggression. Evidence for the link between frustration and reactive aggression is reviewed in the next section.

1.3.2 Frustration and aggression

There is a rich research literature demonstrating frustration as a precursor to aggression. The Frustration-Aggression Hypothesis (Dollard et al. 1939) theorises that frustration is a pre-requisite for an aggressive response, frustration here referring to a goal-blocking incident. The Frustration-Aggression Hypothesis however took a very reductionist approach and has since been revised to suggest that while frustration *can* be a precursor to aggression, that not all frustrations result in aggression and not all aggression occurs due to frustration (Berkowitz, 1989). This revised Frustration-Aggression theory has since been supported by both self-report and behavioural data. For example, the Entitlement subscale of the Frustration-Discomfort Scale ('must not be taken for granted') uniquely predicted anger symptoms in a clinical population (Harrington, 2006) and was positively correlated with hostility in university students (Jibeen, 2013). Anger and hostility are hallmark characteristics of reactive aggression (Blair, 2010; Raine et al. 2006), suggesting the Entitlement facet of frustration may be indicative of reactive aggression, though this remains speculative as reactive aggression was not measured explicitly. Similarly, Lawrence (2006) created the Situational Triggers of Aggressive Responding scale using items created by free recall of events that elicited aggressive responding in the previous three months. Factor analysis of these items revealed two factors: frustration and provocation. The scale has since been validated in five countries (Mylonas, Lawrence, Zajenkowska & Bower Russa, 2017). Again however, the Situational Triggers of Aggressive Responding scale does not explicitly measure reactively aggressive responding, although examination of the items, e.g. 'I feel aggressive when…' 'I am goaded or provoked by someone', 'someone insults me' and 'I am frustrated' suggest they largely represent reactive aggression as opposed to proactive aggression. Looking more specifically at reactive aggression, a recent study using factor analysis of the Reactive-Proactive Aggression self-report questionnaire (Raine et al., 2006) also found that the reactive aggression subscale could be reliably split into two further factors: internal frustration and external provocation (Smeets et al., 2017), again suggesting a strong link between frustration and reactive aggression.

Behavioural research has largely converged with and expanded upon the self-report and questionnaire data. A number of studies have found that manipulating the level of frustration elicited can alter the degree of aggressive responding. Kregarman and Worchel (1961; Worchel, 1974) manipulated the degree of expectation of a goal-blocking event occurring by providing participants with either a description of the negative verbal comments the experimenter would make during a task (Expected condition) or giving only the instructions necessary for the task (Unexpected condition). The negative verbal comments were designed to elicit frustration, such as 'You are working too slowly'. Participants in the Expected condition reported fewer aggressive behaviours than participants in the unexpected condition, suggesting knowledge of the goal-blocking event helps moderate the level of aggression experienced.

Other factors used to manipulate the level of frustration induced include the presence and proximity of a reward. The presence of a reward is assumed to boost incentive to reach the desired goal, initiating a stronger goal-response. It follows that if a highly desired goal is blocked, the greater the level of frustration induced. Buss (1963) explored the effect of the presence of a reward on frustration-induced aggression by manipulating the reward participants would gain for completing a study: money, grade increase or no reward. Participants were paired with a stooge in a learning task where they were told to 'punish' their teammates when they gave an incorrect answer by delivering electric shocks ranging from mild intensity (levels 1, 2) to painful (10) as a more explicit measure of aggression. The researchers noted any shock given at level 3 or greater qualified as aggression since this level of shock was more painful than simply letting the learner know of their mistake. Participants in either reward condition (money or grade increase) delivered more high-level shocks to the learner that those in the no reward condition. However, there was no difference in aggression between the reward types, suggesting the presence of either reward type is sufficient to elicit aggressive responding.

The proximity of the reward or goal can also increase the likelihood of frustration-induced aggression. In a more ecologically valid study, Harris (1974) had stooges 'queue-jump' naturally occurring queues at varying distances from the front, and then observed the number of aggressive behaviours of the person directly behind the stooges. The assumption was the closer to the front of a queue, the higher the motivation or drive to reach the front, i.e. your goal. Therefore, to have this goal blocked would cause greater frustration resulting in more aggressive responses in those closer to the front. As predicted, they found that individuals closer to the front of the queue displayed more aggressive reactions than those further away. One possible confound is that those closer to the front of the queue will also have expended a greater amount of effort in the queueing process. As such, increased proximity *and* effort could amplify the unfairness of the queue jumper's actions, subsequently heightening frustration levels. Indeed, the factors of both proximity and effort were reported more recently in Yu et al., (2014) who found participants reported higher levels of affective frustration the closer they were to the reward and the more effort they had spent in getting to the reward (please see below for a more detailed explanation of this study).

Frustration so far has been measured mainly in terms of the level of aggression it elicits (as demonstrated in the studies above). Acknowledging and defining the link between frustration and reactive aggression is an important start, however it is not sufficient to understand the within- and between-subject variability in the affective experience of frustration itself, and by extension the variability in the likelihood of frustration transitioning to aggression. Many studies have not investigated the frustration process in and of itself, and so our understanding of individual differences in responses to the situational triggers of reactive aggression, e.g. frustration, are lacking (Mylonas, Lawrence, Zajenkowska & Bower Russa, 2017). For example, studies have also shown that a goal-blocking event (frustration *occurrence*) elicits frustration (affective *response*), yet the development of this affective state has not been well studied. To do this, we first need to understand the process of frustration itself from a variety of perspectives including behavioural, physiological and neuroimaging to gain a comprehensive picture of the frustration response.

Looking at the behavioural and physiological components of the frustration response, studies have used goal-blocking paradigms and found greater levels of physiological arousal when participants are blocked, for example reward omission, compared to when they are not, i.e. continue to receive a reward (skin conductance: Dixon, MacLaren, Jarick, Fugelsang & Harrison, 2013; Otis & Ley, 1993). Additionally, Otis and Ley (1993) found that participants would press a lever more forcefully when they stopped receiving rewards than when they were receiving rewards, suggesting frustration is associated with an increased force response or actioned response (also found by Yu et al. 2014, see below). Behavioural and physiological studies play an important role in understanding the frustration response holistically. However, they cannot reveal the mechanisms by which the frustration response occurs, which is why understanding the neural basis of the frustration response *in addition* to the behavioural and physiological characteristics is important.

1.3.3 Neural bases of frustration

Though imaging research is relatively sparse, those studies that have looked at frustration have found that it elicits activity within the amygdala, dorsal prefrontal cortex (dPFC), ventral and ventral-medial prefrontal cortex (vPFC/vmPFC) (Deveney et al., 2013) and anterior cingulate cortex (ACC; Lewis, Lamm, Segalowitz, Stieben, & Zelazo, 2006; Yu et al., 2014), utilising goal-blocking paradigms within a number of imaging methods including electroencephalography (EEG), functional near infrared spectroscopy (fNIRS) and functional magnetic resonance imaging (fMRI).

In healthy adult participants for example, Klöppel et al., (2009) presented participants with two squares sequentially and participants needed to indicate which of two squares were bigger while undergoing fMRI. To induce frustration, on some trials participants would be shown the negative feedback 'Wrong! You lost the round' even when they were correct. Participants also self-reported on feelings of irritability, which has been previously related to frustration processing (Brotman et al. 2017). During negative feedback, amygdala activation increased as irritability increased. Similarly, Abler et al., (2005) had participants make simple left/right decisions in response to presented stimulus to win a monetary reward. Correct responses gave participants only a 60% chance of obtaining the reward, thus on 40% of correct trials, participants would not obtain a reward despite a correct response. Results indicated increased activity in vPFC and anterior insula during omitted reward compared to reward trials. These areas have previously been associated with emotional reactivity and processing salient information (amygdala; Adolphs, 2008) and emotion regulation (PFC areas; Ahmed, Bittencourt-Hewitt & Sebastian, 2015). For example, the vPFC is thought to preferentially process negative emotions (Abler et al., 2005) and the ACC appears to have specialisation in evaluating emotions (Moadab, Gilbert, Dishion & Tucker, 2010) and translating affect into a physiological response (Critchley, 2005).

However, both studies have used block designs, i.e. comparing frustration to no-frustration condition. As with most affective states, frustration is not dichotomous but exists on a continuum (see Mauss & Robinson, 2009 for review of the discrete versus dimensional theory of emotions). As such, this type of design a) fails to capture this dimensional nature of frustration, and; b) does not take into account that one event of frustration may not lead to the same degree of frustration for everybody.

In contrast, Yu et al., (2014) is the only study identified within the literature to account for both the dimensional nature of frustration and to record corresponding affective ratings. Participants (healthy adults) made simple left/right responses to presented stimuli (arrows pointing left or right) to continue through a pre-determined number of stages to complete a level and earn a reward. To induce frustration, participants' progress through the level was systematically blocked by presenting the participant with “blocked” feedback. At the end of each level participants were asked to confirm whether they were blocked or had won the level, at which point response force was recorded. Response force was the pressure with which participants pressed the buttons to respond. This provides a translational measure between affect (frustration) and a physical reaction (e.g. aggression). Indeed, response force has been found to be a valid measure of aggression (Kapoor, Burleson, & Picard, 2007). At the end of the task participants were asked to rate their levels of frustration, motivation and surprise upon being blocked at different stages.

To capture the dimensional nature of frustration, the length of each level was manipulated such that participants had to complete either one, two, three or four stages so the effects of proximity to reward and effort expended in achieving the reward on frustration could be independently measured and analysed. To do this, they kept one factor (either proximity or effort) constant so that the variation in results would be due to the other factor. For example, to examine the effects of proximity, the results of being blocked at the first stage of all possible level lengths (e.g. 1/1, 1/2, 1/3, 1/4) were combined so that effort was kept constant (at stage 1) but proximity varied (1-4 possible stages needed to be completed before they could obtain the reward). To examine the effect of expended effort on the other hand, the results of being blocked at the final stage of all possible level lengths (e.g. 4/4, 3/3, 2/2, 1/1) were combined so that proximity was kept constant (final stage) but effort expended varied in the number of stages participants had completed before reaching the final stage of the level (1-4 possible stages).The paradigm was run both behaviourally (with and without monetary rewards and with response force measure) and with fMRI (with monetary reward but with no measure of response force).

Behaviourally, results indicated that reaction times to task stimuli, self-reported frustration and self-reported motivation increased as a function of proximity to reward. This was the case irrespective of the presence of a monetary reward, though being blocked from obtaining larger monetary reward resulted in increased levels of frustration compared to small rewards, consistent with the studies mentioned above. Self-reported surprise however had no significant correlation with proximity to the reward, which the authors suggest demonstrates that a goal being unexpectedly blocked is not necessary to induce frustration. This conclusion is in line with findings that unexpected blocking of goals may increase level of frustration experienced (e.g. Kregarman & Worchel, 1961), but that a goal-blocking occurrence is the necessary factor for inducing frustration. Finally, response force at the confirmation stage was significantly stronger during blocked conditions than win conditions, suggesting the affective state of frustration can 'spill over' into a behavioural response.

Imaging results found increased activity within the amygdala, dorsal ACC and anterior insula as a function of both proximity to reward and expended effort when blocked. The experimental design of the study meant that the effects of effort and proximity could both be parametrically modulated, allowing the independent effects of each on the frustration process to be analysed. There were no significant differences in the neural response to effort versus proximity, suggesting they both have a significant impact on level of frustration and are represented by the brain in similar ways.

Together these studies have highlighted the neural mechanisms underpinning the frustration response, and appear to overlap with the areas identified as part of the aggression network within animals and humans (dACC-insula-amygdala-midbrain; Panksepp, 2005), suggesting an overlap in the process of frustration and aggression and builds upon the idea that frustration is part of the aggression process. Perhaps most importantly, these findings are consistent with other studies reporting on the neural bases of frustration, again implicating brain regions thought to be involved in emotion reactivity, salience and emotion regulation. Importantly, these are also brain regions that undergo significant structural and functional development during the adolescent period. However, these studies have only examined the frustration process in adults. To understand how the frustration response develops with age we also need to consider the frustration responses in different developmental periods. The next section reviews literature that explores the frustration response in development. By looking at differences across the lifespan we can help identify why adolescence may confer a vulnerability to externalising behaviours.

1.3.4 Frustration in development

The frustration response across development largely reflects that of adults, with frustration-related reactivity and regulation appearing to develop early on. In a longitudinal study, Braungart-Rieker & Stifter (1996) observed infants' responses during age-appropriate frustration paradigms at 5 and 10 months. At both 5 and 10 months, infants' responses could be factored into frustration reactivity behaviours (peak cry intensity, cry latency) and regulatory behaviours (behavioural avoidance, attention orienting to an object unrelated to task and communication), suggesting continuity in the factor structure of behavioural responses to frustration across infancy. However, there were also distinct changes in the level of individual behaviours between 5 and 10 months. For example, peak cry intensity increased, demonstrating increasing frustration reactivity, and both behavioural avoidance and attention orienting decreased while communication increased, suggesting increasing emotion regulation abilities. Notably, the authors found an inverse relationship between reactivity at 5 months and regulation at 10 months, such that infants with higher frustration reactivity at 5 months had lower regulation at 10 months. Moving into toddlerhood and childhood, Deater-Deckard et al (2010) gathered parent-rated reports of overt aggression and frustration reactivity in a sample of 4-9 year old twins. They found a significant positive correlation between overt aggression and frustration/anger. These findings suggest that frustration reactivity is present very early on. Note, frustration reactivity was measured using the frustration/anger subscale from the Child Behaviour Questionnaire (short-form, Putnam & Rothbart, 2006) which reports the frequency of negative affect following the interruption of current tasks or the blocking of a goal. While the subscale is labelled as both frustration/anger it appears to report the affect associated with goal-blocking which previous research has found to elicit frustration, therefore these results are taken to represent frustration reactivity.

Using an experimental frustration paradigm to explore frustration-related regulation, Perlman, Luna, Hein, and Huppert (2014) created a task in which participants (3-5 years) won a dog's bone if they could click on it before their canine competitor (block one, three) only to lose them all (block two) to induce frustration. Functional near-infrared spectroscopy (fNIRS) imaging results found increased activity in the dorso-lateral PFC during the frustration block only, which correlated with parent-reported levels of frustration reactivity, with frustration reactivity taken from the frustration/anger subscale of the Child Behaviour Questionnaire (long form, Rothbart, Ahadi, Hershey & Fisher, 2001). These results suggest an increased recruitment of emotion regulation areas during frustration. Unfortunately, this task was not used with participants in later childhood or adolescence, therefore we cannot draw comparisons with these age groups.

Refining the literature specifically to adolescent samples, Little, Brauner, Jones, Nock and Hawley (2003) used peer and self-reports of both reactive and instrumental (proactive) aggression in both overt and relational forms (e.g. reactive-relational, reactive-overt etc.) and frustration intolerance amongst other measures in a sample of 5^{th} – 10^{th} Graders (~10-16 years old). From the multiple constructs of aggression measured Little et al. were able to create distinct subgroups based on the primary type of aggression exhibited. Of relevance was the reactive aggression subgroup, who scored above the 66^{th} percentile on reactive aggression but below the 66^{th} percentile on instrumental (proactive) aggression. This group of adolescents were reported to have increased levels of frustration intolerance in comparison to other subgroups, as well as increased hostility. However, it is not clear from this study whether the increased level of frustration intolerance is due to increased frustration reactivity, decreased emotion regulation abilities, or an interaction of the two.

Looking more specifically at regulation during a frustrating episode, Lewis et al., (2006) used EEG with 5-16 year olds in a frustrative non-reward go/no-go task. Points were won based on performance in blocks one and three (reward blocks) but were systematically lost and paired with negative feedback to induce negative emotion in block two (point-loss block). Self-report measures confirmed the negative emotion induction during block two; 'mad' and 'upset' had the highest ratings (although 'frustration' was not specifically measured). Focusing on the N2 and P3 components (negative amplitude potential observed at 200-ms and positive amplitude potential observed at 300-ms post stimulus onset respectively, both associated with impulsivity control), Lewis et al found P3 amplitudes were increased during the negative emotion induction block, but only in the adolescent subgroup for the N2 component. This suggests an increased recruitment of response inhibition mechanisms at all ages, perhaps more so during adolescence. The N2 component was also more active during no-go trials (where participants could potentially lose points) in the subsequent non-manipulated block. The authors suggest this activation demonstrates a lasting effect of the emotion induction. Source modelling of the N2 component revealed that the source of the N2 activity moved with age from the mid/posterior cingulate cortex to the anterior cingulate cortex, suggesting changing activation patterns of regulatory response to frustration across development.

Together these studies suggest that frustration reactivity and regulation are apparent in young children but that they continue to develop during adolescence, particularly regarding frustration regulation. This is not surprising considering ample evidence of continuing development in more general self-regulatory behaviour and mechanisms during adolescence (e.g. Ahmed et al. 2015).

Exploring the neural basis of frustration in clinical populations compared to typically developing populations may provide an insight into the aberrant frustration processing that may form a risk factor for developing clinically significant reactive aggression. However, this literature is scarce and is currently not informative of the adolescent period. One study in children with Conduct Disorder (Gatzke-Kopp et al. 2015) used a frustrative non-reward version of a go/no-go task with EEG similar to that used in Lewis et al. (2006) in a sample of kindergarteners (~5-6 years of age). Based on teacher ratings of Conduct Disorder, participants were split into two groups: Conduct Problems and typically developing controls. Results found decreased P3b amplitude in all participants during the frustration block (point-loss block in Lewis et al. 2006) compared to reward blocks, suggesting the manipulation of the frustration induction was consistent across groups. Additionally, both the Conduct Problem and externalising groups had significantly lower P3b amplitude than controls during frustration block and showed increased heart rate between the frustration and final reward block, which the authors described as the reactivity period. These results suggest both heightened reactivity to frustration (heart rate) and impaired emotion regulation of frustration (decreased P3b) in participants with increased levels of reactive aggression.

Studies in children and adolescents without Conduct Problems suggests key developmental differences in the regulation of the frustration response. However, in children with Conduct Disorder, there appear to be both exaggerated frustration reactivity and impaired frustration regulation. This may provide a basis for further studies into maladaptive frustration processing, but it should again be noted that this study was in children and not adolescents, suggesting more work needs to be done before any robust conclusions can be drawn.

1.4 Current thesis

1.4.1 Ongoing research questions

The extant literature has identified a susceptibility to increases in reactive aggression during the adolescent period. Ongoing structural and functional developments in key regions underpinning aggression and related processes (emotional reactivity and regulation) during adolescence, the subsequent imbalance between the efficacy of these brain regions, and the interplay with increasing social pressures and a maturity gap may in part account for adolescence being a window of vulnerability. However, normative adolescent development cannot account for the heterogeneity in the presence of clinically significant reactive aggressive behaviours across adolescents, suggesting other factors may influence these trajectories. One area of potential is the way in which individuals react to antecedent processes of reactive aggression such as frustration, yet little is known about the processes mediating the affective response of frustration and how this may result in reactive aggressive behaviour. Research is beginning to understand the components of the frustration response, e.g. increased arousal, increased force responding, increased anger (e.g. Entitlement facet of the Frustration Discomfort Scale), and increased activation in brain regions associated with emotional reactivity and emotion regulation. However, the extant literature has some limitations.

Firstly, studies often fail to recognise the dimensional nature of frustration (bar Yu et al., 2014), instead opting to use block-designs (i.e. frustration vs. a no-frustration control condition). This is problematic as it is not possible to determine from these types of tasks whether there are individual differences in the point at which a goal-blocking event becomes affectively frustrating. As such, frustration induction via block-design paradigms do not provide a sensitive enough measure of frustration to explore individual differences in the frustration response and how these may be related to reactive aggressive behaviours or how they may change across adolescence. The task employed by Yu et al. (2014), however, does allow for the dimensional nature of frustration to be explored by providing a manipulation of the level of frustration experienced. Unfortunately, the task employed by Yu et al. (2014) was designed for adults, therefore has not been tested in adolescents and may not be appropriate for an adolescent sample (see Chapter 2 for an adapted version).

Relatedly, the above studies have not always employed self-report measures of frustration, either ignoring them altogether or using proxies such as the terms ‘mad’, ‘upset’, or ‘angry’. These are all related emotions, and combined may constitute the emotional frustration response (Bierzynska et al., 2016), and so are useful measures to garner an idea of how frustrated participants felt. However, individually they are not quite the same; frustration is a specific emotion in that it can only be induced under particular circumstances, i.e. a goal-blocking event, whereas mad, upset and angry could occur for a number of reasons. As such, it has not always been possible to match the subjective feeling of frustration to the frustration-induction, limiting the possible conclusions that may be drawn from the results of the characteristics of the frustration response.

Lastly, there are few studies that explore the frustration response in adolescents. While the few that have been reviewed provide a basis from which to further explore the frustration response, when combined with the other two limitations (i.e. block-design and lack of affective ratings), the conclusions that can be drawn from the extant literature is limited. In particular, there is still a lack of understanding of the behavioural performance and neural signature of frustration in healthy/typically developing populations, how this develops across the lifespan and how individual differences in the frustration response may be related to externalising behaviours such as reactive aggression during this developmental period. It is important to understanding how the frustration response manifests in adolescence, and how adolescents vary in their response to frustrating events. Doing so will shed further light on the antecedent processes to aggression at this point in the lifespan, including susceptibility to clinically significant reactive aggressive behaviours in a significant minority of adolescents.

1.4.2 Thesis aims

Given the limitations discussed, the current thesis aims to: 1) develop a suitable paradigm for testing the development of frustration more sensitively that will also be age-appropriate for testing in adolescent samples; 2) examine individual differences in the frustration response and whether these are related to age and/or individual differences in engagement in reactive aggressive behaviours, and 3) explore the behavioural and neural development of frustration in a typically developing sample.

1.4.3 A note on methodology

This introduction Chapter has highlighted the theoretical and experimental literature describing frustration as a precursor or antecedent process to reactive aggression. The extant literature has characterised an ‘aggression network’ from animal and human studies into reactive aggression, but literature addressing frustration specifically, and how it contributes to reactive aggression, is still at an early stage. The frustration literature points to it being a subjective, affective response to goal-blocking, accompanied by changes in physiological arousal, and activating brain regions also implicated in reactive aggression. Therefore, the current thesis will use multiple methods at different levels of explanation (self-report, behavioural and neural) to provide a more complete understanding of the frustration response and how it varies with individual differences and adolescent development.

1.4.3.1 Self-report

In all studies a measure of self-report on frustration has been included, both to check that the paradigm does indeed induce frustration, and to provide a measure of individual differences in the subjective experience of frustration, i.e. the frustration response. Only a small number of previous studies have used frustration paradigms that included an affective self-report measure of frustration, limiting the face validity of the results to some degree. In Chapters 2-4 the measure of self-report frustration (and other affects) is the same 10-point likert scale measure used in Yu et al. (2014) of 1 ('Very slightly or not at all') – 10 ('Extremely). In Chapter 5, this was concatenated to a 5-point Likert scale measure for practical reasons, but the labels 1 ('Very slightly or not at all') – 5 ('Extremely) were retained. See Appendix 1 for the 10-point and 5-point scales.

Additionally, self-report questionnaires were used to assess levels of: dispositional frustration tolerance (Frustration Discomfort Scale [five-factor scale]; Harrington, 2005, and Frustrative Non-reward; Wright, Lam & Brown, 2009); frequencies of reactive aggressive behaviours in day-to-day life (Reactive-Proactive Questionnaire; Raine et al. 2006); internalising behaviours (Revised Child Anxiety and Depression Scale; Ebesutani et al., 2012); aggressive responses to frustrating and provoking scenarios (Lawrence, 2006); irritability (Affective Reactivity Index; Stringaris et al., 2012) and ADHD behaviours (ADHD subscale from the Strengths and Difficulties Questionnaire; Goodman, Meltzer & Bailey, 1998). Throughout the thesis these measures are taken as part of a larger battery but not all are used in subsequent analyses, as will be noted in the relevant sections. See Appendix 2 for measures of all self-report questionnaires.

1.4.3.2 Response force

In Chapter 3, a covert physiological measure of grip force is also used to understand the physiological response to frustration and how this relates to reactive aggression or preparatory responding resulting from frustration. The response force measure used was a uni-manual hand-held device that measured grip force when held and squeezed through two housed sensors (see Jaspers et al. 2018 for technical details). By using calibration trials to obtain a maximum grip force, an estimate of participants' relative grip force can be calculated to be used as an outcome measure that is then comparable across participants, i.e. proportion of the participant's maximum. Previously, studies have demonstrated an increased heart rate (Gatzke-Kopp et al. 2015), skin conductance response (Dixon et al. 2013; Otis & Ley, 1993) and response force (Yu et al. 2014; Otis & Ley, 1993) following a goal blocking occurrence, suggesting frustration elicits a preparatory or actioned response akin to reactive aggressive. Response force therefore provides an outcome measure of aggressive responding that is not obtainable via self-report questionnaires.

1.4.3.3 Magnetic Resonance Imaging (MRI)

Finally, in Chapter 5 functional magnetic resonance imaging (fMRI) was used to identify the neural mechanisms underpinning the frustration response in adolescence. fMRI allows a proxy measure of neural activity by measuring the blood oxygenation levels, known as the 'blood oxygenation level dependent' (BOLD) signal. When neurons are more active, e.g. when they are actively involved in a task, they require more energy, and so more oxygen is sent to those areas via the blood. Oxygenated blood and deoxygenated blood have different magnetic properties, and the BOLD signal detects the signal change in the ratio between oxygenated and deoxygenated blood. From this, it is inferred that these regions are the most active as they require the most oxygen and increased blood flow (Buxton, 2009), though neural activity itself is not measured (Logothetis, 2008).

As such, fMRI is a useful tool in understanding the neural correlates of cognitive processes (Price & Friston, 2005) as it is able to cover the whole brain with good spatial resolution without compromising temporal resolution too much (coverage of the whole brain on the order of a few millimetres and a few seconds respectively). Therefore, entire brain regions, as well as the networks of which they are a part, can be investigated non-invasively (Logothetis, 2008). This makes it an ideal technique for exploring the neural underpinnings of frustration in a developing sample such as adolescents.

There are of course limitations to using fMRI, mainly related to the interpretation of the BOLD signal. One difficulty is that cognitive processes are inferred from BOLD activity, but regions are rarely (if ever) one-to-one mapped with a particular function. As such, one region may be active in a number of cognitive processes, and given that fMRI analyses are correlational, it is impossible to identify exactly which process is implied by activity in a given region. This renders fMRI data susceptible to the reverse inference problem (Poldrack, 2006), especially when the cognitive processes of a task are not well evidenced. For example, if amygdala is activated by a fearful face one might assume that the amygdala 'does' fear. However, such an inference is not warranted and goes beyond the data in the absence of corroborating evidence from other methods or studies.

There are additional inference-related challenges when using fMRI in developmental populations, and/or when comparing developing groups with adults (Blakemore, 2018). Given that brain regions and/or networks are likely to be involved in a number of cognitive processes, it is not always possible to infer whether differences in neural activity represent age-related differences in the cognitive process being examined or more general cognitive differences, e.g. attention, working-memory (Luna, Velanova & Geier, 2010). This is additionally problematic when neural correlates of cognitive processes and/or tasks are not well characterised, and again comes back to the reverse inference problem. However, many of these limitations can be addressed by appropriate experimental design and additional appropriate behavioural correlates. Additionally, using 'basic' tasks with simple instructions for which performance can be matched across ages will help to control for developmental effects irrelevant to the process being investigated, e.g. executive function demand. Another difficulty is increased head movement in children and adolescents, which may mean the quality and quantity of data available is reduced, and which can also represent a confound between adolescents and adults (who tend to move less). However, taking adequate breaks and being able to split the task into short runs has been shown to help with acquiring usable data, even in participants prone to movement (Luna, Velanova & Geier, 2010). Realignment parameters across the task, as well as images corrupted by motion, can also be regressed out at the analysis stage (although this is not a perfect solution).

Despite these challenges, using fMRI to understand the neural bases of frustration provides an additional level of explanation. Self-report and behaviour, e.g. response force, can measure whether frustration has been elicited and to what degree, but they cannot reveal *how* the frustration response is elicited. fMRI is able to investigate the underlying neural mechanisms of the frustration response: which brain regions are activated and how neural responses may vary with individual differences in, e.g. magnitude of the frustration response or reactive aggressive behaviours.

1.4.4 Summary

Utilising the multiple methodologies described above, this thesis will describe an adapted age-appropriate frustration paradigm (research aim one) to be subsequently used to explore how individual differences in the frustration response relate to individual differences in reactive aggressive behaviours (research aim two) and how the frustration response may change across adolescence (research aim three).

Specifically, in Chapter 2 the development of the adapted age-appropriate frustration paradigm (based on Yu et al., 2014) is described, and the validity of the adapted paradigm across three pilot studies involving both adult and adolescent samples is demonstrated. In Chapter 3, the adapted frustration paradigm is used to incorporate a measure of 'of-the-moment' reactive aggressive responding using a response force measure in order to explore individual differences of the frustration response and reactive aggressive responding and to characterise the 'tipping point' of frustration into reactive aggression (research aim two). In Chapter 4, the frustration response was investigated in a sample of adolescents aged 11-16, including how responses varied with participants' age and self-reported levels of reactive aggression. Additionally, this Chapter tested the framework of the I^3 model of aggression by using the frustration response and age as impellence factors, a measure of inhibitory control (Go/No-Go) as an inhibition factor, and self-reported reactive aggression as the aggressive outcome. Finally, in Chapter 5, the neural bases of the frustration response were explored in a sample of adolescents (11-18 years) to understand a) the neural underpinnings of the frustration response, and b) whether these may change with age across the adolescent period.

The following Chapter will address the first research aim of the thesis: the development of a sensitive, age-appropriate frustration-induction paradigm.

Chapter 2: Development and Validation of a Frustration-Induction Task

This Chapter reports three pilot studies conducted to validate an age-appropriate adaptation of a pre-existing frustration paradigm. The adaptation was developed to be used in subsequent studies to explore the developmental effects of frustration in an adolescent sample as an antecedent process to reactive aggression. The introduction will discuss the frustration paradigm selection and adaptation choices, aims and hypotheses for all three pilot studies. Each of the pilot studies will then be presented sequentially, followed by a broader discussion covering the three pilot studies to conclude the Chapter.

2.1 Introduction

2.1.1 Frustration paradigm selection

The frustration paradigm developed and reported by Yu et al. (2014) was chosen to be adapted to create an age-appropriate frustration paradigm as it addressed several limitations previously reported in the frustration literature. Specifically, it was the only paradigm identified within the literature that manipulated the level of frustration induced in a parametric fashion and which incorporated affective ratings of frustration after frustration-induction (see Chapter 1 for descriptions of frustration tasks within the literature [1.3.1] and for critiques of these tasks [1.4.1]). The ability to manipulate frustration parametrically allows the frustration experience to be measured dimensionally as opposed to categorically (e.g. 'Frustrated' or 'Not Frustrated' as seen in block designs). This is an important aspect of the design as it mirrors frustration as a dimensional affective experience and individual differences can be more easily captured. Additionally, the inclusion of affective ratings ensures the participants' subjective experience is one of frustration and checks that the manipulation of frustration has been successful.

The Yu et al. frustration paradigm was designed as a goal-blocking paradigm to induce frustration, i.e. by blocking participants progress to a goal (e.g. monetary reward), paired with a simple left/right decision-making task (see Figure 5a for task timeline). The task design was set up such that for each trial participants had to complete a pre-determined number of stages to win the trial and earn a reward. The number of stages to be completed by the participant in each trial could vary between one and four and were represented as 'empty' rectangles on the screen. On some trials, the computer would 'pre-complete' between one and three stages, represented as gradient filled rectangles, therefore participants had to complete a minimum of one trial. In total there were 210 trials, with the task taking approximately 60 minutes to complete.

At each stage of the trial, participants had to correctly respond to an onscreen presented arrow facing either to the left or right. When participants responded correctly, they would move on to the next stage. However, participants were told that if they responded incorrectly or too slowly then they would be blocked, terminating the trial and losing the reward. This was in fact the task manipulation to induce frustration, and participants would be blocked at one of the four possible stages irrespective of response accuracy or speed, based on a pre-determined hidden feedback structure (see Figure 5b). To ensure participants did not get discouraged from the task or suspect the task manipulation they were told that the computer randomly assigned a time limit that participants must respond within at each stage of the trial. At the end of each trial participants were asked to confirm whether they were blocked or had won the trial, known as the confirmation stage. At the end of the task, participants rated how frustrated, motivated and surprised they were at being blocked at each of the possible stage configurations on a 10-point Likert scale 0 ('Not at all') – 10 ('Very intensely'), providing the affective measure of frustration and addressing that limitation of other frustration paradigms within the literature.

In order to parametrically modulate frustration, both the number of stages needed to be completed and the stage at which participants were blocked was pre-determined in order to systematically manipulate a) the proximity to the reward and b) the effort expended to obtain the reward. Proximity and effort were the two manipulations of frustration induction, whereby each could be held constant to test the effects of the other. For example, to test the effect of proximity, performance (i.e. affective ratings of frustration when blocked) would be compared on the first stage when participants had to complete either 1, 2, 3 or 4 stages to win the trial, i.e. expended effort was kept constant at stage 1 (only one stage completed) but proximity to the trial reward was manipulated between 1-4 (number of stages in the trial to be completed to win). In contrast, to test the effect of effort, performance would be compared on the final stages when participants had to complete either 1, 2, 3 or 4 stages to win the trial, therefore expended effort was manipulated between 1-4 (number of stages participants have to complete to win) but proximity was held constant at stage 4 (the final stage of the trial).

Results converged across a number of studies (Yu et al. 2014) and robustly demonstrated increasing levels of induced frustration with increasing proximity, i.e. the closer to the reward participants were when blocked, and with increasing effort, i.e. the more stages participants had completed to get to the reward before being blocked. However, the effects of the two manipulations on the level of frustration induced were not statistically significantly different from one another. These results suggest that this frustration paradigm can robustly induce frustration based on both proximity to reward and effort expended, and can manipulate the level of induced frustration parametrically which allows frustration to be measured in such a way that mirrors the continuum of the subjective frustration experience. Results also showed that reaction times decreased with proximity, suggesting participants were increasingly engaged in the task and motivated to earn the reward by winning the trial with each additional stage. Moreover, using self-report affective ratings did not appear to interfere with the paradigm efficacy.

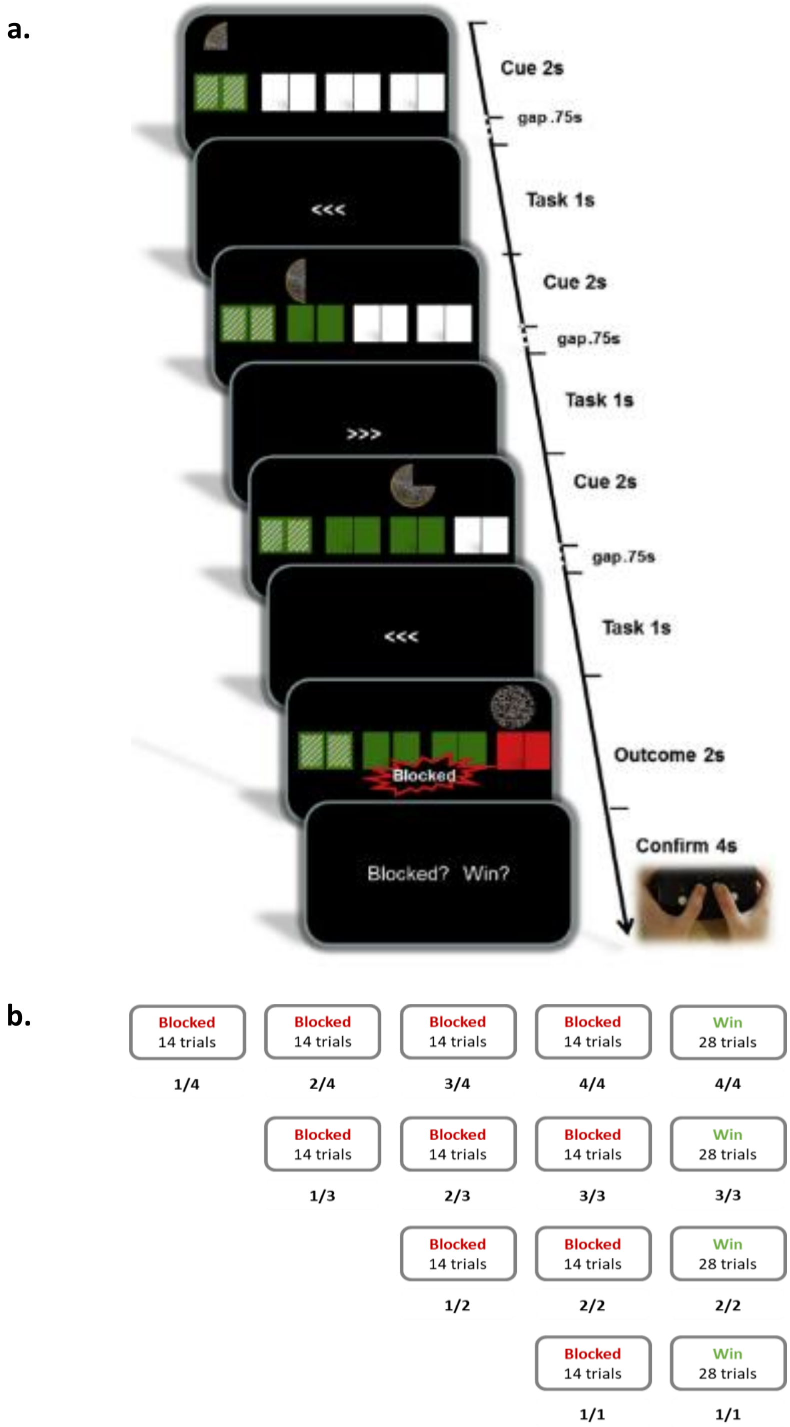


Figure 5. Yu et al. (2014) frustration induction paradigm. *Permission for reuse from Elsevier*. *a.* Task timeline showing stimuli, order of presentation and timings of presentation. Illustrated example shows a trial in which the participant is blocked at the final stage (red) where the first stage was 'pre-completed' by the computer (green crosshairs) and the remaining stages 2 and 3 were completed correctly by the participant (green block colour). *b.* Hidden feedback structure showing the number of trials on which participants would be blocked at each of the stages (14 trials) and the number of trials participants would be able to win (28 trials) for each trial type.

2.1.2 Frustration paradigm adaptation

Though the Yu et al. (2014) paradigm overcomes the main limitations of other paradigms in the frustration literature as has been discussed, the paradigm was designed with adult participants in mind and is unsuitable for an adolescent sample for a number of reasons. Firstly, the task manipulation of both proximity and effort to induce frustration is quite complex and may not be understood with ease by the youngest participants of an adolescent sample, e.g. 11-year olds. As the aim is to use the paradigm in a sample of 11-18 year olds, the paradigm has to be accessible to all age groups in the sample, including providing adequate instructions to the participants and for them to engage in the task. The inclusion of both manipulations also leads to the second limitation which is the length of the paradigm and subsequent completion time. In order to manipulate both proximity and effort the paradigm consisted of 210 trials with an estimated completion time of approximately 60 minutes. A paradigm of this length is not practical for adolescents as they would find it difficult to sustain an acceptable degree of concentration on the task, which would limit the data quality and validity of the findings. A paradigm of this length would also not be feasible in terms of practicality and logistics of testing sessions with adolescents, for example in a school setting. As there were no significant differences found between the effects of proximity and effort on the level of frustration induced in either the behavioural or neuroimaging results, the manipulation of effort was removed from the paradigm. By doing so, this removed the necessity of the 'pre-completed' stages, leaving only the manipulation of proximity using four stages per trial. This reduced the complexity and length of the task to 84 trials, equating to approximately 25 minutes to complete. To ensure that frustration would still be suitably induced we kept the hidden feedback structure for each stage the same as was originally used for a four stage trial (see the top row of Figure 5b).

Thirdly, the stimuli used in the task portion of the paradigm (arrows facing to the left or to the right) may not be engaging enough for an adolescent sample, which again may compromise data quality. To ensure an adolescent sample would remain more engaged, the task stimuli were replaced with a ‘Pacman’ inspired ghost character called ‘Ghostie’ (see Figure 6.3). In order to maintain the left/right element and low task demands of the original arrow stimuli, participants would be required to indicate whether Ghostie was looking to the left or to the right.

There were also two changes made to the aesthetics of the paradigm to create a less busy visual representation of the task. In the original paradigm each stage was represented by two rectangles presented adjacently. These were replaced by a single rectangle, providing a one-to-one direct mapping between visually depicted progress (rectangle) and trial progress (stage). Additionally, the original paradigm depicted progress through each trial by presenting the reward, e.g. a £2 coin, above the stages, representing the proportion of the trial completed so far. For example, stage 3 was represented by 3/4 of a £2 coin (the reward itself was ‘all-or-none’ depending on win or block outcome respectively). However, accumulated rewards earned across the task was not shown and using a coin restricted the rewards to money. Therefore, the coin was removed (since within-trial progress was now more clearly represented via green rectangles), and a progress bar was added to the right hand side of the screen that would update with cumulative rewards obtained as participants progressed through the task. This aimed to ensure participants would stay motivated throughout to maximise rewards and allowed flexibility in the types of rewards that participants could work towards. See Figure 6 for a side-by-side comparison of the original Yu et al paradigm and the adapted, age-appropriate version.

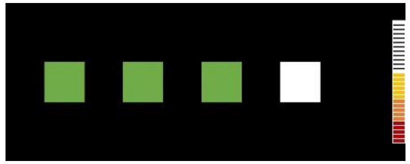
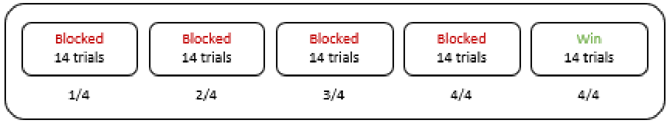
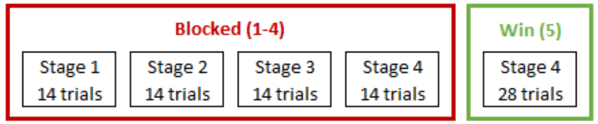
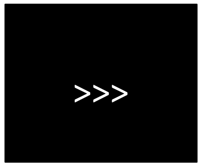
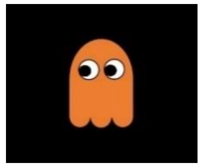
Adaptation	Yu et al. (2014) Paradigm	Adapted Paradigm
1, 4, 5		
2	Number of trials: 210; completion time: ~60 minutes 	Number of trials: 84; completion time: ~25 minutes 
3		

Figure 6. Comparison of the original Yu et al. (2014) paradigm and the adapted version. Yu et al. (2014) examples re-drawn.

1. Removal of the 'effort' manipulation, therefore removing the need for 'pre-completed' stages as indicated by the gradient-filled stages in the Yu paradigm.
2. Shortening the trial length and time from 210 trial (~1 hour) to 84 (~25 minutes) by only using the 'proximity' manipulation keeping the hidden feedback structure the same across the four blocked stages and one win condition.
3. Replacing the arrow stimuli with a cartoon ghost character 'Ghostie'.
4. Re-drawing the aesthetics of the task such that one stage was represented by one single rectangle as opposed to two.
5. Filled green rectangles indicated within-trial progress and a new progress bar at the side indicated cumulative reward across the task.

2.1.3 Aim and hypotheses

The aims of the pilot studies were three-fold. The first aim was to replicate the findings of the frustration-induction task reported in Yu et al., (2014) using the adapted paradigm outlined above in both an adult (Pilot Study One) and an adolescent (Pilot Study Two) sample. Though the focus of the replication was on the frustration induction, this also included replication of decreasing reaction times to ensure the adapted paradigm was motivating and engaging. The second aim was to test a further modified version of the task to validate a more sensitive measure of frustration based on feedback from the first two pilot studies (described below in Pilot Study Three). The final aim of the pilot studies was to verify that the task-elicited frustration was conceptually similar to other measures of frustration (i.e. construct validity, Pilot Study One) and whether it was related to reactive aggression (Pilot Study Three). To this end, Pilot Studies One and Three respectively explored whether the frustration elicited in the task was related to two existing frustration related questionnaires (Frustration-Discomfort Scale [Harrington, 2005]; Frustrative Non-Reward [Wright et al., 2008]) and an aggression questionnaire (Reactive-Proactive Aggression [Raine et al., 2006]).

It was hypothesised that for all pilot studies: a) frustration induction would be parametrically modulated such that the closer participants are to the reward when blocked, the greater the self-reported level of frustration; b) task reaction time would decrease as the number of successfully completed stages increases, suggesting investment in the task and increased motivation to win as the participant gets closer to the reward, and; c) questionnaire measures of frustration tolerance (Frustration Discomfort Scale; Frustrative Non-Reward) would be correlated with self-report measures of frustration, suggesting construct validity for our frustration task, and revealing reliable individual differences in the self-reported affective experience of frustration. Further, for Pilot Study Three it was hypothesised that task-elicited frustration would correlate with the reactive aggression subscale (Reactive-Proactive Aggression questionnaire; Raine et al., 2006) reflecting the relationship between frustration and reactive aggression.

2.2 Pilot Study One: Adult sample

2.2.1 Methods

2.2.1.1 Participants

Participants were 31 undergraduate students (Age_M=20.79 years, Age_{SD}=4.15; 93% female; 93% right-handed) recruited through the participant pool in the Department of Psychology at Royal Holloway. Participants received course credit for participation. Sample size was determined by the number of participants in the studies reported by Yu et al. (2014) which averaged an N=22 (range=20-27). Ethical approval for the study was granted by Royal Holloway College Ethics Committee and participants gave informed consent.

2.2.1.2 Materials

2.2.1.2.1 Frustration paradigm

The computerised task was a 25-minute game-like frustration paradigm adapted from Yu et al., (2014) as described above (see Figure 7 for task timeline) and was presented using Psychtoolbox v3.0.11 (Brainard, 1997; Kleiner et al, 2007) running in Matlab

2014a (MathWorks, 2014). The adapted paradigm was composed of 84 trials, each trial comprised of four identical stages of ‘game play’. Participants had to successfully complete all four stages to win a trial and earn a reward token. Each stage began with a ‘cue’ image presented for 2 seconds. This was replaced with a fixation cross for 0.75 seconds, followed by the task stimuli (cartoon Ghostie looking left/right), presented once per stage. The order of eye-gaze direction for the task stimuli was randomised. The task stimuli were displayed on screen until participants responded or for a maximum of 1 second. To respond correctly participants had to press the left/right arrow key that corresponded to the direction in which Ghostie was looking. If participants responded correctly and within the time limit they would continue on to the next stage in the trial, indicated by the presentation of an updated ‘cue’ image to show their progress through the trial. If participants responded incorrectly or too slowly, they would be presented with the feedback ‘blocked’ which would end the trial and forfeit the reward token for that trial.

As in the Yu et al. (2014) paradigm, to induce frustration participants were systematically blocked at each of the four stages within the trial irrespective of their response, in line with a hidden feedback structure. Participants were blocked at stages 1-4 (blocked conditions 1-4 respectively) 14 times each and were able to win in 28 trials, i.e. participants were able to complete the trial with no pre-determined blocked feedback (condition 5, or ‘Win’ conditions). Trial order was pseudo-randomised such that the same condition would not be repeated more than twice in a row. To avoid suspicion about the task manipulation, participants were told that the computer randomly allocates a response time for each stage of each trial that they must respond within to win as in Yu et al. Once a trial ended (either participants are blocked or win the trial), corresponding feedback of ‘BLOCKED’ or ‘WIN’ was presented on screen for 2 seconds. Finally, as a manipulation check, participants were asked to confirm whether they were blocked or had won the trial by selecting one of the two options: BLOCKED or WIN. The confirmation options were presented side by side and the order of presentation was randomised such that each option appeared on either the left or right hand side of the screen approximately 50% of the time. Participants were not encouraged to respond as quickly as possible during the confirmation stage, only as accurately as possible, and so were given a maximum of 3 seconds to respond. In the Yu et al., (2014) study this instruction was given to ensure that response force (i.e. pressure with which participants pressed the response buttons) was not confounded by speed of response, such that a quicker response would more likely result in greater response force. Although the present study did not use a response force measure, instructions were kept consistent so that a force measure could be used in subsequent studies (see Chapter 3), and to enable replication of behavioural effects.

At the end of the task participants were then asked to self-report on how frustrated, motivated and surprised they felt at each of the four blocked conditions (blocked at stages 1-4) on a Likert-scale of 1 (‘Very slightly or not at all’) – 10 (‘Extremely). For self-report ratings of frustration and surprise participants were asked ‘How _______ did you feel when you were blocked at this stage’. For motivation ratings the question was slightly adapted for clarity and asked ‘How motivated did you feel before you were blocked at this stage?’ (the meaning of the motivation question as used by Yu et al. (2014) was clarified with the author and interrogates how motivated participants were to win the trial at a given stage prior to blocking). There were no restrictions on time for these to be answered and the order of which they were presented were randomised. The motivation and surprise items were included as greater motivation is associated with an increased frustration response (Buss, 1963), and surprise acts as a measure of the unexpectedness of the blocking, as unexpected goal-blocking has been associated with a greater frustration response (Kregarman & Worchel, 1961). An optional 1-minute break was also added to the midpoint of the paradigm (42nd trial) mid-testing of the first pilot study following participant feedback. Consequently, 17 participants had no break while the remaining 14 had the option of a 1-minute break.

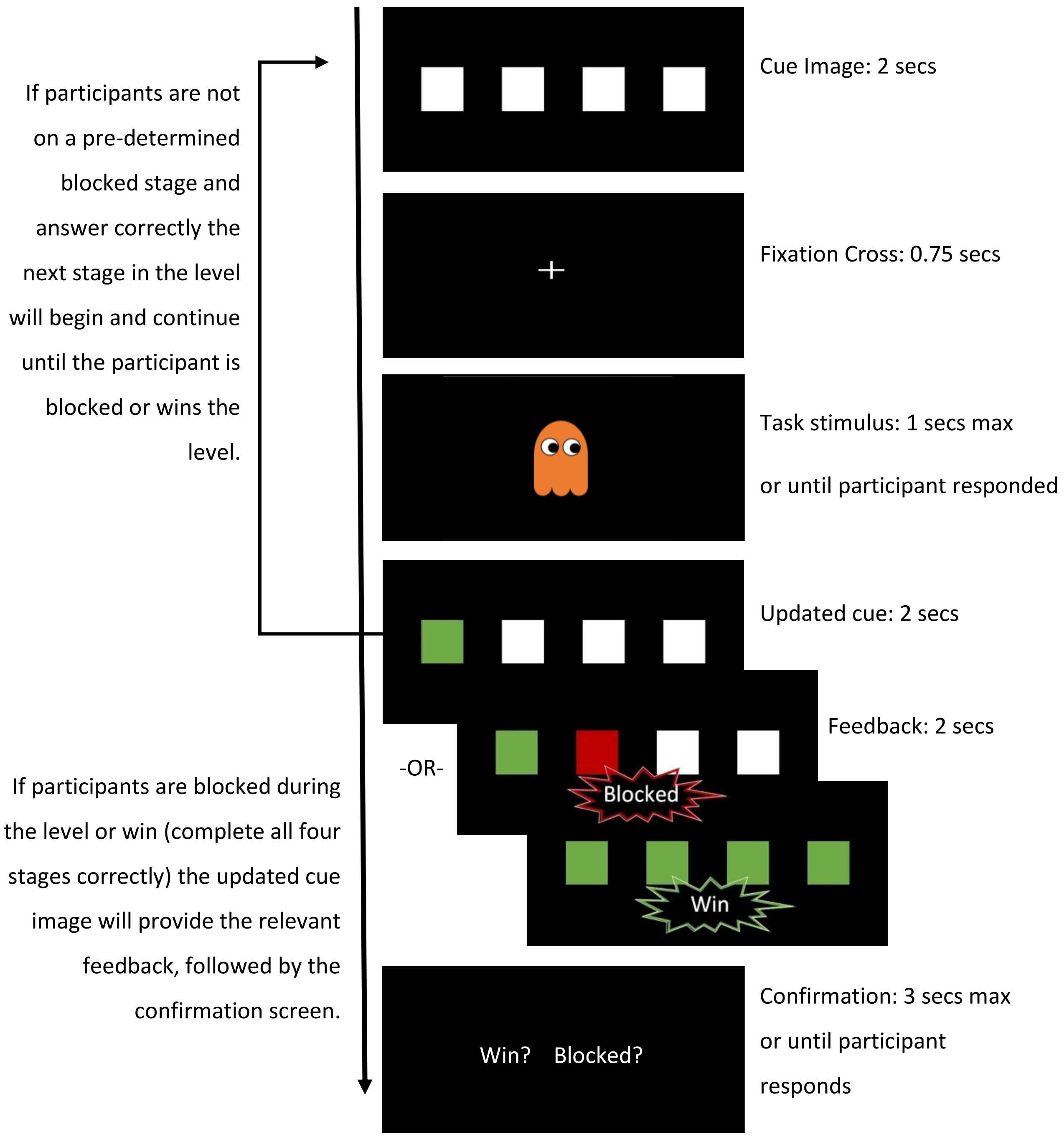


Figure 7. Task timeline of the adapted frustration paradigm. Not shown is the progress bar presented to the right of the screen.

2.2.1.2.2 Questionnaire battery

The questionnaire battery was completed by pen and paper.

Demographics

Basic demographic information was recorded including age, gender and handedness.

Frustration-Discomfort Scale (FDS) subset

The FDS is a 35-item (five-factor) measure of frustration intolerance (Harrington, 2005). An example item is 'I can't bear it if people stand in the way of what I want', and all items are scored on a 5-point Likert scale 1 ('Absent') – 5 ('Very strong'). However, only 9-items (see Appendix 2) were chosen from the entire FDS scale for the current study as these had been identified as most closely related to the frustration response in a previous study (Bebane et al. 2015). These items primarily came from the 'Fairness' and 'Gratification' subscales which were derived from splitting the 'Entitlement' subscale from the four-factor model (see Chapter 1.3.1 for more details), plus one item from the 'Discomfort Intolerance' subscale.

Frustrative Non-Reward (FNR)

The FNR is a 5-item subscale designed by Wright, Lam & Brown (2009) to measure an individual's propensity for low levels of 'approach' motivation after experiencing non-reward. That is, how likely is a person willing to persist towards a goal following the experience of non-reward (frustration). An example item is *'when circumstances prevent me from achieving my goal, I find it hard to keep trying'*. All items are scored on a 4-point Likert scale 1 (‘Very true for me’) – 4 (‘Very false for me’) and reverse scored such that a high score would suggest a low propensity to continue or low approach motivation following non-reward, e.g. goal-blocking.

The FNR was designed as an add-on to the pre-existing Behavioural Approach and Inhibition Systems questionnaire (BAS/BIS; Carver & White, 1994). Both the BAS and BIS are motivational systems which differentially respond to levels of reward and non-reward. Frustrative non-reward has been theorised to activate both systems, therefore Wright et al., (2009) sought to measure this independently. While the FNR subscale was not designed as a stand-alone measure, the FNR may be a proxy to frustration tolerance, although to our knowledge this has not been explored empirically. Given frustration is defined as a blocking of a goal or reward, the addition of the 5-item FNR scale to the questionnaire pack was deemed worthwhile as an exploratory validation of a potential frustration tolerance measure.

2.2.1.3 Procedure

Participants read and signed the information sheet and consent form, then were given the instructions for the computer task and an opportunity to ask questions. Participants completed the adapted frustration paradigm followed by the questionnaire measures. Participants were verbally debriefed and provided with a debrief sheet including the mild deception (i.e. that blocking was predetermined and not a result of their responding) but no participants expressed concern or withdrew their data as a result.

2.2.1.4 Data analyses

All analyses were conducted in R using RStudio (R Core Team, 2017; RStudio Team, 2016) and SPSS (version 21)[1] unless otherwise stated.

A repeated measures ANOVA was used to test the efficacy of the frustration manipulation across the four blocked conditions (i.e. blocked at stages 1, 2, 3 or 4) with self-reported frustration as the dependent variable. Specifically, the linear contrast term of increasing frustration (1<2<3<4) was explored as there was a clear prediction for frustration to follow this pattern based on Yu et al's (2014) findings. Repeated measures ANOVAs were also used to analyse differences in motivation and surprise across the four blocked conditions. All ANOVA post-hoc analyses used Bonferroni corrections to be conservative.

In line with Yu et al. (2014), correlations were used to explore the relationships between overall mean ratings of frustration, motivation and surprise. However, given the findings of increasing frustration and motivation reported by Yu et al., using a mean score to explore the nature of the relationships between the different ratings may dilute the effect. As such, the nature of these relationships were further explored by running correlations between the self-reported measures at corresponding stages (i.e. Frustration at Stage 1 and Motivation at Stage 1) as this may provide a more

[1] ANOVAs were conducted in R but the associated Mauchly's sphericity test and linear/quadratic trend were calculated in SPSS.

nuanced understanding of whether frustration may be differentially related to motivation and surprise at different stages . Yu et al. among others in the literature have highlighted the potential influence of motivation and surprise on frustration, and indeed Yu et al. found motivation increased as a function of proximity and that mean motivation was positively correlated with mean frustration, though there was no significant effect of surprise. Therefore, these correlations were included to check whether motivation and surprise would relate to frustration.

Repeated measures ANOVA was used to assess change in task reaction time (tRT) across all five conditions with post-hoc analyses using Bonferroni corrections in line with Yu et al. (2014) analyses.

Finally, to explore the relationship between the FDS and FNR items and frustration induced in the task, total scores were summed for each of the FDS and FNR scales and correlated with overall mean self-report task-induced frustration, with frustration ratings at each of the four blocked conditions and with each other.

2.2.2 Results

Exclusion criteria were: >± 3 SD above the group mean on total mean errors at confirmation phase (i.e. response of ‘win’ or ‘blocked’ to outcome of the trial, N=1); >± 3 SD in reaction times collapsed across conditions during task phase (N=1; this participant also had no saved self-report data due to technical faults), and; >± 3 SD above the group mean on total mean errors collapsed across conditions during task phase (i.e. responses to ghost eye-gaze direction; N=0). This resulted in a final sample of 29 participants. Mean accuracy for the task was high (93.60%; total no. errors collapsed across conditions: M = 5.38, SD = 4.48), suggesting participants were able to complete the task with ease.

2.2.2.1 Self-report task data

a. Task-induced self-reported frustration

Repeated measures ANOVA of self-report data found a significant main effect of blocked condition (blocked at each of stage 1, 2, 3 or 4; $F(3, 84)= 20.84$, $p<.001$, $\eta_p^2=.43$; Greenhouse-Geisser corrected due to violated Mauchly's sphericity [$X^2(5)=26.98$, $p<.001$]). Post-hoc analyses showed that frustration ratings were significantly higher after being blocked at stage 4 (M=8.03, SD=2.03) than when blocked at stage 3 (M=5.97, SD=1.70), stage 2 (M=4.41, SD=1.90) and at stage 1 (M=4.90, SD=3.23; all $p's<.001$). Additionally, frustration ratings were significantly higher after being blocked at stage 3 than stage 2 ($p<.001$), but there were no other significant differences between stages (see Figure 8a). That is, frustration at stage 1=2<3<4. Overall, participants reported higher levels of frustration when they were blocked at a later stage i.e. closer to the reward. Results also show a significant linear trend ($p<.001$), suggesting the task is broadly able to parametrically modulate levels of frustration (although the lack of a significant difference between stages 1 and 2 was not in line with predictions).

b. Self-reported Motivation

Repeated measures ANOVA of self-report motivation found a significant main effect of Condition ($F(3,84)=25.86$, $p<.001$, $\eta_p^2=.48$; Greenhouse-Geisser corrected due to violated Mauchly's sphericity [$X^2(5)=23.13$, $p<.001$]). Post-hoc analyses revealed that motivation was significantly increased with each stage compared to the prior stage, following a parametric fashion of stage 1 ($M=3.34$, $SD=2.48$) < stage 2 ($M=4.52$, $SD=2.06$) < stage 3 ($M=5.38$, $SD=1.52$) < stage 4 ($M=6.72$, $SD=2.12$), all *p's*<.05. As with frustration ratings, motivation ratings across the four stages followed a significant linear trend ($p<.001$), indicating that participants were more motivated the closer they were to the reward (see Figure 8b).

c. Self-reported Surprise

Repeated measures ANOVA analyses for self-reported surprise found a significant main effect ($F(3,84)=10.59$, $p<.001$, $\eta_p^2=.28$; Greenhouse-Geisser corrected due to violated Mauchly's sphericity [$X^2(5)=29.80$, $p<.001$]). Post-hoc analyses found ratings of surprise were significantly greater when blocked at stage 4 ($M=7.45$, $SD=2.18$) compared to stage 3 ($M=5.76$, $SD=1.92$) and stage 2 ($M=5.07$, $SD=2.49$; all *p's*<.001), but no significant difference between surprise at stage 4 and stage 1 ($M=6.76$, $SD=3.00$). Rather, surprise at stage 1 was significantly greater than at stage 2 ($p<.001$). These findings were supported by a significant quadratic trend ($p<.001$). See Figure 8c.

d. Frustration, Motivation and Surprise correlations

Correlations between overall mean frustration, motivation and surprise (collapsed across the four blocked conditions) revealed no significant relationship between frustration and motivation, but did reveal a strong positive relationship between frustration and surprise ($r(27)=.60$, $p<.001$). Correlations between the frustration, motivation and surprise ratings at each of the four stages (i.e. stage 1 frustration correlated with stage 1 motivation etc.) also found no consistent relationship between either frustration and motivation or frustration and surprise, i.e. no correlation when any of the four corresponding stages across ratings were correlated (e.g. frustration and motivation ratings at stage 1). There were however some significant correlations at corresponding stage; frustration and motivation were significantly positively correlated at stages 2 ($r(27)=.39$, $p=.037$ (although note that this would not survive correction across the four correlations conducted) and stage 4 ($r(27)=.53$, $p=.003$), while frustration and surprise were significantly positively correlated at stage 1 (r=(27).57, $p=.001$) and stage 3 ($r(27)=.55$, $p=.002$).

2.2.2.2 Reaction time data

Repeated measures ANOVA analyses of task reaction time, i.e. response time to indicate ghost eye-gaze direction, revealed a significant main effect of blocked condition ($F(4,112)=28.17$, $p<.001$, $\eta_p^2=.50$; Greenhouse-Geisser corrected due to violated Mauchly's sphericity [$X^2(9)=24.13$, $p=.004$]). Post-hoc analyses reveal significantly faster reaction times at stage 4 (win condition (M=375ms, SD=50ms);

blocked condition (*M*=374ms, *SD*=52ms)), stage 3 (*M*=391ms, *SD*=59ms) and stage 2 (*M*=387ms, *SD*=53ms) compared to stage 1 (*M*=431ms, *SD*=48ms; all *p's*<.001). Additionally, reaction times at stage 4 on win conditions and at stage 4 on blocked conditions were significantly (*p*<.001) and marginally significantly (*p*=.057) quicker than at stage 3 respectively. The data fit both linear and quadratic trend equally well (both *p*<.001). See Figure 8e.

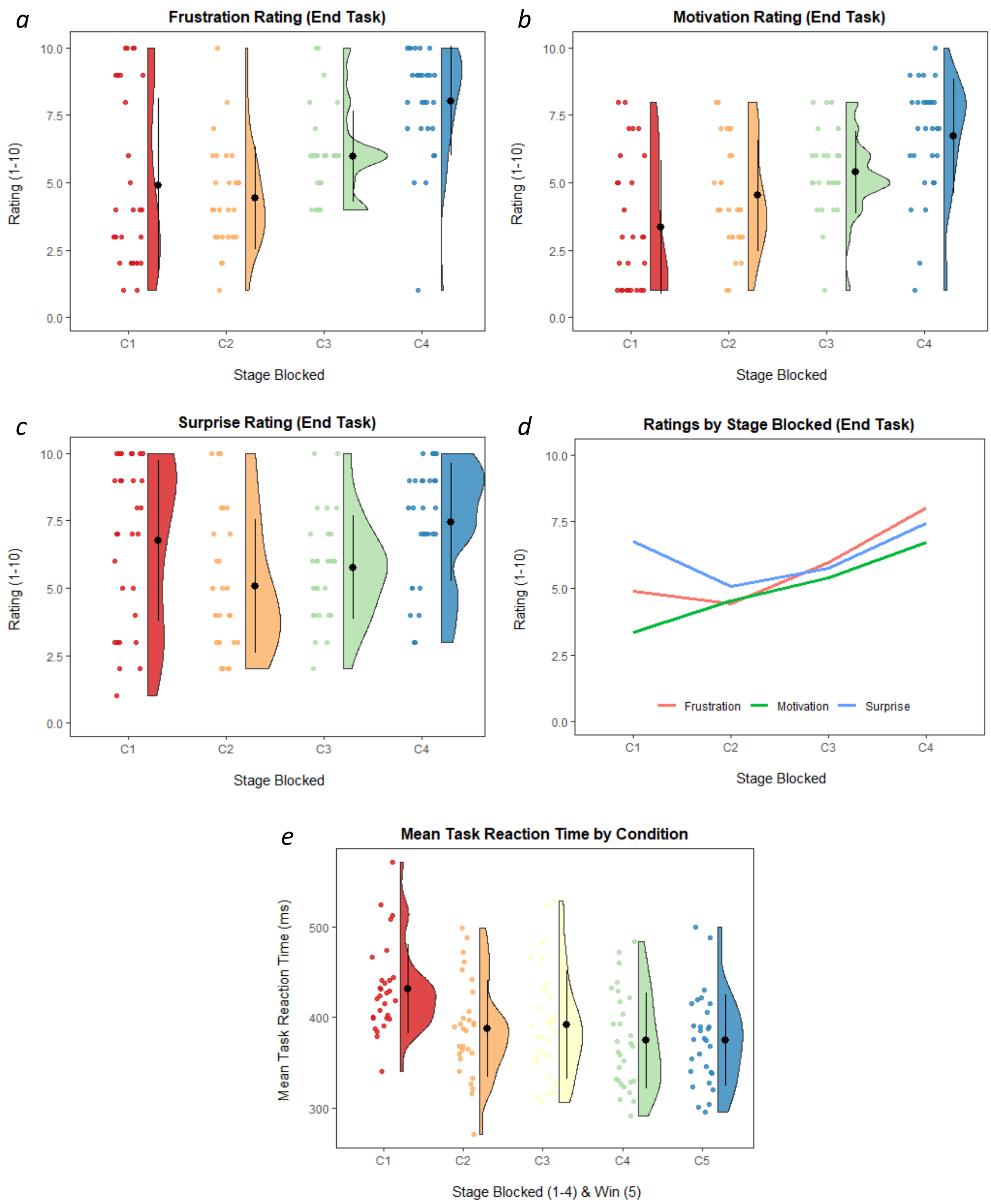


Figure 8. Raincloud plots[2] of the end task self-report ratings of a) frustration, b) motivation and c) surprise at each stage blocked; d) overall mean of each rating type at each stage blocked, and; e) task reaction times across each stage including stage 4 during blocked conditions (C1-C4) and win conditions (C5).

[2] Raincloud plots are an alternative, richer, way to display descriptive statistics (mean and standard deviation depicted with the black dot (mean) and lines (standard deviation)), which allow you to also see the raw data, depicted in the individual plot points to the left hand side, and the dispersion and density of the data, depicted in a half-violin plot shown on the right hand side (Allen, Poggiali, Whitaker, Marshall & Kievit, 2019).

2.2.2.3 Relationships between Task-induced and Questionnaire-based Frustration

Overall mean frustration was not significantly related to scores on either the Frustration Discomfort Scale (FDS) or the Frustrative Non-Reward (FNR), although there was a trend towards a positive relationship with the FNR ($r(27)=.36$, $p=.074$). Similarly, frustration ratings at each of the four blocked stages were not significantly related to either the FDS or FNR. The FDS and FNR scales were also not significantly correlated with each other.

2.2.3 Discussion

The current study investigated the replicability and validity of an adapted version of a pre-existing frustration paradigm in a sample of adults. In line with the first hypothesis, task-induced frustration linearly increased as a function of proximity to reward, though this increase was not parametrically modulated to the extent hypothesised (i.e. results showed the pattern 1=2<3<4, rather than 1<2<3<4). Additionally, generally increasing patterns were found in the ratings of motivation (1<2<3<4) while ratings of surprise (1>2=3<4) were a better fit to a quadratic 'U'-shaped trajectory. The relationship between frustration, motivation and surprise remains complex, with the data suggesting that frustration, motivation and surprise may vary differentially by stage. Consistent with our second hypothesis, and replicating Yu et al. (2014), task reaction times followed a significantly decreasing linear trend such that participants were quicker to respond to the direction of the ghost character across the four stages as participants got closer to the reward. These results suggest that participants were increasingly motivated to win the trial as they progressed through the stages, providing additional information with which to interpret the increasing frustration findings. Reaction time data were also more sensitive than the self-report ratings of motivation, since reaction times were measured on every trial. Finally, contrary to our final hypothesis there were no significant relationships between task induced frustration and questionnaire measures of frustration tolerance (Frustration Discomfort Scale and Frustrative Non-Reward questionnaire).

These results confirm the first research aim of replicating the key findings from Yu et al. (2014) of increasing frustration and decreasing reaction time across the four stages. The frustration findings in particular are consistent with previous literature that goal-blocking is a robust method of eliciting affective frustration (De Botton, 2011; Rich et al. 2007). This suggests that the adapted paradigm is a valid frustration paradigm as it elicits frustration in a similar parametric fashion to the original paradigm and shows an increase in frustration in response to goal-blocking as has been reported more generally in the literature when block-design frustration paradigms have been used (e.g. Klöppel et al. 2009; Abler et al. 2005; Lewis et al. 2006). The generally decreasing pattern of reaction times (1>2=3>4/5) suggests increased engagement and investment in the task and increased motivation to win when the reward is closest, i.e. participants are on the final stage. That participants were significantly quicker to respond at all subsequent stages compared to stage 1 may reflect a generally increased preparedness to respond, with stage 1 acting as a prompt that the trial has begun.

This study also replicated Yu et al.'s subsidiary analyses of increasing self-reported motivation with stage, but unlike Yu et al. the current study also found increased levels of surprise at stages 1 and 4 relative to 2 and 3 (Yu et al. reported no overall effect of surprise). One interpretation is that the elevated ratings of surprise at stages 1 and 4 are related to the probabilities associated with being blocked at these stages. At the beginning of the trial, there are four possible stages at which one could be blocked, therefore being blocked at the initial stage of play is less likely and more unexpected (surprising). Similarly, the probability of having succeeded until the final stage of play to then be blocked at stage 4 is small, whereas the probability of winning the trial has now increased compared to at earlier stages as there are fewer stages left to complete, i.e. fewer chances of being blocked (see Figure 9 for probabilities of winning each stage and the trial). Additionally, even though participants are told the reaction time threshold changes, that their responses have been quicker than the changing thresholds so far participants might assume they have a good chance of beating the threshold again, particularly since the ratings are taken as an average over a number of trials and participants will learn over time what the smallest threshold is for reaction time. At the same time, motivation to win is increased at stage 4 as the participants are the closest to the reward and, again, the probability of winning the trial is higher compared to previous stages. As a result, both surprise and motivation increase when participants are blocked at stage 4.

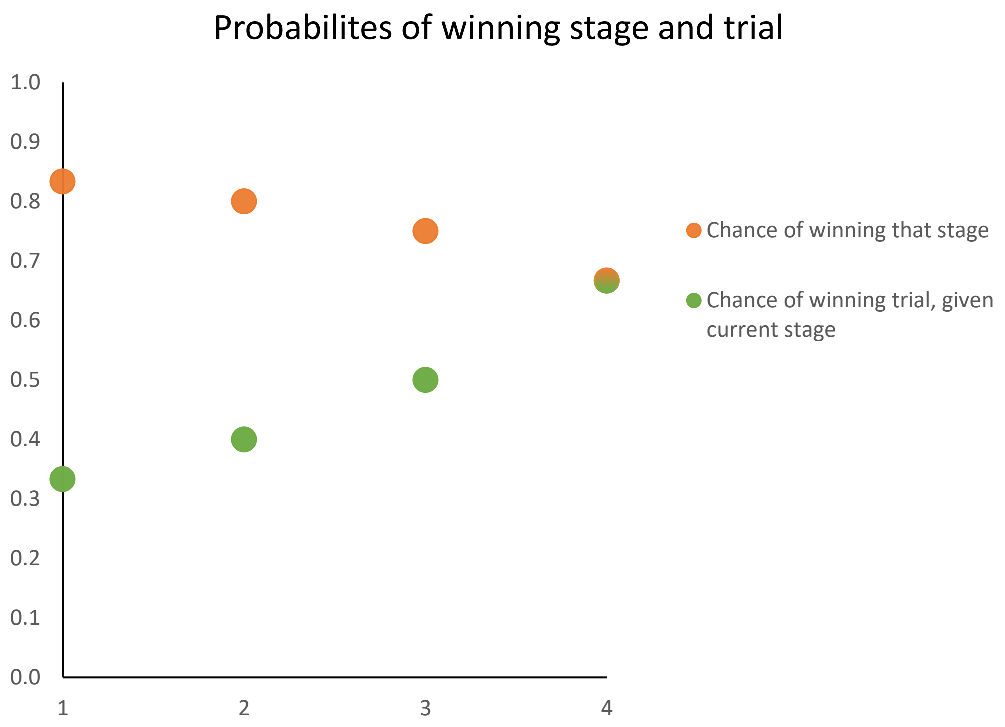


Figure 9. Plot of the probabilities of winning each stage, given the current stage of the trial (orange) and of winning the trial given the current stage (green). This was calculated based on the total number of trials (84) and the number of blocked trials for each condition (14).

Given that the ratings of both motivation and surprise show changes as a function of the task manipulation, it is important to consider how motivation and surprise may interact with frustration. Previous research suggests that both motivation and surprise may influence the strength of the frustration response (e.g. Dollard et al. 1939; Kregarmen & Worchel, 1961; Worchel, 1974). In these analyses there was no evidence of multicollinearity (*r*>.80) or even of significant correlations at each of the four stages of the task between frustration, motivation and surprise, suggesting each scale captured different things. However, it should be noted that both motivation and surprise were significantly correlated with frustration at two of the four stages and these correlations all showed large effect sizes (*r*>.50; Cohen, 1998) with the exception of one medium effect size (*r*>.30; stage 2 ratings of frustration and motivation). Overall mean surprise was significantly positively correlated with overall mean frustration, again with a large effect size (*r*=.60). The evidence appears to suggest that the levels of motivation and surprise may influence (or at least be related to) the level of frustration elicited, but at different stages of the trial. For example, at stage 1 surprise is greater than frustration but is also positively correlated, i.e. as surprise increases frustration increases. This suggests that frustration may be more strongly influenced by surprise at this stage, where surprise is high and motivation low. In contrast, at stage 4 frustration was positively correlated with motivation, at a point where participant motivation levels were highest compared with earlier stages. These findings highlight the importance of taking additional self-report measures, which can help to contextualise the key variable of interest (i.e. frustration).

Finally, there were no significant relationships between task induced frustration and either measure of frustration tolerance (Frustration Discomfort Scale or Frustrative Non-Reward). This may suggest that the task-elicited frustration is not conceptually similar to frustration (in)tolerance. However, it is important to interrogate the suitability of the two frustration tolerance measures used for the purpose of this study. The FDS may not be reflective of frustration in the same way that the task elicits frustration. The task elicits frustration due to blocking a desired goal, however the FDS items are related to 'common thoughts and beliefs that people may have *when* they are distressed or frustrated' (Harrington, 2005, p.381). This suggests the items are measuring beliefs they may hold when they are *already* frustrated, i.e. frustration tolerance, rather than how easily they may become frustrated. Additionally, although the items used were the only items to load on a factor labelled ‘frustration’ in a previous study (Bebane et al. 2015), at face value they seem to be more related to entitlement or personal injustice, such as ‘people stand[ing] in the way of what I want’ or ‘being treated unjustly’. Indeed, Harrington (2005) noted that high scores on the entitlement scale (from which the two subscales ‘Fairness’ and ‘Gratitude’ are derived and are where the majority of the 9 items used in the current study were taken) are more related to control over others, and so is not necessarily targeting frustration in the same way that the task is measuring it. Similarly, the FNS was not designed as a standalone measure of frustration, but as part of a broader measure of approach/avoidance motivation. Wright et al. (2009) mention that the scale had adequate reliability and validity, however the construct validity of the scale was based on measures of apathy and persistence, not frustration. As such, in the broader context of what the measure was designed for it is perhaps unsurprising that it is not related to the task induced frustration in the present study. Indeed, throughout the frustration literature there appears to be a lack of questionnaire measures tapping individual differences in the affective experience of frustration specifically.

In sum, the task functioned as expected; the findings replicated those of Yu et al. (2014). While task elicited frustration does not appear to be conceptually similar to existing self-report measures of frustration tolerance, these measures appear to tap subtly different constructs. Overall, the adapted paradigm appears a valid measure of escalating frustration in an adult population. In Pilot Study 2, the paradigm was tested in an adolescent sample.

2.3 Pilot Study Two: Adolescent sample

Pilot Study One replicated the results of the adapted paradigm in an adult sample, however the paradigm was adapted to be age-appropriate for an adolescent population in order to explore how frustration may develop across adolescence. As such, it was necessary to validate the adapted paradigm in an adolescent sample.

2.3.1 Methods

2.3.1.1 Participants

Participants were 29 adolescent students recruited through a university 'taster day' organised by the Royal Holloway Department of Psychology for students aged 16-18 (Age_{M}=16.76 years [Age_{SD}=.70 years]; 71% female; 92% right-handed). Ethical approval for the study was granted by Royal Holloway College Ethics Committee and participants' provided their own informed consent (as all were over the age of 16).

2.3.1.2 Materials

Participants completed the adapted frustration paradigm as in Pilot Study One using Psychtoolbox v3.0.11 run in Matlab 2015a. Participants also completed the Frustration Discomfort Scale and the Frustrative Non-Reward questionnaire measures by pen and paper, however these were not included in the analyses due to experimenter error and will not be further discussed.

2.3.1.3 Procedure

The current study was run as two group testing sessions (morning and afternoon; participants were split between the two sessions with ~46% and ~54% in the morning and afternoon session respectively) held at Royal Holloway, University of London as part of a Psychology taster day event. Participants were provided with an information sheet and consent form, which were verbally explained by the experimenter. Participants were then explained task instructions and given the opportunity to ask questions. All participants were then orally debriefed.

2.3.1.4 Data analyses

Data were analysed as outlined in Pilot Study One.

2.3.2 Results

Exclusion criteria were: >± 3 SD above the group mean on total mean errors at confirmation phase (i.e. response of 'win' or 'blocked' to outcome of the trial, N=1); >± 3 SD in reaction times collapsed across conditions during task phase (N=0), and; >± 3 SD above the group mean on total mean errors collapsed across conditions during task phase (i.e. responses to ghost eye-gaze direction; N=0). Additionally, two participants were excluded due to age exceeding the adolescent age range (>18 years) and one participant was excluded due to technical issues resulting in no saved data. This resulted in a final sample of 25 participants. As with Pilot Study One, mean accuracy for the task was high (90.52%; total no. errors collapsed across conditions: *M*=7.96, *SD*=9.24).

2.3.2.1 Self-report task data

a. Task-induced self-reported frustration

Repeated measures ANOVA of self-report frustration data found a significant main effect of blocked condition (blocked at stage 1, 2, 3 or 4; $F(3,72)=5.15$, $p=.006$, $\eta_p^2=.18$; Greenhouse-Geisser corrected due to violated Mauchly's sphericity [$X^2(5)=11.14$, $p=.049$]). Post-hoc analyses revealed only one significant difference between blocked conditions; frustration ratings were significantly higher after being blocked at stage 4 ($M=7.04$, $SD=3.06$) than when blocked at stage 1 ($M=4.68$, $SD=3.08$; $p=.019$). There were no significant differences between stage 2 ($M=5.20$, $SD=2.53$) or stage 3 ($M=6.28$, $SD=2.17$) and any other stages. Results also show a significant linear trend ($p=.003$), see Figure 10a. The parametric modulation of frustration is not as strong as in the adult sample (Pilot Study One), therefore a 2 (Age: adult, adolescent) x 4 (Blocked condition 1-4) ANOVA was run to explore whether the level of frustration induced was different between the adult sample in Pilot Study One and the current adolescent sample at each of the blocked stages. There was no significant main effect of Age ($F(1,52)=0.003$, $p=.953$) or significant interaction between Age and Blocked condition ($F(3,56)=1.76$, $p=.158$). There was a significant main effect of Blocked condition ($F(3,156)=21.36$, $p<.001$) as has been reported in both Pilot Study One and the current study, so will not be explored further here.

b. Self-reported Motivation

Repeated measures ANOVA of self-report motivation found no significant main effect of blocked condition (*F*(3,72)=1.04, *p*=.380, η_p^2=.04) and there was no significant linear or quadratic trend, see Figure 10b. Given there was a significant main effect of motivation in both Yu et al. (2014) and in Pilot Study One, a 2 (Age: adults, adolescent) x 4 (Blocked condition 1-4) ANOVA was conducted to explore whether the level of motivation, and therefore engagement with the adapted paradigm, was different between the adult sample (Pilot Study One) and the adolescent sample of the current study in each of the four blocked conditions. There was no significant main effect of Age (*F*(1,52)=2.22, *p*=.142), however there was a significant main effect of Blocked condition (*F*(3,156)=13.07, *p*<.001) and a significant interaction between Age and Blocked condition (*F*(3,156)=3.83, *p*=.011). To explore this interaction further, t-tests were run between the adult and adolescent samples at each of the four blocked conditions. Adolescents reported significantly higher levels of motivation prior to being blocked at stage 1 (*t*(52)=2.57, *p*=.013) but there were no significant differences at any other stage.

c. Self-reported Surprise

Repeated measures ANOVA analyses for self-reported surprise found a significant main effect of blocked condition (*F*(3,72)=4.91, *p*=.004, η_p^2=.17). Post-hoc analyses found ratings of surprise were significantly greater when blocked at stage 4 (*M*=6.64, *SD*=2.94) compared to stage 2 (*M*=4.64, *SD*=2.36, *p=.007*) and were marginally significantly greater compared to stage 3 (*M*=5.40, *SD*=2.58, *p*=.086), but revealed no other significant differences between surprise at stage 4 and stage 1 (*M*=5.12, *SD*=3.00). See Figure 10d for plot. Linear and quadratic trends were significant (*p*=.019; *p*=.034 respectively).

d. Frustration, Motivation and Surprise correlations

Correlations between overall mean frustration, motivation and surprise (collapsed across the four blocked conditions) revealed significant positive relationship between frustration (*M*=5.80, *SD*=1.84) and motivation (*M*=5.64, *SD*=1.57; *r*(23)=.51, *p*=.010) and between frustration and surprise (*M*=5.45, *SD*=2.17; *r*(23)=.46, *p*=.020) but no significant relationship between motivation and surprise. While there were no consistent correlations between the ratings at each of four stages, there were some significant correlations at some of the stages: as in Pilot Study One, frustration and motivation were significantly positively correlated at stage 4 (*r*(23)=.44, *p*=.029), while frustration and surprise were significantly positively correlated at stage 1 (*r*(23)=.52, *p*=.007).

2.3.2.2 Reaction Time Data

Repeated measures ANOVA analyses of task reaction time, i.e. response time to indicate ghost eye-gaze direction, revealed a significant main effect of condition ($F(4,96)=14.53$, $p<.001$, $\eta_p^2=.38$; Greenhouse-Geisser corrected due to violated Mauchly's sphericity [$X^2(9)=30.14$, $p<.001$]). Post-hoc analyses reveal significantly increased (i.e. slower) reaction times at stage 1 (*M*=507ms, *SD*=103ms) compared to stage 2 (*M*=453ms, *SD*=103ms; *p*<.001), stage 3 (*M*=469ms, *SD*=98ms; *p*=.003) and stage 4 (blocked condition (*M*=443ms, *SD*=101ms; $p<.001$); win condition (*M*=454ms, *SD*=106ms; $p<.001$)). Reaction times at stage 3 were also significantly increased (i.e. slower) than at stage 4 (blocked condition, $p=.019$). Though data fit both linear and quadratic trends equally well ($p<.001$; $p=.005$ respectively), visual inspection (see Figure 10e) and post hoc tests suggests participants were responding more quickly with stage completed successfully, following a broadly linear pattern of 1>2=3>4 (whether blocked or win conditions at stage 4).

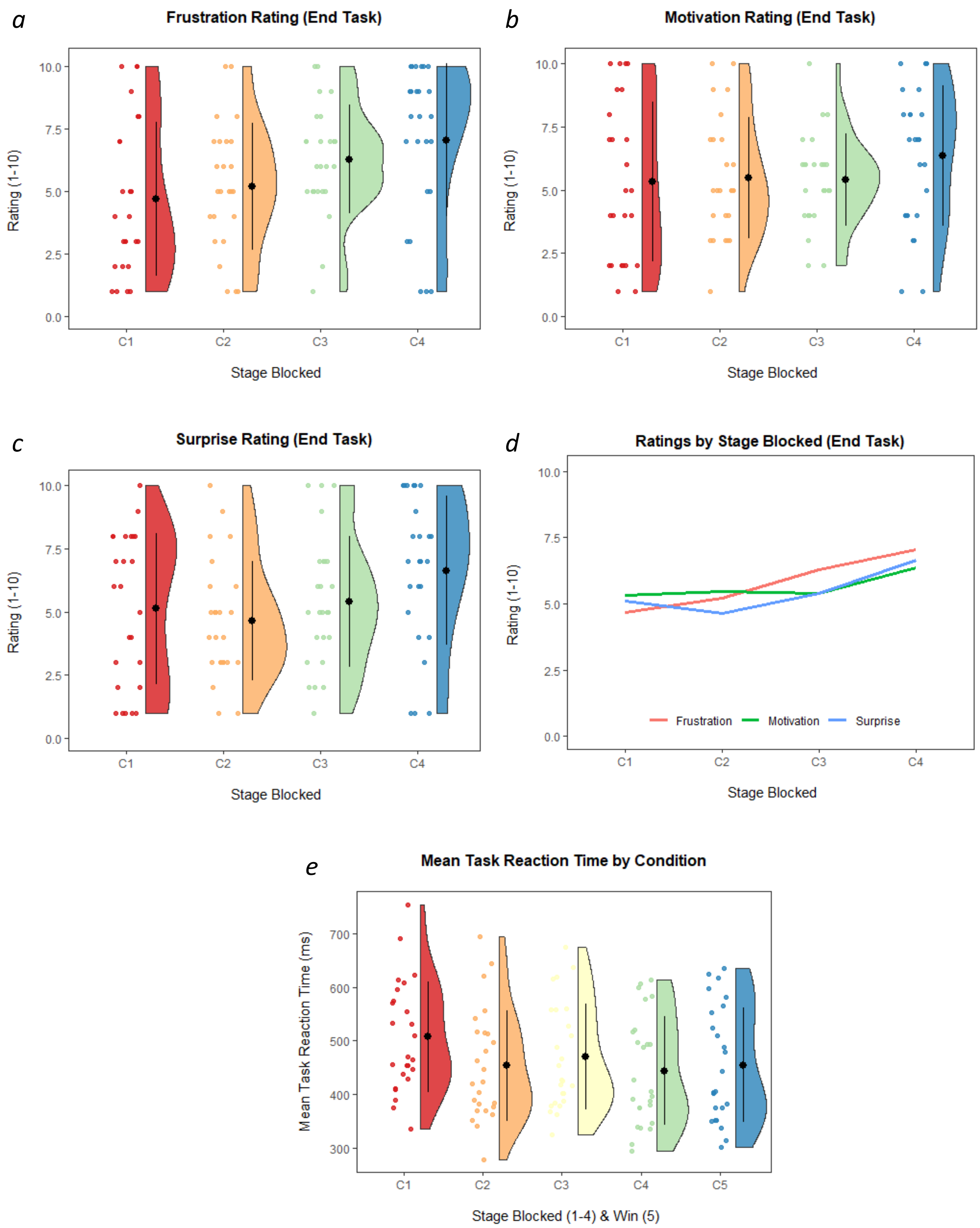


Figure 10. Raincloud plots of the self-report ratings of a) frustration, b) motivation and c) surprise at each stage blocked collected at the end of the task and raincloud plot of task reaction times across each stage including stage 4 during blocked conditions (C4) and win.

2.3.3 Discussion

Pilot Study Two further investigated the validity of an adapted frustration induction paradigm designed for adolescents by testing the paradigm with an adolescent sample. Consistent with the first hypothesis, frustration was rated the highest when participants were blocked the closest to the reward, following a linear trend. However, the degree of frustration elicited at each stage was not as differentiated in the adolescent sample as in the adult sample (Pilot Study One). Ratings of surprise followed a similarly increasing trajectory, however the current study found no significant change in motivation with blocked stages. The relationship between frustration, motivation and surprise is again not consistent, with overall mean ratings finding positive relationships between frustration and motivation and frustration and surprise but this not being replicated at the individual stage level, i.e. significant relationships at each of the four stages. Finally, consistent with the second hypothesis, reaction times were reduced the closer participants were to the reward.

Results from the current study largely mirror those of the adult sample (Pilot Study One) and Yu et al., (2014) suggesting the adapted paradigm can elicit frustration in an adolescent sample. However, it is important to note some of the discrepancies between the two pilot studies. Firstly, while the increasing linear trend of self-reported frustration is present, the modulation is not as strong in the adolescent sample as seen in the adult sample, i.e. the only statistically significant difference was between stage 4 and stage 1. Secondly, the adolescent sample did not show any differentiation between stages with the level of motivation. However, the frustration and motivation ratings of the adult and adolescent samples were on the whole not significantly different (except for motivation at stage 1 which was higher in adolescents), suggesting the task elicits broadly the same level of frustration and motivation in the adolescent sample as in the adult sample. One interpretation may be that while the goal is not immediately attainable (i.e. in stages 1, 2 and 3), adolescents may not be as incentivised to win, limiting the amount of frustration that would occur when they are blocked. Indeed, in the delay discounting literature adolescents show a steeper rate of delay discounting than adults. That is, the subjective value assigned to a reward decreases as a function of time more quickly in adolescents than in adults (de Water et al. 2017), suggesting a preference for immediate over delayed rewards in adolescents (O'Brien, Albert, Chein & Steinberg, 2011). Moreover, research has suggested that adults are able to compare immediate and delayed rewards more accurately than adolescents (Scheres, de Water & Mies, 2013). This might account for the similar levels of frustration and motivation reported between stages 1-3 in adolescents, compared to a steadily increasing level of motivation and frustration across the stages in adults.

An alternative but not necessarily mutually exclusive explanation could be that ratings reported at the end of the task ratings may not be sensitive enough to capture any potentially significant differences in frustration and motivation by stage blocked. End-task ratings require retrospective reflection of affective state over a ~25 minute period. With the length of the task and the randomisation of the trials it may be more difficult for an adolescent sample to accurately separate out their affective state by stage blocked. Using end-task ratings therefore presents a possible limitation with the current version of the adapted paradigm. Additionally, the end-task ratings were presented as each of the four blocked stages presented sequentially (though randomised) for one rating type, e.g. frustration, before moving on to the next rating, e.g. motivation. This might result in systematic effects on ratings due to order effects and demand characteristics, e.g. participants knowing that being blocked at stage 4 should induce more frustration and so rate it as such. The order of the stages presented for each question was randomised to minimise this effect, but as the ratings were only reported once in the whole task, it is still unclear as to whether order effects and/or demand characteristics may have confounded the results. Using in-task ratings that are taken immediately after participants are blocked may be better able to detect any modulation of affective state across the stages. It would also reduce noise in the measure, since multiple ratings would be averaged across several trials rather than participants reporting only one rating per stage, both of which would provide a stronger measure of frustration from a methodological standpoint.

One further limitation of the current version of the adapted paradigm is that there is no measure of how pleasant the reward ('win') condition was to participants. Motivation and pleasantness of a reward are related but not identical factors associated with inducing frustration (Yu et al., 2014). If the participant was not particularly incentivised by the reward, it is possible that the frustration induction would be less effective. As such, including a self-report rating related to the reward such as how pleasant participants find it to 'win' would provide a good control measure to ensure that participants are finding the task pleasant when winning, and are therefore incentivised to obtain the reward.

To summarise, the adapted paradigm was able to elicit frustration in an adolescent sample. While the adolescent sample did not show such a clear modulation of frustration by stage blocked, the descriptive statistics suggest a linear increase in frustration with stage blocked. However, there are two areas of potential improvement to the paradigm which may make it more effective for an adolescent sample. In the final version below, in-task ratings plus a measure of reward pleasantness were piloted in an adult sample.

2.4 Pilot Study Three: Adult sample

2.4.1 Aims

In Pilot Studies One and Two an adapted frustration induction was piloted in both an adult and adolescent sample, broadly replicating Yu et al. (2014). However, the results of Pilot Study Two highlighted two areas for improvement, namely, to include in-task ratings to provide more sensitive measures of affective state in response to being blocked, and to include a measure of how pleasant participants find ‘Win’ trials. Additionally, one purpose of creating an adapted frustration paradigm is to explore individual differences in the frustration response, e.g. with age, and the relationship this has with reactive aggression. Yet, neither of the previous pilot studies have included a measure of reactive aggression to explore whether the task-elicited frustration is associated with reactive aggression behaviours. The aim of this Pilot study therefore is three-fold. Firstly, to replicate the findings of Yu et al. and the previous two pilot studies using in-task self-report measures to a) establish whether in-task ratings may be a more sensitive measure of frustration and b) demonstrate that the reported increases in frustration are due to the task manipulation and not order effects. Second, to additionally measure the pleasantness of the 'Win' trials. Third, to explore the relationship between task-elicited frustration and reactive aggression.

2.4.2 Methods

2.4.2.1 Participants

Participants were undergraduate students (N=24, Age_M=21.39 years, Age_{SD}=2.86) recruited through Royal Holloway's Psychology departmental participant pool and were paid in line with departmental norms (£7/40 minutes). Participants were recruited via opportunity sampling from an undergraduate pool (18+) as opposed to an adolescent sample (11-18) since the adapted version of the paradigm was previously shown to elicit frustration in adolescents (Pilot Study Two) and the aim of the current study was to explore the efficacy of a more sensitive measure of frustration and how pleasant participants found 'Win' trials. In addition to time and resource constraints, it was not deemed necessary to recruit another adolescent sample for piloting purposes. Ethical approval for the study was granted by Royal Holloway College Ethics Committee and participants gave informed consent.

2.4.2.2 Materials

2.4.2.2.1 Adapted frustration paradigm

The adapted Yu task used in the previous pilot studies was modified to address some of the limitations discussed. Firstly, the self-report measures now included a rating of pleasantness presented on "Win" trials to gain a measure of how pleasant/desirable the reward is for participants ('How PLEASANT did it feel when you won the level?').

Secondly, all self-report ratings were presented within the task on approximately 20% of trials for each condition (blocked conditions 1-4: three times; win condition: five times) as well as at the end of the task as before. The number of times to record the self-report ratings was chosen as a compromise between providing enough data points so as to increase sensitivity and reduce sampling noise, while not interrupting the flow of the task too much or increasing the time it took to complete the task. The in-task self-report ratings were programmed to appear after a set number of trials per condition had been completed (blocked conditions 1-4: 4^{th}/8^{th}/12^{th} trial; win condition: 5^{th}/10^{th}/15^{th}/20^{th}/25^{th} trial). As the order of conditions is randomised the in-task ratings appeared at different points during the task for each participant. The adapted frustration paradigm was presented using Psychtoolbox v3.0.11 run in Matlab 2015a.

2.4.2.2.2 Questionnaire battery

Participants were asked to report on standard demographic information, the full five-factor Frustration Discomfort Scale, the Frustrative Non-Reward questionnaire (as used in Pilot Study One) and the Reactive-Proactive Aggression Questionnaire (Raine et al., 2006). The full five-factor FDS was included as opposed to the nine items as while we found no significant association with task-elicited frustration in Pilot Study One, the additional subscales may capture individual differences in frustration tolerance at a broader level. These were completed on the testing computer using Qualtrics (www.qualtrics.com).

Reactive-Proactive Aggression Questionnaire (RPQ)

Reactive-Proactive Aggression Questionnaire is a 23-item measure of frequency of reactive and proactive aggressive behaviours in everyday life. Participants are asked to rate the frequency of a such behaviours in the last six months, e.g. '[have] damaged something when you felt mad' or '[have] hurt others to win a game' (examples of reactive and proactive aggression respectively). Items are scored on a 3-point Likert scale 0 ('Never') – 2 ('Often'), with high scores representing a higher frequency of aggressive behaviours exhibited in day-to-day life. Importantly, as some items pertain to antisocial and/or unlawful behaviours, participants were reminded that their responses were confidential and to answer honestly.

2.4.2.3 Procedure

Pilot Study Three followed the same procedure as Pilot Study One, with additional instructions pertaining to the in-task self-report ratings.

2.4.2.4 Data analyses

Analyses were identical to Pilot Study One, with the extension of one-way repeated measures ANOVAs to explore the in-task self-report ratings across blocked conditions (stages 1-4) for ratings of frustration, motivation and surprise. In-task self-report ratings were averaged across the number of iterations completed to provide a single value for each, and the mean values were used in the subsequent analyses. As with Pilot Studies One and Two, all ratings were correlated with each other (i.e. in-task correlated with in-task and end-task correlated with end-task ratings). For the current study, in-task and end-task ratings of the same type were also correlated to check they were capturing the same effect. In contrast to the previous pilot studies, in the current study we excluded analyses of reaction time data as these results have been replicated in Pilot Studies One and Two and the aim of the current study was to explore the validity of a more sensitive measure of frustration. Finally, to explore the relationship between task-elicited frustration and reactive aggression we ran correlations between the reactive aggression subscale of the RPQ and overall mean frustration self-report ratings (collapsed across blocked conditions).

2.4.3 Results

Exclusion criteria were: >± 3 SD above the group mean on total mean errors at confirmation phase (i.e. response of ‘win’ or ‘blocked’ to outcome of the trial, N=1); >± 3 SD in reaction times collapsed across conditions during task phase (N=0), and; >± 3 SD above the group mean on total mean errors collapsed across conditions during task phase (i.e. responses to ghost eye-gaze direction; N=0). This resulted in a final sample of 23 participants. As with both Pilot Studies One and Two, mean accuracy for the task was high (93.58%; total no. errors collapsed across conditions: *M*=5.39, *SD*=5.42).

2.4.3.1 Self-report task data

See Figure 11 for end-task and in-task self-report ratings for frustration, motivation and surprise.

a. Frustration

i. End-task ratings

Repeated measures ANOVA of end-task self-report data found a significant main effect of condition (blocked at each of stage 1, 2, 3 or 4; $F(3,66)=13.76$, $p<.001$, $\eta_p^2=.39$; Greenhouse-Geisser corrected due to violated Mauchly's [$X^2(5)=.48.48$, $p<.001$]). Post-hoc analyses found frustration ratings were significantly higher after being blocked at stage 4 ($M=8.61$, $SD=1.27$) than when blocked at stage 3 ($M=7.39$, $SD=1.44$; $p<.001$), stage 2 ($M=6.17$, $SD=1.87$; $p<.001$) and stage 1 ($M=6.3$, $SD=2.93$; $p=.006$). Additionally, frustration ratings were significantly higher after being blocked at stage 3 than stage 2 ($p<.001$), but there were no other significant differences between stages. That is, as in Pilot Study One, frustration followed the pattern of 1=2<3<4. Overall, participants reported higher levels of frustration when they were blocked at a later stage i.e. closer to the reward. Results also show a significant linear trend ($p<.001$).

ii. In-task Ratings

Repeated measures ANOVA of in-task self-report data also found a significant main effect of blocked condition ($F(3,66)=4.24$, $p=.008$, $\eta_p^2=.16$). Post-hoc analyses found frustration ratings were significantly higher after being blocked at stage 4 ($M=7.41$, $SD=1.43$) than when blocked at stage 3 ($M=6.74$, $SD=1.51$; $p=.039$) and stage 2 ($M=6.61$, $SD=1.75$; $p=.044$), but not at stage 1 ($M=6.59$, $SD=2.01$; $p=.099$). There were no other significant differences between stages 1, 2 or 3. Results showed a significant linear trend ($p=.017$).

b. Motivation

i. End-task Ratings

Repeated measures ANOVA of self-report motivation found a significant main effect of blocked condition ($F(3,66)=15.63$, $p<.001$, $\eta_p^2=.42$; Greenhouse-Geisser corrected due to violated Mauchly's [$X^2(5)=.22.28$, $p<.001$]). Post-hoc analyses revealed that motivation was significantly increased at stage 4 ($M=7.57$, $SD=1.78$) compared to stage 3 ($M=6.65$, $SD=1.61$; $p=.026$), stage 2 ($M=5.48$, $SD=1.83$; $p<.001$) and stage 1 ($M=5.30$, $SD=2.30$; $p=.002$). Similarly, motivation was significantly increased at stage 3 compared to stage 2 ($p<.001$) and stage 1 ($p=.022$). Overall, motivation followed a significant linear trend ($p<.001$).

ii. In-task Ratings

Repeated measures ANOVA of self-report motivation also found a significant main effect of blocked condition ($F(3,66)=8.95$, $p<.001$, $\eta_p^2=.29$). Post-hoc analyses revealed that motivation was significantly increased only at stage 4 ($M=6.70$, $SD=1.28$) compared to stage 1 ($M=5.36$, $SD=1.64$; $p=.004$). Motivation was also marginally significantly increased at stage 4 compared to stage 2 ($M=6.00$, $SD=1.31$; $p=.070$), stage 3 ($M=6.09$, $SD=1.22$) compared to stage 2 ($p=.070$) and stage 3 compared to stage 1 ($p=.075$). Overall, motivation followed a significant linear trend ($p=.001$).

c. Surprise

i. End-Task Rating

Repeated measures ANOVA analyses for self-reported surprise found a significant main effect ($F(3,66)=6.68$, $p<.001$, $\eta_p^2=.23$; Greenhouse-Geisser corrected due to violated

Mauchly's [$X^2(5)=13.02$, $p=.023$]). Post-hoc analyses found ratings of surprise were significantly greater when blocked at stage 4 ($M=6.87$, $SD=1.94$) compared to stage 3 ($M=5.96$, $SD=1.72$; $p=.022$) and stage 2 ($M=5.13$, $SD=1.71$; $p<.001$), and was significantly greater at stage 3 compared to stage 2 ($p=.043$). However, there were no significant differences between stage 1 ($M=5.78$, $SD=2.75$) and other stages. These findings were supported by a significant quadratic trend of surprise ($p=.004$), though a linear trend also significantly fit the data ($p=.02$).

ii. In-Task Rating

Repeated measures ANOVA analyses for self-reported surprise found no significant main effect ($F(3,66)=0.50$, $p=.632$, $\eta_p^2=.02$; Greenhouse-Geisser corrected due to violated Mauchly's [$X^2(5)=15.70$, $p=.008$]).

d. Pleasantness of reward

Both end-task ($M=8.74$, $SD=1.14$) and in-task ($M=8.02$, $SD=1.28$) ratings of pleasantness were high, equating to the second highest descriptive value of 'quite a lot'.

e. Frustration, Motivation, Surprise and Pleasantness Correlations

Correlations between overall mean in-task and end-task ratings found significant positive correlations for frustration, motivation, surprise and pleasantness, all of which are highly correlated ($r(21)>.67$; see Table 1).

Overall mean end-task ratings of frustration were significantly positively correlated with overall mean end-task ratings of motivation but not surprise. At the individual stage level, end-task ratings of frustration were correlated with motivation at all stages but only with surprise at stage 1. End-task rating of frustration was also significantly positively correlated with pleasantness of winning the reward (see Table 2).

Overall mean in-task ratings of frustration were also significantly positively correlated with overall mean in-task ratings of motivation, surprise and pleasantness. At the individual stage level, in-task ratings of frustration were significantly positively correlated with motivation at stages 3 and 4 and surprise at all stages (see Table 3).

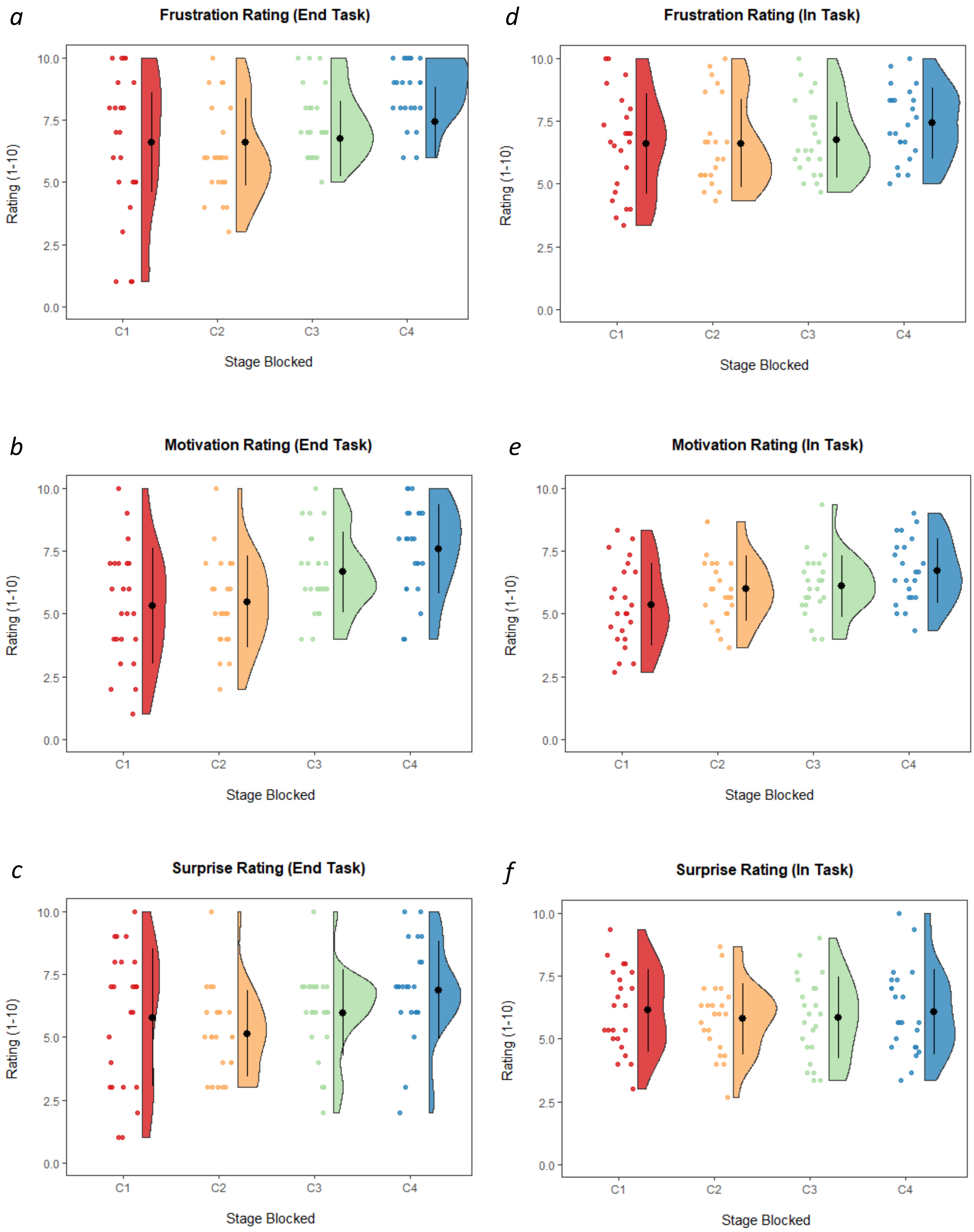


Figure 11. Raincloud plots of end-task self-report ratings of a) frustration, b) motivation and c) surprise and in-task self-report ratings of d) frustration, e) motivation and f) surprise at each stage blocked.

In-Task and End-Task Ratings

		End-Task Ratings				In-Task Ratings			
		Frustration	Motivation	Surprise	Pleasant	Frustration	Motivation	Surprise	Pleasant
End-Task	Frustration	–							
	Motivation	0.53**	–						
	Surprise	0.16	0.05	–					
	Pleasant	0.43*	0.18	-0.01	–				
In-Task	Frustration	0.80***	–	–	–	–			
	Motivation	–	0.74***	–	–	0.50*	–		
	Surprise	–	–	0.64**	–	0.73***	0.31	–	
	Pleasant	–	–	–	0.84***	0.78***	0.32	0.74***	–
	Mean	7.13	6.25	5.93	8.74	6.84	6.04	5.96	8.02
	SD	1.54	1.54	1.72	1.14	1.50	1.14	1.28	1.28

**p*<.05 ***p*<.01 ****p*<.001

Table 1. Correlation matrix showing the correlations between overall mean end-task ratings and overall mean in-task ratings for frustration, motivation, surprise and pleasantness.

End-Task Ratings

		Frustration				Motivation				Surprise			
		C1	C2	C3	C4	C1	C2	C3	C4	C1	C2	C3	C4
Frustration	C1	–											
	C2	0.69***	–										
	C3	0.40	0.75***	–									
	C4	0.28	0.43*	0.81***	–								
Motivation	C1	0.45*	0.51*	0.25	-0.02	–							
	C2	0.42*	0.45*	0.37	0.14	0.76***	–						
	C3	0.36	0.49*	0.59**	0.49*	0.53**	0.75***	–					
	C4	0.07	0.19	0.48*	0.44*	0.27	0.39	0.67***	–				
Surprise	C1	0.52*	0.10	0.06	0.18	0.11	0.22	0.23	0.25	–			
	C2	0.21	0.12	0.09	0.15	0.06	0.14	0.17	0.26	0.67***	–		
	C3	0.08	-0.01	0.03	0.01	-0.11	-0.02	0.01	0.35	0.65***	0.70***	–	
	C4	-0.09	-0.22	-0.06	0.13	-0.51*	-0.37	-0.25	-0.03	0.48*	0.55**	0.74***	–
Mean		6.35	6.17	7.39	8.61	5.30	5.48	6.65	7.57	5.78	5.13	5.96	6.87
SD		2.93	1.87	1.44	1.27	2.30	1.83	1.61	1.78	2.75	1.71	1.72	1.94

**p<.05   **p<.01   ***p<.001*

Table 2. Correlation matrix showing correlations between end-task ratings of frustration, motivation and surprise at each of the 4 blocked stages.

In-Task Ratings

		Frustration				Motivation				Surprise			
		C1	C2	C3	C4	C1	C2	C3	C4	C1	C2	C3	C4
Frustration	C1	–											
	C2	0.76***	–										
	C3	0.79***	0.75***	–									
	C4	0.66***	0.69***	0.74***	–								
Motivation	C1	0.35	0.39	0.09	0.19	–							
	C2	0.55**	0.38	0.35	0.54**	0.73***	–						
	C3	0.44*	0.40	0.48*	0.49*	0.63**	0.72***	–					
	C4	0.34	0.27	0.24	0.56**	0.42*	0.56**	0.55**	–				
Surprise	C1	0.68***	0.57**	0.37	0.57**	0.48*	0.45*	0.32	0.53**	–			
	C2	0.51*	0.55**	0.57**	0.62**	0.12	0.29	0.35	0.26	0.52*	–		
	C3	0.45*	0.39	0.55**	0.46*	-0.06	0.11	0.15	-0.06	0.35	0.83***	–	
	C4	0.56**	0.43*	0.57**	0.57**	-0.03	0.21	0.07	0.22	0.43*	0.49*	0.53**	–
Mean		6.59	6.61	6.74	7.41	5.36	6.00	6.09	6.70	6.13	5.80	5.83	6.07
SD		2.01	1.75	1.51	1.43	1.64	1.31	1.22	1.28	1.64	1.41	1.63	1.70

**p<.05 **p<.01 ***p<.001*

Table 3. Correlation matrix showing correlations between in-task ratings of frustration, motivation and surprise at each of the 4 blocked stages.

2.4.3.2 Task and questionnaire measures

Overall mean end-task frustration was significantly positively correlated only with the Fairness subscale of the FDS (*M*=25.04, *SD*=4.87; *r*(21)=.47, *p*=.023), while in-task frustration was significantly negatively correlated with the Distress Intolerance subscale of the FDS (*M*=18.65, *SD*=3.07; *r*(21)= -.41, *p*=.049), but neither the end-task or in-task ratings were significantly correlated with the Frustrative Non-Reward questionnaire. End-task ratings of frustration were marginally significantly positively correlated with reactive aggression (*M*=7.87, *SD*=3.71; *r*(21)=.41, *p*=.051), but in-task ratings revealed no significant correlation. Correcting for multiple comparisons across all correlations (N=14; $p \leq .004$) however, none of these results would survive.

2.4.4 Discussion

The current study investigated whether further modification to the adapted paradigm improved sensitivity to the frustration induction and were used as a check that results of increasing modulation were not as a result of order effects. Results revealed both end-task and in-task ratings show similar patterns of linearly increasing frustration and motivation, but that surprise only showed significant change across stages in the end-task ratings, linearly increasing between stages 2-4 but with (not significantly) greater surprise ratings at stage 1. Importantly, end-task and in-task ratings both appear to be capturing affective state as all ratings were positively correlated. Finally, end-task and in-task rated task-elicited frustration appear to show differential relationships to the Frustration Discomfort Scale, and end-task ratings were related with reactive aggression.

That end-task and in-task show similar patterns of increasing frustration and are highly positively correlated with each other suggest that both ratings are capturing the same task-elicited frustration. It is worth noting that the end-task ratings revealed a stronger modulation than the in-task ratings, which could be due to demand characteristics. Generally, however, there are minimal differences between the end-task and in-task ratings and the in-task ratings do not appear to be detracting from the effects of the task manipulation (e.g. by potentially distracting participants). Additionally, using the in-task ratings compared to the end-task ratings also has its own methodological advantages. In-task ratings allow the frustration response to be measured as soon as it is elicited, and also to reduce noise in the data as it is measured multiple times and measured in such a way as to diminish the influence of demand characteristics. As such, the in-task ratings were chosen as the primary measure of the frustration response in the subsequent studies as a stronger methodological approach.

Inclusion of the pleasantness ratings were also helpful in ensuring that participants were engaged with the task. The high mean scores equated to a rating of 'quite a lot', and combined with the low standard deviations, suggest that participants are reliably finding the reward sufficiently pleasant. That participants find the reward pleasant suggests the reward is a good goal to work toward for participants and is integral to the task manipulation, as evidenced by the positive relationship between pleasantness and frustration in both end-task and in-task ratings. Additionally, the relationship between pleasantness, motivation and frustration appear to be dissociated. While both pleasantness and motivation were positively related to frustration, pleasantness and motivation were not related to each other. This suggests that both pleasantness of winning and motivation to engage with the task may have independent effects on the level of frustration induced.

Supporting our third hypothesis was the finding that task-elicited frustration (measured by end-task ratings) was positively related to reactive aggression, albeit marginally. Frequency of reactive aggressive behaviours were relatively low (though in line with reported mean scores in typical adolescents; Raine et al. 2006) but fairly homogenous, suggesting a typical sample engages in reactive aggression very infrequently. As such, frustration may not elicit these types of behaviours unless the frustration is more extreme or that individual differences in the frustration response may only be explanative of reactive aggression in individuals with a greater propensity to engage in reactive aggressive behaviours. It is worth noting though that the relationship between frustration and reactive aggression just breached significant levels (*p=.051*), and given the small sample size it is possible that the current study was underpowered to detect a significant effect. Indeed, observed power of the correlation was 0.51. Additionally, the RPQ is a trait-like measure of reactive aggressive behaviours measured independently of the frustration response, whereas previous studies that have found an association between frustration and reactive aggressive behaviours have measured behavioural responses elicited immediately following the frustration response (e.g. Harris, 1974; Buss, 1963) or during the frustration response (e.g. Yu et al. 2014). It is therefore also possible that individual differences in the frustration response better predict immediate reactive aggressive behaviours as opposed to trait-like behaviours (see Chapter 3 for a discussion of this).

Overall, results of the current study suggest that the further modifications to the adapted paradigm provide further meaningful data. Specifically, the in-task ratings replicate the results of Yu et al. (2014), Pilot Study One, Two and the end-task ratings of the current study, validating the in-task ratings as a measure of frustration.

2.5 General discussion

This Chapter investigated the validity of an adapted frustration-induction paradigm for use with adolescents in three pilot studies. In all three pilot studies, the adapted paradigm was able to elicit a frustration response replicating that found in the multiple Yu et al. (2014) studies. Importantly, the results were replicated in an adolescent sample (Pilot Study Two) for whom the task was adapted, completing the first research aim (see Figure 12). Further modification of the task to include in-task ratings suggest in-task ratings may provide a more sensitive and methodologically sound measure of affective state which does not appear to interfere with task efficacy, achieving the second research aim. Additionally, the inclusion of both in-task ratings and the rating of pleasantness of winning the reward may provide meaningful data in understanding the frustration response, such as the independent effects of motivation, surprise and pleasantness on the frustration response. Finally, these pilot studies have begun to unpick the nature of the task-elicited frustration response by exploring the relationship between related concepts such as frustration tolerance and reactive aggression, in line with the third and final research aim for the Chapter.

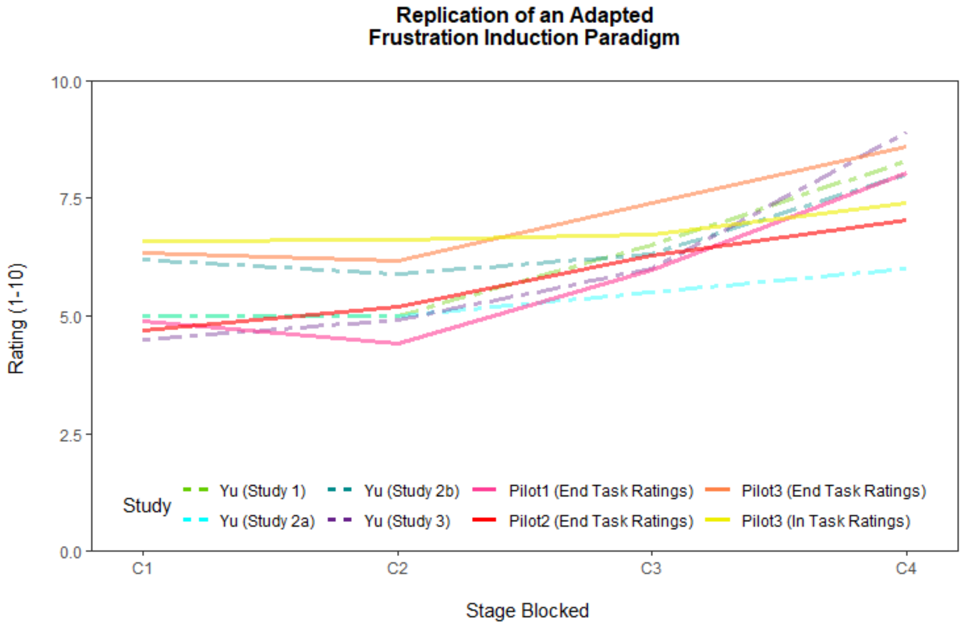


Figure 12. Plot of the frustration ratings at each of the four blocked stages reported in Yu et al. (2014) and in the above pilot studies. The plot shows the similarities both in magnitude of the task-elicited frustration response but also in the change in the frustration response across the 4 stages, demonstrating replicability and validity of the adapted frustration-induction

Specifically, task-elicited frustration may be related to some aspects of frustration tolerance, such as obstructions based in unfairness or entitlement to the goal. However, the confidence in this relationship is undermined by inconsistent findings and discussed limitations of the measures used. In particular, there may be a lack of convergent construct validity between task-elicited frustration and frustration tolerance measured by the Frustration Discomfort Scale and the Frustrative Non-Reward questionnaire due to the way frustration is operationalised in the questionnaire measures. With regards to reactive aggression, there appears to be a positive relationship with task-elicited frustration, but this was not strictly statistically significant. However, this does warrant further exploration as it is unclear whether the relationship is not being truly captured due to a small sample size. Alternatively, it may be that the relationship between frustration and reactive aggression is less pronounced in a typical sample who show generally low levels of reactive aggressive behaviours, or that trait-like measures of reactive aggression are less sensitive to the association between frustration and reactive aggression.

To conclude, the three pilot studies conducted in this Chapter provide evidence to suggest the adapted frustration paradigm can elicit frustration in both adult and adolescent samples, with some evidence of convergent validity to frustration tolerance and reactive aggression. Therefore, this paradigm will be used in the subsequent studies of the thesis to investigate the two overarching research aims of the thesis of whether there are associations between individual differences in the frustration response and a) age and b) reactive aggression. In particular, the in-task ratings will be used as these provided a good balance between capturing the parametric modulation of the frustration response and providing immediate ratings and reduced noise in the data.

The next Chapter will focus on exploring the associations between the frustration response and behavioural 'of-the-moment' reactive aggression, i.e. immediate reactive aggressive responses to frustration with the use of a grip force measure of aggressive responding. While the trait-like measure of reactive aggression used in Pilot Study Three hinted at a relationship between the frustration response, it is possible that this relationship is more nuanced and/or specific to immediate responses to frustration. This will also help characterise the frustration response more holistically as to what associations it has with trait-like and ‘of-the-moment’ reactive aggression.

Chapter 3: Frustration and Aggression: A Response Force Measure

As discussed previously, reactive aggression refers to defensive or retaliatory aggression in response to threat, provocation or frustration (Berkowitz, 1989; Hubbard, McAuliffe, Morrow & Romano, 2010). In Chapter 2, previous work was replicated (Yu et al. 2014) using ad age-adapted paradigm, showing that it is possible to experimentally manipulate self-reported frustration by varying the point at which goal-blocking occurs. While Chapter 2 replicated the self-report results of the Yu et al. paradigm, it did not examine the link between frustration as an emotional response and subsequent aggressive behaviour as did experiments 1a and 1b in Yu et al., using an incorporated force response measure as a proxy for reactive aggressive responding. The current Chapter therefore will operationalise reactive aggression using a response force measure to replicate this aspect of the original paradigm and further validate the adapted frustration paradigm. Further, it will extend these findings to examine the role of individual differences in factors such as trait-like reactive aggression and inhibitory control that might impact upon such aggressive responding based on models of aggression.

3.1 Introduction

Frustration is an antecedent process to reactive aggression and is defined as the emotional response to the thwarting or blocking of one's goal, will or desire (De Botton, 2011; Abler et al. 2005; Dollard, Miller, Doob, Mowrer & Sears, 1939). Though considered a purely emotional response, frustration has been repeatedly linked with reactive aggression (e.g. Otis & Ley, 1993; Munyo & Rossi, 2013; Card & Dahl, 2011). In real-life settings for example, Card and Dahl (2011) found a 10% increase in police reported cases of domestic violence during the American Football season following the unexpected loss of a home-team game. Conversely, home team games resulting in unexpected wins or losses when there was no clear expectation of the outcome did not result in significant changes in police reported cases of domestic violence. The authors concluded the pent-up frustration derived from the unexpected losses of home-team football games led to a 'spill-over' effect into aggressive behaviour. Individual differences in the frustration response have also been associated with individual differences in the degree of reactive aggression elicited. For example, Little et al. (2003) found that frustration tolerance was negatively correlated with reactive aggressive tendencies in a sample of adolescents (aged 10-16 years), such that individuals less able to tolerate frustration were more likely to engage in reactive aggressive behaviours. In a similar study, Dane and Marini (2014) found frustration proneness to be positively related to reactive aggression in a sample of 10-17 year olds, such that individuals who were more prone to frustration were more likely to engage in reactive aggressive behaviours (though this relationship was stronger for relational than overt reactive aggression).

Together, these studies suggest that a) the frustration response and reactive aggression may represent different stages along a continuum from input (frustrating event) to emotion (frustration response) to output (aggressive behaviour); b) there may be a threshold or 'tipping point' at which frustration *translates* into reactive aggression, and; c) there may be individual differences in the intensity of the frustration response, as well as the trigger point and intensity of the reactive aggression response. Yet, the mechanisms underpinning the relationship between frustration and reactive aggression remain unclear. Specifically, we understand little about the circumstances under which frustration translates into reactive aggression.

According to the I^3 model (Finkel & Hall, 2018; described in more detail in Chapter 1), the likelihood of an aggressive act is dependent on three factors. First, the urge to aggress must be initiated by an instigating factor, such as a prior event. That aggressive urge may then be amplified by impellence factors, e.g. trait aggression, or attenuated by inhibition factors, e.g. inhibitory control. The net strength of the impellence and inhibition factors then determines whether the initiated urge to aggress will result in an aggressive act. In the current study, the I^3 framework was applied to the frustration task piloted in Chapter 2, with the task serving as the instigating factor, trait-like reactive aggression as an impellence factor, and Go/No-Go task performance as a measure of inhibitory control. Crucially, an outcome measure of reactive aggressive response was added by using a response force measure following frustrating task events.

3.1.1 A force response measure of frustration-related aggression

The frustration literature has not really explored aggression in direct response to frustration (see as exceptions Yu et al. 2014; Harris, 1974; Buss 1963). Rather, the majority of recent studies examining the link between frustration and aggression use trait-like measures of reactive aggression. For example, Little et al. (2003) used a 6-item self-report measure of aggression (both reactive and proactive) in which participants were asked to rate how true each item was for them, i.e. how reflective was the item of their typical behaviour. Other studies have used similar self- and parent-report questionnaires (e.g. Dane & Marini, 2014) or questionnaires that ask participants/parents to rate the frequency of reactive aggressive behaviours (e.g. Deater-Deckard et al. 2010). Trait-like measures of reactive aggression such as these (reporting on truthfulness and frequencies of reactive aggressive behaviours) are limited in that they only provide a measure of *tendencies* of aggressive behaving, particularly when they are used in isolation. They do not provide a measure of aggression in direct response to a frustrating event. Thus, frustration and reactive aggression are typically measured independently of each other, despite evidence to suggest they are related constructs which lie at different stages of the aggression process. The extant frustration paradigms therefore are currently limited by difficulties in measuring the *translation* between frustration and 'of-the-moment' reactive aggression, in that there is often no direct mapping between experimentally induced frustration and aggressive outcomes, or 'of-the-moment' aggressive responding. To allow a more comprehensive understanding of how and under which circumstances frustration translates into aggressive behaviour the two should be measured in tandem, and this would also more accurately reflect organic occurrences of frustration which may result in reactive aggressive acts.

Inspiration for how to measure both frustration and the resulting reactive aggression can be found in the aggression literature. Standard existing aggression paradigms provide a good model for measuring aggressive responding to provocation, such as the Taylor Aggression Paradigm (Taylor, 1967) or Point-Subtraction Aggression Paradigm

(Cherek et al. 1997). In a typical aggression paradigm, participants compete against a fictitious opponent who is experimentally manipulated to deliver differing levels of provocation to the participant. On trials where the participant beats their opponent, they can administer a 'punishment', e.g. an aversive noise blast (Taylor Aggression Paradigm) or steal points (Point-Subtraction Aggression Paradigm). The degree of punishment administered by the participant is measured as the level of aggressive responding. Therefore, these paradigms allow both the antecedent process, e.g. provoking event, and the resulting aggressive response to be measured in relation to each other. While these aggression paradigms are primarily focused toward provocation and not frustration, that tasks exist which can provoke *and* measure the resulting aggressive response provides a good template to integrate into frustration paradigms.

There are also limitations to these aggression paradigms that mean they are not directly transferable to the frustration literature. Firstly, as participants have to administer a *punishment,* this implies that the measure of aggressive responding is reasonably overt and so may be influenced by demand characteristics (Tedeschi & Quigley, 1996). Secondly, the range of the severity of the punishment available to the participants to deliver is typically restricted to low-high continuums, often omitting a non-aggressive response option (Beyer, Buades-Rotger, Claes & Krämer, 2017). As such, the current measure of aggressive responding, i.e. punishment severity, may not be sensitive to the full range of individual differences in aggressive responding to a situation. For example, Beyer et al. (2017) found that participants chose to *avoid* a provocative opponent rather than aggress when given the option to do so, particularly under certain circumstances, such as when threat reactivity was high. A suitable alternative to measuring aggressive responding therefore would need to provide covert, unrestricted responses of moment-to-moment aggressive responding which can be easily integrated into frustration paradigms. This will enable the entire process from emotion (frustration) to actioned response (reactive aggression) to be investigated.

One solution may be to use a measure of response force, e.g. force of button press, mouse clicks or grip strength. Response force was found to be predictive of participants' frustration during exposure to a malfunctioning computer screen with 79% accuracy (Kapoor et al. 2007). More relevant to the frustration literature, previous studies have found increased response force as a result of frustration. For example, Otis & Ley (1993) found participants would press a lever with more force when frustrated (rewards omitted) than when they were not frustrated (rewards received). Similarly, the series of studies by Yu et al. (2014; discussed previously in Chapters 1 and 2) integrated a response force measure into the confirmation stage of the task, that is at the end of each trial when participants confirmed whether they were blocked or had won the trial. Participants' response force (button press) was recorded and used as the measure of aggressive responding. Results showed that both self-reported ratings of frustration and response force increased when blocked closer to the reward, i.e. when blocked at stages closer to the end of the trial. Moreover, mean frustration was significantly positively correlated with mean response force, suggesting greater levels of frustration were paired with greater levels of aggressive responding. That reactive aggressive responding appears to be parametrically modulated in the same fashion as frustration suggests the frustration paradigm as being able to elicit an affective state of frustration that could in turn elicit reactive aggression, and mirrors the naturalistic expression of frustration-related reactive aggression (e.g. Card & Dahl, 2011).

Though there are a limited number of studies on response force in frustration, these studies converge to provide preliminary evidence that response force may be a valid measure of 'of-the-moment' aggressive responding as it can be covert, allows unrestricted responding that can be easily integrated within existing frustration paradigms, and is seemingly sensitive to subtle changes in the frustrating episode (i.e. proximity) as is the frustration response.

3.1.2 The current study

This study will therefore investigate the relationship between frustration and reactive aggression by using a frustration paradigm that incorporates an 'of-the-moment' metric of reactive aggression. To do this, the study will validate a response force measure using a grip force handle as a metric of 'of-the-moment' reactive aggression with the aim of replicating the results of Yu et al. (2014). By doing so, this will also further validate the adapted paradigm over and above the self-report ratings analysed in Chapter 2. Additionally, this study will extend these findings to examine relationships between individual differences in trait-like reactive aggression and inhibitory control as impellence and inhibition factors respectively, in line with the I^3 model of aggression.

As such, the research questions for the current study are: is response force (reactive aggression) related to: 1) the level of task-induced self-report frustration (in-task ratings); 2) individual differences in trait-like reactive aggression, and; 3) individual differences in inhibitory control? Specifically, results were predicted to show a positive relationship between response force and frustration (question one), a positive correlation between response force and trait-like reactive aggression (question two), but a negative correlation between response force and inhibitory control (question three).

3.2 Methods

3.2.1 Participants

Forty-seven participants were tested from an opportunity sample of undergraduates (Age_{M}=20.56 years, Age_{SD}=5.31 years; 87%=female). Sample size was determined from a power calculation in GPower (Faul, Erdfelder, Lang & Buchner, 2007) using 80% power at alpha level α=0.05 with a moderate effect size of d=0.4-0.5. This was based on conducting a correlational analysis between frustration and response force and from the effect sizes reported in experiments 1a (r=.66) and 1b (r=.19) in Yu et al. (2014). This rendered an N between 35-45. This study was approved by the Royal Holloway College Ethics Committee and participants provided informed consent.

3.2.2 Materials

Participants completed two computerised cognitive tasks and a short set of questionnaires, and these are detailed below. Computerised cognitive tasks were presented via Psychtoolbox v3.0.11 run in Matlab 2015a and questionnaires were completed on the same testing computer.

3.2.2.1 Experimental tasks

3.2.2.1.1a Frustration task with grip force measure

The frustration task is a ~25-minute computer-based 'game' adapted from Yu et al. (2014) to induce frustration using a goal-blocking element paired with a simple left/right decision-making paradigm. As a brief overview (see Chapters 1 and 2 for a detailed description of the task), the task is comprised of 84 trials, with each trial consisting of four stages. Participants must complete all four stages to earn a reward token, but their progress through the trial is systematically but randomly blocked at each of the four stages (four 'blocked' conditions). When blocked, participants are presented with 'blocked' feedback and that trial is terminated wherein participants would lose the reward token for that trial and the next trial would start. At the end of each trial participants are asked to confirm whether they were blocked at any stage or if they won the trial. In the Chapter 2, this was recorded using a key press. However, in order to measure response force, in the current study participants were asked to confirm if they were blocked at any stage in the trial by squeezing a hand-held pressure-sensitive device (detailed below), but to not respond if they won the trial. This confirmation section of the trial allowed a measure of response force to be used as a proxy for 'of-the-moment' aggression following frustrating blocking events, with response force predicted to increase with increased proximity to the reward. As such, response force was only measured on blocked trials (N=56). Additionally, an overall mean response force was calculated (response force collapsed across the four stages) to be used in the analyses. Finally, to provide a baseline measure of response force participants were periodically instructed to 'squeeze once to continue' throughout the task. A total of six baseline measures were recorded.

As in previous iterations of this task, self-report measures of frustration were recorded for each stage of blocking both in-task (presented immediately after being blocked on approximately 20% of trials) and post-task (end-task ratings). In-task ratings will be used in the analyses as well as a measure of overall mean frustration derived from the in-task ratings (collapsed across the four stages). Additionally, self-report measures of motivation, surprise and pleasantness were recorded as control variables.

3.2.2.1.1b Grip force tracking device (GriFT Device)

To measure response force we used a uni-manual grip force handle held in the non-dominant hand (100 x 30 x 38mm) called the GriFT Device (see Jaspers et al. 2018 for technical details). This device houses two compressive force sensors (see Figure 13) that measure participants grip strength in kilograms which are converted to newtons using a data acquisition device (NI-DAQ USB-6009, National Instruments). To account for individual differences in participants' baseline grip strength we calculated a 'relative' response force measure (as used in Jaspers et al. 2018). To calculate the relative response force we first measured the maximum grip strength of each participant over five seconds on three independent calibration trials at the start of the task. This yielded a 'mean calibration response force' of participants strength. Each subsequent response during the confirmation stage of the task (and at baseline prompts) was divided by the mean calibration response force to create a ratio score. This ratio score was used as the dependent variable for 'of-the-moment' reactive aggression. Response force was measured as the maximum response force detected over a two second window, with response force sampled every 2-ms.

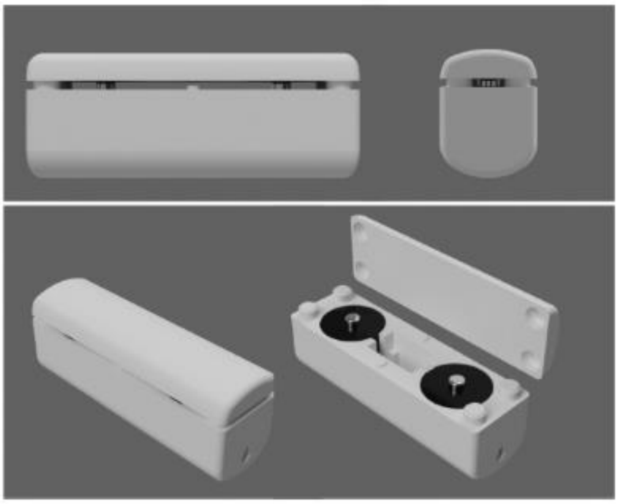


Figure 13. Illustration of the response force handle.
Top: Side and front view of one handle as participants would use it.
Bottom: 3D view of one handle, closed (left) as participants would use it and open (right) to show the two embedded sensors.
From Jaspers et al. © (2018) IEEE.

3.2.2.1.2 Go/No-Go task

The Go/No-Go is a 5-minute task that measures 'cold' inhibitory control based on previous designs. Participants are shown one of two stimuli (circle/square) sequentially on screen and are instructed to respond to one of the shapes only. ‘Go’ trials comprised 75% of total trials (N=150) and represent trials where participants were required to respond (e.g. “only press when you see a circle”). The remaining 25% of trials were ‘No-Go’ trials (N=50). On these trials, participants should not respond (e.g. “If you see a square, do not respond”). Total number of trials were 200. Both ‘Go’ and ‘No-Go’ stimuli were presented for 500-ms irrespective of response time, with an inter-stimulus interval of 750-ms which corresponded with the presentation of a fixation cross. To ensure that the task did not become predictable the number of ‘Go’ trials that preceded a ‘No-Go’ trial was pseudo-randomised between one and five. These five trials made up one sequence of ‘Go’ trials, with the same number of ‘Go’ trials presented prior to the ‘No-Go’ trial never repeated within a sequence.

Percentage commission errors on No-Go trials were used as the dependent variable, in line with standard practice (e.g. Humphrey & Dumontheil, 2016; Passamonti et al. 2010). Low error rates reflect greater ability to inhibit a pre-potent response. ‘Go’ and ‘No-Go’ stimuli were counterbalanced across participants. Note, inhibitory control ability was pre-registered to be operationalised as d-prime score as this takes into account response bias. However, given the mean percentage accuracy on ‘Go’ trials was high (*M*=97.32%, *SD*=2.78%), percentage commission errors were used instead, in line with previous literature using Go/No-Go paradigms.

3.2.2.2 Questionnaire battery

The questionnaire battery was completed online via Qualtrics (www.qualtrics.com) and consisted of demographics (age, gender, ethnicity and handedness), Reactive-Proactive Aggression Questionnaire (to provide a measure of 'trait-like' reactive aggression in everyday life; Raine et al., 2006), and the State-Trait Anxiety Inventory Trait form (to control for trait anxiety which is highly correlated with reactive aggression; Spielberger et al., 1983; Card & Little, 2006).[3]

State-Trait Anxiety Inventory: Trait Form (STAI)

The STAI trait form is a 20-item measure of trait anxiety. Items are scored on a 4-point Likert scale (1='Never' – 4='Almost Always') such that higher scores indicate higher levels of trait anxiety. This measure was used in secondary analyses to control for possible comorbidity between anxiety symptoms and reactive aggression.

3.2.3 Procedure

Informed consent was obtained from all participants prior to testing and participants were given the opportunity to ask questions. Task order was kept consistent across participants: 1) Frustration task; 2) Go/No-Go task; 3) questionnaires. Prior to each task participants were given verbal instructions. For the frustration task, a PowerPoint presentation was also used. Then participants were taken through the calibration

[3] Participants also completed the Affective Reactivity Inventory (Stringaris et al. 2012) in order to conduct exploratory analyses regarding irritability; however this does not form part of the current thesis and as such is not discussed further.

stages of the task (maximum grip force trials). Prior to completing the questionnaires, participants were made aware that they were able to omit answers if they wished. Finally, participants were verbally debriefed, provided with a debrief sheet, and given the option to withdraw their data retrospectively (N=0). Participants received £5 for taking part. Total battery length was ~45 minutes and was conducted with a researcher available at all times.

3.2.4 Data analyses

All analyses were pre-registered at https://osf.io/d6p5m/ (see Appendix 3). See footnotes below for reported deviations and ad hoc exploratory analyses. All analyses were conducted in R using RStudio (R Core Team, 2017; RStudio Team, 2016) and SPSS (version 21)[4] unless otherwise stated.

The main dependent variables are overall mean relative response force (GriFT response force), overall mean frustration (self-report), trait-like reactive aggression (RPQ reactive scale self-report) and inhibitory control (percentage commission errors on the Go/No-Go task).

To first check the frustration induction was successful (replicating Chapter 2), a repeated measures ANOVA with 4 levels (each of the blocked stages) and post-hoc planned contrast was conducted on self-reported in-task frustration ratings to test the

[4] ANOVA's were conducted in R but the associated Mauchly's sphericity test and linear/quadratic trend were calculated in SPSS.

pattern that frustration induced at stage 1<2<3<4. Multiple comparison corrections were used for the planned comparisons (three comparisons) therefore $p \leq 0.016$, ($p = 0.05/3$). In addition, to validate the response force measure, and to examine the change in response force across the four conditions and relative to baseline, a repeated measure ANOVA model with five levels (baseline and four blocked conditions) was conducted using post-hoc planned contrast to test the pattern that response force elicited at stage baseline<1<2<3<4. Multiple comparison corrections were used for the planned comparisons (four comparisons) therefore $p \leq 0.013$, ($p = 0.05/4$). This is a deviation from the pre-registration as the planned analysis for response force was a repeated measures ANOVA with four levels (four blocked conditions) as is conducted for the frustration ratings. However, to check the task manipulation was effective the baseline measure needed to be included. To avoid repetition in the analyses, only the exploratory ANOVA was included.

Pearson's correlations were then used to observe the relationship between overall mean relative response force ('of-the-moment' reactive aggression) and a) overall mean frustration (question one); b) trait-like reactive aggression (question two), and; inhibitory control (question three). As a secondary pre-registered analysis, the above correlations were also conducted while controlling for anxiety. Finally, as an exploratory analysis, correlations between overall mean frustration, motivation and surprise were conducted as in Chapter 2. To check that these were not influencing the relationship between overall mean frustration and response force, the correlation between overall mean relative response force and overall mean frustration was run again controlling for overall mean motivation and overall mean surprise.

3.3 Results

A final sample of 40 participants were included in the analyses due to six participant exclusions. Pre-defined exclusion criteria were >3SD in: task errors collapsed across all conditions (N=1); confirmation errors (N=1); commission errors (N=0); or questionnaire subscales (N=1). Additionally, participants were excluded for >3SD in response force collapsed across all four stages of blocking (N=0), technical faults (N=2) and where participants were known to not be engaging with the task (N=1).

3.3.1 Replication: Effect of task manipulation on self-reported frustration

There was a significant main effect of stage of blocking ($F(3,117)=9.88$, $p<.001$, $\eta_p^2=.20$) with post-hoc analyses revealing significantly higher frustration ratings after being blocked at stage 4 (*M*=6.80, *SD*= 1.95) than when blocked at stage 2 (*M*=5.81, *SD*=2.33, $p<.001$), and stage 3 (*M*=5.99, *SD*=2.04, $p<.001$). There were no significant differences in frustration rating when blocked at stage 4 compared to stage 1 (*M*=6.47, *SD*=2.17). Frustration levels at stage 1 were significantly higher than at stage 2 ($p=.002$). The model fit a quadratic trend ($p<.001$) rather than a linear trend as seen in Chapter 2, though the linear fit was toward trend level ($p=.079$) and the quadratic trend appears to be driven by increased ratings at stage 1 followed by steadily increasing levels across stages 2-4. See Figure 14a.

3.3.2 Validation: Effect of task manipulation on the response force measure

There was also a significant main effect of response force across the baseline condition and the four stages of blocking ($F(4,156)=8.94$, $p=.002$, $\eta_p^2=.19$; Greenhouse-Geisser corrections applied due to violated Mauchly's sphericity [$X^2(9)=131.05$, $p<.001$]). Participants responded more forcefully at all stages than at baseline ($M=0.61$, $SD=0.18$, all *p's*<.010). Showing a similar pattern to the self-reported frustration ratings, post-hoc analyses also revealed participants responded more forcefully at the confirmation stage when blocked at stage 4 ($M=0.74$, $SD=0.23$) than when blocked at stage 1 ($M=0.71$, $SD=0.22$, $p=.001$) and stage 2 ($M=0.70$, $SD=0.22$, $p<.001$), and were marginally significantly greater than when blocked at stage 3 ($M=0.71$, $SD=0.22$, $p=.013$). Response force data fit both a linear[5] and quadratic model ($p<.001$ and $p=.035$ respectively; see Figure 14b).

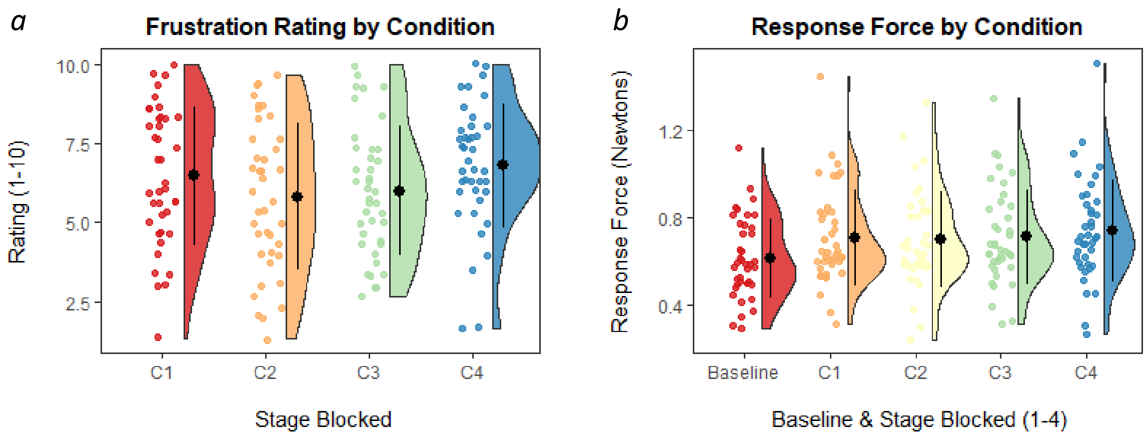


Figure 14. Raincloud plot of a) self-report frustration rating by blocked condition (C1-4) and b) response force at baseline and by blocked condition (C1-4).

[5] The pre-registration analyses included an analysis using a measure of frustration sensitivity to be conducted if response force showed a linear increase across blocked conditions, and to be used with self-report ratings. Frustration sensitivity was operationalised as the beta value of the slope across the four blocked conditions, calculated by conduction linear regressions on the frustration ratings across the four stages for each participant. This would be used as an index of how steeply frustration escalated between stages 1 and 4 could provide an alternative dependent variable of participants frustration, and potentially a more theoretically informative one. However, this was not reported as it is not relevant to the purpose of this chapter.

3.3.3 Relationship between frustration and aggression

Contrary to the hypothesis, overall mean frustration rating and mean response force were not significantly correlated ($r(38) = -.08$, $p=.590$) and remained non-significantly correlated when controlling for trait anxiety ($M=50.24$, $SD=11.09$; $p=.492$). As exploratory analyses[6], overall mean motivation ($M=5.54$, $SD=1.24$) and overall mean surprise ($M=5.63$, $SD=1.85$) were significantly correlated with overall mean frustration (*p's*<.001) but not with overall mean response force. We ran an exploratory partial correlation between overall mean frustration and overall mean force, controlling for overall mean motivation and overall mean surprise. However, this was also non-significant. As an exploratory analysis to see whether this relationship was present at the highest stage of frustration induction and force response, a correlation was run between frustration and response force when blocked at stage 4, however this also revealed a non-significant relationship ($r(38) = -.23$, $p=.159$). Exploratory Bayesian correlation using JASP (2019; version 0.11.1) of overall mean frustration and overall mean response force found that there was not enough evidence to support either the null or the alternative hypothesis ($r=.09$, $b=.332$), suggesting more evidence is needed before strong conclusions can be made. All results are reported in Table 4.

[6] These are exploratory analyses that were not included in the pre-registration.

	Mean frustration	Mean force	STAI	Mean motivation	Mean surprise
Mean frustration	–				
Mean force	-0.09	–			
STAI	-0.18	-0.13	–		
Mean motivation	0.59*	0.01	-0.08	–	
Mean surprise	0.77*	<0.01	-0.14	0.57*	–

**p<.001*

Table 4. Correlation matrix reporting r values of overall mean frustration rating, overall mean force, state anxiety scores (STAI), overall mean motivation rating and overall mean surprise rating.

3.3.4 Response force and individual differences

Reactive aggression scores (*M*=8.35, *SD*=3.34) were in line with typical scores for adults (Brugman et al. 2017). In the Go/No-Go task, mean percentage commission errors was 25% (SD=12%). Correlations revealed no significant relationship between mean response force and trait-like reactive aggression or between mean response force and inhibitory control ability, or between mean frustration and any other measure (see Table 5 for all correlations).

	Mean frustration	Mean force	Reactive aggression	Inhibitory control
Mean frustration	–			
Mean force	-0.09	–		
Reactive aggression	0.06	-0.20	–	
Inhibitory control	-0.12	-0.24	0.21	–

**p<.05 **p<.01 ***p<.001*

Table 5. Correlation matrix reporting r values of overall mean frustration rating, overall mean force, trait-like reactive aggression, inhibitory control ability (percent commission errors).

3.4 Discussion

This study investigated the relationship between experimentally induced frustration and 'of-the-moment' reactive aggression, trait-like reactive aggression and inhibitory control abilities. While frustration and response force increased as a function of stage blocked, frustration and response force were not significantly correlated with each other or with trait-like measures of reactive aggression or inhibitory control abilities.

3.4.1 Hypothesis One: Frustration and 'of-the-moment' aggression

Frustration and response force both increased in a broadly parametric fashion as a function of the task manipulation, i.e. the closer they were to the reward when blocked. This replicated both the parametrically increasing self-report ratings of frustration and response force as a result of stage blocked reported in the two studies by Yu et al. (2014). In line with Yu et al's conclusions, that increasing response force broadly followed the same trajectory as the increasing frustration response suggests increasing response force represents increasingly aggressive responding the closer participants were to the reward. This could be due to a 'spill-over' effect of the increasing frustration resulting in increased aggressive responding (e.g. Otis & Ley, 1993; Munyo & Rossi, 2013; Card & Dahl, 2011). Additionally, the current study included a baseline measure of an affect-neutral response force. Response force at each of the blocked stages was increased in comparison to the baseline measure, providing further evidence to suggest response force may be interpreted as aggressive responding as a result of a frustrating event (task manipulation of blocked stages). These results also further validate the adapted frustration paradigm in being able to elicit an affective (frustration) and actioned (reactive aggression) response, and that response force is a useful tool to measure aggressive responding within a frustration paradigm. However, the prediction that overall mean frustration and response force would be positively correlated was not supported, irrespective of controlling for potential comorbid (anxiety) or confounding (motivation, surprise) factors. As such, this finding of Yu et al (2014) was not replicated.

There are several possible reasons as to why the relationship between overall mean frustration and overall mean response force seen in Yu et al. did not replicate. One reason may be that the overall mean collapsed across the four stages of blocking may not be a sensitive enough measure to the individual differences in the frustration response. There was high variability in frustration, both in magnitude and change over the four stages. As such, overall mean that is collapsed across the four stages of blocking may mask some of the individual differences in the frustration response. However, it does have the advantage of using all the data from a participant to determine their score. Another possibility is that, as both overall mean frustration and mean frustration elicited when blocked at stage 4 equated to 'Moderate' levels based on the descriptive labels of the 10-point Likert scale, it might be that the level of frustration induced in the task is not sufficient to cross the 'tipping point' into responses that would be aggressive enough to show reliable individual differences. However, it does appear sensitive enough to elicit general increases in aggressive responding (both parametrically with blocked stage, and relative to baseline).

Another potential explanation relates to caveats of the Yu et al. (2014) studies. Across the two studies which reported a significant positive correlation between overall mean frustration and overall mean response force there were quite small sample sizes for correlational data (N=~20), making it difficult to obtain reliable estimates of effect size. Indeed, the two studies reported quite inconsistent findings, with one study reporting a large effect size (r=.85, p<.005) and the other a small effect size (r=.19, p=.031). These disparate results make sample size calculation for the current study more difficult to estimate. Though the current sample size was larger (N=40), given that the true effect size may be small (e.g. r=.19) and Bayesian correlation results show there is not enough evidence to make a conclusion, the non-significant correlation may be in part influenced by a small sample size in the current study, not large enough to detect a small effect size.

Together, this evidence suggests that either a) the strength of the relationship is perhaps not as strong as anticipated, or; b) the degree of experimentally induced frustration may not be sufficient to elicit a strong enough 'aggressive' response to show individual differences.

3.4.2 Hypothesis Two: Frustration, response force and trait reactive aggression

In contrast to predictions, there were no significant correlations between frustration, response force and trait-like reactive aggression or inhibitory control ability. These findings do not replicate the limited but existing literature on individual differences in frustration being related to individual differences in aggression (e.g. Dane & Marini, 2014; Little et al. 2003). It also does not coincide with the meta-theories of aggression (I^3 model) which show trait aggression may increase aggressive responding.

Previous research found individual differences in frustration tolerance to be related to the likelihood of engaging in aggressive behaviours (Little et al. 2003). However, these results were based on a comparison between a ‘typical’ subgroup and a ‘reactive aggressive’ subgroup, the latter consisting of participants who scored above the 66th percentile for reactive aggressive behaviours. As such, the comparison is between a ‘typical’ and ‘extreme’, whereas this study examined individual differences within a ‘typical’ sample. Responses in the trait-like measure of reactive aggression in this sample appear to be fairly homogenous, with the majority of responses seated within 1SD of the distribution of scores (M=8.35, SD=3.34, IQR=4.25), reducing the within subject variability.

The current study sample was primarily comprised of female university students (87%). The aggression literature reports that females typically show fewer physically or overtly reactive aggressive behaviours, whereas males show higher levels of overt aggression. (Buades-Rotger, 2017; Nivette, Eisner, Malti & Ribeaud, 2014; Card, Stucky, Sawalina & Little, 2008). The lower prevalence of overtly reactive aggressive behaviours within the sample therefore may be due to the sample being female dominated. Additionally, Dane and Marini (2014) found frustration proneness to be more strongly positively related to *relational* reactive aggression, i.e. aggression that harms the relationships or social status of the victim, than *overt* reactive aggression, i.e. the more physical type of reactive aggression. In the current sample, the reactive aggression scale used is heavily focused on physical and overt forms of reactive aggression, e.g. “Damaged things because you felt mad”, “Felt better after hitting or yelling at someone” and “Hit others to defend yourself”. Relational aggression on the other hand is often represented in items such as “When I am mad at others, I often gossip or spread rumours about them” or “If others upset or hurt me, I often tell my friends to stop liking them”. It is possible that the measure of reactive aggression used in this study therefore may not be sensitive enough to individual differences related to frustration. However, there is still a wealth of evidence to suggest a relationship between frustration and overt reactive aggression (e.g. Yu et al. 2014; Smeets et al. 2017; Lawrence, 2006), suggesting this is less likely to be the case than limitations with the current sample.

3.4.3 Hypothesis Three: Frustration, response force and inhibitory control

Inconsistent with the final prediction that inhibition factors such as inhibitory control serve as a protective factor between affect (frustration) and actioned response (aggression), we found no significant correlation between frustration, response force or inhibitory control abilities. This is also not in line with the I^3 model of aggression. Denson, DeWall & Finkel (2012) reported on findings in the literature that demonstrate an inverse relationship between self-control and reactive aggression. However, the studies the authors drew from experimentally manipulated the level of self-control such that self-control ability was either depleted or bolstered, i.e. at levels lower or higher than normal. In contrast, this study used a ‘baseline’ level of inhibitory control elicited under neutral circumstances. In combination with the moderate level of frustration induced, it is possible the relationship between the two could not be detected. Specifically, the frustration elicited may not have been enough to elicit individual differences in aggressive response, meaning that individual differences in inhibitory control would not necessarily relate to responses recorded.

3.4.4 Conclusions

This study partially replicated the findings by Yu et al. (2014) finding increasing levels of frustration and response force in line with the experimental manipulation. However, the two were not correlated with each other, nor with trait reactive aggression or inhibitory control. Limitations of the study, namely the moderate levels of elicited frustration, the low levels of self-reported reactive aggression in a primarily female sample, and the potentially small sample size (according to the Bayesian analyses) may have contributed to null effects. Future studies would benefit from using a frustration paradigm that robustly elicits high levels of frustration and integrates an 'of-the-moment' reactive aggression measure to more fully understand the translation between frustration and reactive aggression. Specifically, what is the true effect size of the relationship between the two? Future studies may also want to explore whether individual differences in different measures of trait-like reactive aggression are related to individual differences in aggressive responding. For example, the measures used by Little et al. (2003) and Dane and Marini (2014) which include both relational and overt/physical reactive aggression.

In the next Chapter, the adapted frustration paradigm will be used in a larger sample of both male and female adolescents aged 11-16 to explore the behavioural associations between frustration, trait-like reactive aggression and inhibitory control, and whether these differ with age in adolescence.

Chapter 4: Development of the Frustration Response During Adolescence

The adaptation of the original frustration paradigm (Yu et al. 2014) was made so that the frustration response could be studied more appropriately in an adolescent sample. Chapters 2 and 3 demonstrated the validity of the adapted frustration paradigm to elicit parametrically modulated affective frustration in both adults and adolescents and 'of-the-moment' reactive aggressive responses in adults. In the current study, the adapted frustration paradigm was used in a sample of adolescents (11-16 years, N=71) to characterise the frustration response, to explore whether there are developmental differences across adolescence in the frustration response, and to examine whether these developmental differences might account, at least in part, for the increase in reactive aggressive behaviours reported to occur during adolescence. While the 'of-the-moment' reactive aggressive response force measure was validated in the previous Chapter, the current Chapter focuses on trait-like reactive aggression as a factor that may potentiate the frustration response. The current Chapter will also place the frustration response and individual differences related to reactive aggression in the context of aggression models, and includes a measure of inhibitory control as used in the previous Chapter, in line with the I^3 model of aggression.

4.1 Introduction

Reactive aggressive behaviours, that is behaviours elicited in response to threat, provocation or frustration as opposed to being pre-meditated (Dodge & Coie, 1987) normatively peak in toddlerhood. For a subset of individuals (~5-10%) these behaviours were found to persist throughout childhood, adolescence and into adulthood (Moffitt, 1993; Moffitt et al., 1996). A larger subset of individuals (~25-32%) however, were found to develop clinically significant levels of reactive aggressive behaviour which typically emerge for the first time during adolescence (Moffitt, 1993) and peak around mid-adolescence (Ahmed, Somerville & Sebastian, 2018; Martino et al., 2008; Raine et al., 2006).

High levels of reactive aggression feature trans-diagnostically in disorders such as anxiety, depression, oppositional defiant disorder, conduct disorder (Haller, 2017; Card & Little, 2006) and is one of the leading causes of child and adolescent referrals to mental health services (Rutter et al., 2010). This subset of individuals therefore represents a significant minority for whom reactive aggressive behaviours present significant potential implications. Yet, remarkably little is understood about how antecedent processes, for example frustration, give rise to reactive aggression. The present study will therefore focus on frustration and its development during adolescence as a possible factor related to the increase in clinically significant levels of reactive aggression during adolescence. In order to test the relationship between frustration and reactive aggression, the current study places this into a testable framework laid out in the I^3 model of aggression.

To recap, meta-theories of aggression such as the General Aggression Model (GAM; Anderson & Bushman, 2002) and I^3 Theory (Finkel & Hall, 2018) provide testable frameworks within which the frustration response and its relationship to reactive aggression can be investigated. These theories posit there are a number of contributing factors that can determine whether an act of aggression will occur (see Chapter 1, section 1.2.1 for a detailed discussion of both aggression models). The I^3 model in particular provides an organisational approach, whereby an instigation of aggression may be bolstered or attenuated (impellence and inhibition factors respectively). The I^3 model therefore provides a template to look at individual and developmental differences in the frustration response and how these may inform the relationship between frustration and reactive aggression. For example, the frustration response and age may serve as impellence factors and inhibitory control an inhibition factor in the likelihood of a reactive aggressive act.

Additionally, the General Aggression Model discusses the importance of how different factors may interact with each other in a more cyclical fashion, suggesting that while 'impellence' like factors such as frustration can influence the likelihood of an aggressive act occurring, the knowledge structure that is built from acting aggressively may feedback into increasing the likelihood of an aggressive act occurring as a distal factor, e.g. by having an aggressive personality. This Chapter therefore, will explore how individual differences in 1) age during adolescence and 2) inhibitory control inform the relationship between frustration and reactive aggression, with age serving as an impellence factor and inhibitory control ability serving as an inhibition factor. Additionally, it will examine how individual differences in trait-like reactive aggression may also serve as an impellence factor in individual differences in the frustration response.

4.1.1 Frustration response

As previously discussed, the Yu et al. (2014) set of studies found increased frustration modulated by the degree of the instigating factor, in this case goal-blocking. By manipulating the stage at which participants were blocked, the level of frustration induced could be modulated such that the closer to the reward when blocked (or the greater the effort expended prior to blocking), the greater the frustration. Yu et al. also took a measure of response force as a proxy for aggressive responding (reactive aggression) and found a similar pattern in that response force increased the closer the reward was when blocked, demonstrating that goal-blocking increases both self-reported frustration and aggressive responding. These findings were broadly replicated in Chapters 2 and 3 with the adapted frustration paradigm.

A frustrating event does not necessarily elicit the same response in everybody, however, and research has begun to shed light on individual differences in the frustration response and how this relates to reactive aggression. For example, individuals scoring more highly on questionnaire measures of frustration also report higher levels of anger (adults; Harrington, 2006) and show greater levels of overt aggression (children; Deater-Deckard et al., 2010). Similarly, Little et al. (2003) found that 10-16 year olds categorised as engaging in primarily reactive aggressive behaviours had the highest levels of frustration intolerance, based on peer and self-report ratings of aggression motivations (why they aggress) and aggression correlates (e.g. frustration, hostility).

Together, these studies demonstrate differences in the frustration response both within participants (Yu et al., 2014) and between participants (Deater-Deckard et al., 2010; Harrington, 2006; Little et al., 2003). Interpreting these findings through the lens of the I^3 model, these studies provide evidence that the relationship between frustration and aggression may be modulated at both the instigation stage, e.g. by varying the goal-blocking element, and at the impellence stage, e.g. individual differences in frustration tolerance, such that those with lower frustration tolerance have higher levels of aggression, aggressive responding, or aggressive correlates, e.g. anger. Frustration tolerance may play a role in the relationship between the frustration response and reactive aggression. One factor that may influence frustration tolerance (and therefore the propensity for frustration to lead to an aggressive response) is participant age, particularly during the period of adolescence as discussed in Chapter 1.

4.1.2 Age

As discussed in Chapter 1, the adolescent period may represent a developmental period of susceptibility for developing clinically relevant levels of reactive aggression compared to other ages such as in childhood or adulthood. Adolescence is a period of rapid development with individuals negotiating significant social, biological and cognitive change. Of particular relevance here, there is protracted development of prefrontal cortex (Gogtay et al., 2004), while related processes such as emotion regulation are still improving (Silvers et al., 2017; Silvers et al., 2012). Dual-systems or 'developmental mismatch' models suggest the imbalance in maturation of these systems (PFC and limbic) may explain the increase in aggression during adolescence.

While there is no consensus on the exact mechanisms underlying the increase in reactive aggression during adolescence, a number of developmental models highlight the vast amount of change that is characteristic during adolescence as a proponent factor for increased aggression or risk-taking (see Chapter 1.2.4 for more detail, specifically the dual-systems model, e.g. Casey et al., 2008; Seesaw model, Blakemore & Mills, 2014).

Indeed, longitudinal trajectory and taxonomic studies robustly find a peak in reactive aggressive behaviours around mid-adolescence which appear to decline into adulthood (Jennings & Reingle, 2012). For example, the dual-taxonomy model (Moffitt et al., 1996; Moffitt, 2018) drew upon longitudinal data of antisocial behaviours and found a distinct 'adolescent-limited' group who engaged primarily reactive aggressive antisocial behaviours (Frick et al. 2003) and whose behaviours emerged in adolescence but desisted by early adulthood. Subsequent taxonomic research has found more nuanced trajectories of antisocial behaviour (e.g. Martino et al. 2008; Barker et al., 2006; Vitaro et al., 2006; see Fairchild, van Goozen, Calder & Goodyer, 2013 for a reformation of the dual-taxonomic view). In a 5-year longitudinal study of 13-year olds (followed until age 17), Barker et al. (2006) identified three trajectories of reactive aggressive behaviours. The largest group were at low but stable levels (52.6%), followed by the second largest group which showed moderate levels from 13-15 years that subsequently declined (40.8%), and the final and smallest group which showed elevated levels at 13 years, with reactive aggressive behaviours peaking at 15 years, desisting thereafter to lower levels than at 13 years (6.6%). While the proportions in each group differ depending on study, these results were closely replicated by Martino et al. (2008) who reported groups of low (37.33%) or desisting (22.29%) reactive aggression, as well as two groups that showed this adolescent peaking trajectory at moderate (23.15%) and severe (17.23%) levels of reactive aggression. These results demonstrate that a significant proportion of adolescents follow this quadratic inverted 'U' shaped pattern of peaking reactive aggressive behaviours around mid-adolescence which subsequently decline, being observable in both the most severe and in the moderate groups, suggesting there is a potentially normative developmental trend worth exploring. Given frustration is a precursor to reactive aggression, is it possible that the adolescent susceptibility to reactive aggression is in part explained by ongoing development in the frustration response and its regulation?

A limited number of studies have investigated development in the frustration response during adolescence (Lewis et al., 2006; Ernst et al., 2005). One study by Ernst et al. (2005) compared adult (*M*=26.7, *SD*=5.0 years) and adolescent (*M*=13.3, *SD*=2.1 years) brain activation using fMRI during a reward omission task. Though reward omission does not measure frustration explicitly it fits the definition of a frustrating event due to the goal-blocking element of reward omission. Ernst et al. found a reduction in the amygdala BOLD response to reward omission in the adults compared to adolescents, suggesting that adolescents are perhaps more reactive to frustrating events, or less able to down-regulate the initial reactivity. Another study by Lewis et al. (2006) used EEG during a frustration induction Go/No-Go task in 5-16 year olds. Results found increased N2 site amplitude during the frustration block for the adolescent subgroup only (13-15 years), in comparison to a decreased P3 amplitude during the frustration block found across all ages. Both the P3 and N2 amplitudes are thought to proxy inhibition or cognitive control. Though all age groups showed some recruitment of inhibition at the P3 site, only the adolescent subgroup showed increased amplitude at the N2 site when frustrated, suggesting adolescents required and/or engaged in greater recruitment of inhibitory control areas when frustrated. Taken together, these studies suggest that adolescents may process the frustration response differently than at other ages.

The development of the frustration response is therefore likely to follow one of two possible routes. It may develop in response to similar developmental shifts as those seen in related emotion regulation abilities, i.e. improvements in emotion regulation capabilities resulting in a linearly decreasing frustration response during age (Lewis et al. 2006; Silvers et al. 2017). Alternatively, it may follow the typical trajectory of reactive aggression seen during adolescence (Martino et al. 2008; Moffitt, 1993), specifically the quadratic inverted ‘U’ shape whereby the frustration response is at its most pronounced during mid-adolescence but declines thereafter. In either instance, age may act as an impellence factor for the frustration response, with frustration-driven reactive aggression more likely in the adolescent period than for other age groups. It may also be possible to observe development (whether linear or an inverted U shape) within adolescence.

4.1.3 Inhibitory control

Following the I^3 framework, inhibition factors may also play a role in the relationship between the frustration response and reactive aggression during adolescence. Perhaps the most appropriate measure of inhibition is inhibitory control ability. Inhibitory control is an executive function that enables individuals to exert control over and regulate their actions, particularly when these actions are inappropriate (Casey, 2015). There is a body of literature in adults suggesting an inverse relationship between inhibitory control and reactive aggression (e.g. Dambacher et al., 2015; Finkel, DeWall, Slotter, Oaten & Foshee, 2009), with reactive aggression thought to involve a lack of inhibitory functions and reduced self-control abilities (Atkins et al, 1993; Raine et al., 1998). For example, Finkel et al. (2009) ran multiple studies that found a negative relationship between self-control, related executive functions, and reactive aggression. First, participants with low dispositional self-control reported a greater number of instances of physical violence towards a romantic partner (operationalised as someone they were on a date with) compared to individuals with high dispositional self-control (study 1). Second, participants who were experimentally depleted of self-control resources and subsequently told by the experimenter that their romantic partner had negatively evaluated their performance on a previous task (provocation) displayed higher levels of an experimental analogue of physical aggression towards their romantic partner than those with no experimentally depleted self-control (longer duration of holding an uncomfortable pose). In contrast, participants who had engaged in a 2-week training course to bolster self-control resources showed greater decreases in the likelihood they may engage in physical aggression toward a romantic partner in response to provoking partner scenarios compared to participants in the control condition (no effects on self-regulation). Further, scores on the common executive function factor (measured by scores across inhibition, monitoring and flexibility tasks) were associated with lower levels of reactive aggression (Hecht & Latzman, 2017). The authors concluded that as the common executive function factor represents goal-directed inhibitory control, these results suggest increased goal-directed inhibitory control is associated with lower levels of reactive aggression.

Furthermore, there is emerging evidence to suggest inhibitory control may be inversely associated with frustration. EEG studies have found increased activity in areas associated with inhibitory control during frustrating events, particularly at the N2 and P3b sites (Lewis et al., 2006; Pincham et al., 2015). Additionally, questionnaire measures of frustration were found to be moderately negatively related to inhibitory control, with high frustration but low inhibitory control being associated with greater levels of externalising problems in a longitudinal study with 7 year olds (Muris, Meesters & Blijlevens, 2007). The research on the relationship between inhibitory control and frustration is sparse but warrants investigation given the association of inhibitory control with both reactive aggression, and with frustration as an affective precursor to reactive aggression. In addition, there is a paucity of literature regarding how inhibitory control and frustration may interact with each other as examples of Inhibition and Impellance factors respectively, to predict reactive aggression.

Finally, there is evidence to suggest inhibitory control continues to develop during the adolescent period in both emotionally neutral contexts, i.e. 'cold' inhibitory control, and emotionally charged contexts, i.e. 'hot' inhibitory control (Aite et al. 2016). Therefore, it makes sense to measure individual differences in inhibitory control in the present study to better understand how this factor relates to frustration sensitivity and reactive aggression over the dynamic period of adolescence.

4.1.4 The current study

The current study aims to investigate the frustration response in a sample of adolescents (11-16 years) using the age-appropriate frustration modulation paradigm developed and validated in Chapters 2 and 3. The development of the frustration response in and of itself has not been well studied. Therefore, this Chapter will describe how frustration response, age during this important developmental period, and inhibitory control may be associated with reactive aggression, in line with the meta-theories of aggression (I^3 and GAM).

It is predicted that 1) the adapted task will induce linear modulation of the frustration response in an adolescent sample; 2) we will see development of the frustration response during adolescence following either a linear declining pattern or quadratic inverted 'U' pattern; 3) individual differences in the frustration response will be positively related to individual differences in reactive aggression tendencies in everyday life; 4) individual differences in the frustration response and reactive aggression will be negatively related to inhibitory control as measured with a Go/No-Go task. Additionally, exploratory regression analyses investigated the relationship between the frustration response and trait-like reactive aggression such that individual differences in reactive aggression may explain individual differences in the degree or magnitude of the frustration response, in line with the trait aggression and aggressive personality impellence factors mentioned in the aggression models.

4.2 Methods

This study was pre-registered (see Appendix 4; https://osf.io/7ser3/). Any analyses that were deviations from the pre-registration or not included in the Chapter will be noted as such.

4.2.1 Participants

A total of 75 participants aged 11-16 years (Age_{M}= 12.97 years, Age_{SD}=1.36 years; see Table 6 for further demographic information) were recruited from a mainstream secondary school. Informed assent was obtained from the participants, and parents provided consent on an opt-out basis (2-week period). This study was approved by the Royal Holloway University of London ethics committee.

Measure		Demographics	
		N	%
Gender			
	Male	32	45.1%
	Female	39	54.9%
Handedness			
	Left	7	9.9%
	Right	62	87.3%
	NA	2	2.8%
Socio-Economic Status			
Most deprived ↑	*10% most deprived*	0	–
	20% most deprived	0	–
	30% most deprived	7	9.9%
	40% most deprived	19	26.8%
	50% most deprived	4	5.6%
Least deprived ↓	*50% least deprived*	6	8.5%
	40% least deprived	4	5.6%
	30% least deprived	13	18.3%
	20% least deprived	9	12.7%
	10% least deprived	0	–
	NA	9	12.7%
Special Educational Needs			
	Yes	3	4.3%
	(ADHD: N=2; 66.7%)		
	(Dyslexia: N=1; 33.3%)		
	No	65	92.9%
	Don't know	2	2.9%

Table 6. Demographic information for the final analysed sample (N=71).

4.2.2 Materials

4.2.2.1 Experimental tasks

Two computerised cognitive measures were used in the battery, the adapted frustration task to measure frustration response and a standard Go/No-Go task to measure inhibitory control. Both were completed on a laptop computer with 15.6 inch screen and were run and programmed in Psychtoolbox via Matlab (2015b).

Frustration Task

The frustration task is a 25-minute computer-based 'game' adapted from Yu et al. (2014) to induce frustration using a goal-blocking element within a simple left/right decision-making paradigm (see Chapter 2 for full details). As in previous iterations of the task, in-task self-report ratings were used as the primary measure of all affect ratings, and in-task ratings of motivation, surprise and pleasantness were recorded as control variables. Self-report ratings provided a measure of overall mean frustration (collapsed across the four blocked conditions) and a measure of frustration sensitivity. The outcome measure of frustration sensitivity was included as a means of capturing the stage-based modulation of frustration in a single metric that could be used in individual difference analyses and may provide a more theoretically informative measure of the frustration response. This measure was calculated by creating a beta value of a regression slope across the four blocked conditions (four stages of blocking) for each participant, such that a steeper (positive) slope would suggest that participants have a higher sensitivity to escalating frustration.

Go/No-Go Task

The Go/No-Go task is a 5-minute task that measures ‘cold’ inhibitory control (as used in Chapter 3.2.2.1.2 for task details). Percentage commission errors[7] on No-Go trials were used as the dependent variable, in line with standard practice and as was used in the previous Chapter (e.g. Humphrey & Dumontheil, 2016; Passamonti et al. 2010). Low commission error rates reflect greater ability to inhibit a prepotent response.

4.2.2.2 Questionnaire battery

The questionnaires were completed online via Qualtrics (www.qualtrics.com). Participants completed the following measures that were included in the analyses: Reactive-Proactive Aggression Questionnaire (Raine et al., 2006), Revised Child Anxiety and Depression Scale (Ebesutani et al., 2012), Pubertal Development Scale (Carskadon & Acebo, 1993) and postcode as a measure of socio-economic status (see English Indices of Deprivation, 2015). Participants also completed typical demographic measures (age, gender, ethnicity, handedness) and reported the presence of any special educational needs (see Table 6). The Affective-Reactivity Index (Stringaris et al., 2012), Frustration-Discomfort Scale (Harrington, 2005), and the ADHD subscale from the Strengths and Difficulties Questionnaire (Goodman et al., 1998) were also collected as part of a larger battery but are not discussed further. As the Reactive-Proactive

[7] Inhibitory control ability was pre-registered to be operationalised as d-prime score as this takes into account response bias. However, d-prime is a measure of discriminability which may represent the ability to discriminate between the stimuli used to represent the Go and No-go stimuli as opposed to inhibitory control ability. As such, and in line with previous literature using Go/No-go paradigms, inhibitory control ability was operationalised as percentage commission errors on No-go trials.

Aggression questionnaire and Frustration Discomfort Scale have been discussed in Chapter 2 (Pilot Study Three, section 2.4.2.2.2) they will not be detailed below.

Revised Child Anxiety and Depression Scale (short-form)

This measure was included to control for internalising symptoms (anxiety and depression), since these are typically positively correlated with reactive aggression (e.g. Card & Little, 2006). The short-form version of the Revised Child Anxiety and Depression Scale is a 25-item self-report questionnaire with two subscales: a broad anxiety scale (15-items; 3-items taken from each of the anxiety subscales from the full-form) and a depression scale (10-items, all retained from the full-form) reported on a 4-point Likert scale 0 ('Never') – 3 ('Always'). High scores represent higher levels of anxiety/depression.

Pubertal Development Scale

The Pubertal Development Scale is a 5-6 item (depending on sex and items responded "yes") self-report measure used to ascertain the pubertal status of an individual using Tanner stage (1-5) as the outcome variable where high scores reflect later developmental stages. This measure was taken in order to control for heterogeneity in pubertal development across chronological age.

English Indices of Deprivation (SES)

The English Indices of Deprivation was used as a measure of SES based on small areas of the UK and obtained by a postcode. It calculates a single value of multiple deprivation from seven indices of deprivation: income, employment, education, health, crime, barriers to housing and services, and living environment. Regions are scored from 1-32844, where a score of 1 represents the most deprived area, which was used as the main outcome variable for SES. Scores may also be represented as deciles (1-10), where 1 reflects the 10% most deprived area and 10 reflects the 10% least deprived area, though this was used only to display demographic data in Table 6. SES was included as a control variable to ensure results were not influenced by a skewed distribution across ages.

4.2.3 Procedure

Participants were randomly allocated to a task order to fully counterbalance tasks and questionnaires within each year group tested (year 7 [age 11-12] – year 11 [age 15-16]). Instructions were verbally given at the beginning of each task. Participants were given the opportunity to ask questions and the experimenter was available to assist participants upon request. Following testing, participants were fully debriefed verbally and given an information sheet. The debrief informed participants about the minor deception in the frustration task (i.e. participants were blocked randomly, regardless of their speed), and participants were given the option to withdraw their data retrospectively (N=0). Participants then received a small gift for taking part. Total battery length was ~50 minutes.

4.2.4 Data analyses

4.2.4.1 Missing Data:

Ratings for each blocked condition were calculated as a mean collapsed across the number of in-task ratings completed (typically three per condition, but see below for missing data rates). Missing data in the questionnaire items were interpolated, using mean interpolation at the item level, i.e. missing values were replaced with the mean of available items.

4.2.4.2 Question 1: Frustration Response

To test the adapted frustration task induced frustration as predicted, a repeated measures ANOVA with four levels (each of the blocked stages) was conducted, with post-hoc planned contrasts to test the linear modulation of the frustration response showing the pattern of increasing frustration at stage 1<2<3<4 using Bonferroni correction to correct for multiple comparisons.

4.2.4.3 Question 2: Frustration and Age

To test whether overall mean frustration and frustration sensitivity declined linearly with age respectively, two Pearson's product moment correlations were conducted between a) overall mean frustration and age, and b) frustration sensitivity and age, corrected for multiple comparisons ($p \leq 0.025$; 0.05/2). To test the alternative hypothesis that frustration and age would show a quadratic inverted 'U' shape relationship, two regressions (also corrected for multiple comparisons) were conducted where overall mean frustration or frustration sensitivity were the outcome variables and mean-centred age and mean-centred age squared were the predictor variables. Including both the linear term of age (mean-centred age) and the quadratic term of age (mean-centred age^2) allow the quadratic trend to be explored. Age was mean-centred to reduce multicollinearity between the linear and quadratic terms of age in order to meet the assumptions of linear regression.

4.2.4.4 Question 3: Frustration and Reactive Aggression

To test whether individual differences in the frustration response were related to individual differences in trait-like reactive aggression two Pearson's correlations were conducted between reactive aggression scores and a) overall mean frustration and b) frustration sensitivity. To correct for two correlations regarding the frustration response (overall mean and sensitivity), multiple comparison corrections were used, therefore $p \leq 0.025$ (0.05/2).

4.2.4.5 Question 4: Frustration and Inhibitory Control

To address the prediction that individual differences in inhibitory control may be related to individual differences in the frustration response two Pearson's correlations between inhibitory control ability and a) overall mean frustration and b) frustration sensitivity were conducted. To correct for two correlations regarding the frustration response (overall mean and sensitivity), multiple comparison corrections were used, therefore $p \leq 0.025$ (0.05/2). Additionally, a Pearson's correlation between inhibitory control ability and reactive aggression was conducted, to test the prediction that inhibitory control ability would be related to reactive aggression.

4.2.4.6 Exploratory Analyses

The following analyses were not reported in the pre-registration but were conducted to further explore the research questions and hypotheses of the current study.

To see whether age predicted frustration uniquely when including other individual difference variables of interest (i.e. variables which could be considered potential impellence factors), and to measure the relative unique contributions of these other individual difference variables, an exploratory linear regression was conducted which included all individual difference variables that showed a significant simple linear relationship with frustration as predictors (reactive aggression, anxiety and SES), in addition to age, age^2 and pubertal status. Mean in-task frustration response was the dependent variable. It was important to include this analysis in addition to the simple correlations and regressions between frustration, age and reactive aggression as while the simple correlations/regressions show what the relationships between these factors looks like, this exploratory regression will also provide information on how much of the variation within the frustration response they each uniquely contribute towards.

4.3 Results

Of the 75 participants recruited, a final sample of 71 participants were analysed. Pre-defined exclusion criteria were: >± 3 SD above the group mean on total mean errors collapsed across conditions during task phase (i.e. responses to ghost eye-gaze direction; N=0); >± 3 SD above the group mean on mean task reaction time collapsed across conditions (N=0); >± 3 SD above the group mean on total mean errors at confirmation phase (i.e. response of ‘win’ or ‘blocked’ to outcome of the trial, N=2); >± 3 SD in omission errors (N=0) or commission errors (N=0) on the Go/No-Go task; and finally ± 3 SD on any questionnaire scale or subscale included in the analyses (N=1). Additionally, one participant had no data for the frustration task due to time restrictions of the testing session therefore is not included in the analyses.

4.3.1 Missing data

In the frustration task, missing data occurred most frequently for one iteration of the in-task ratings when blocked at stage 4 since there were more stages where participants could respond incorrectly, and therefore were less likely to complete all four stages accurately. However, the majority of participants completed all three iterations of in-task ratings at each stage blocked (percentage of participants completing all iterations at: stage 1=71%; stage 2=69%; stage3 =69%; stage 4=61%) with the remaining participants having at least two in-task ratings for each blocked condition. Interpolated questionnaire items were rare and accounted for less 1% of all items, with an average of less than one item per participant interpolated.

4.3.2 Frustration and task manipulation

One-way repeated measures ANOVA (four blocked conditions, N=71) found a significant main effect of blocked condition on level of frustration reported (F(3, 210)=7.75, p<.001, η_p^2=.10; Greenhouse-Geisser corrected due to violated Mauchly's sphericity [X^2(5)=24.52, p<.001]). Post-hoc analyses showed frustration was significantly higher after being blocked at stage 4 (M=5.56, SD=2.61) than when blocked at stage 1 (M= 4.93, SD=2.52; p<.001), stage 2 (M=4.80, SD=2.44; p<.001) and stage 3 (M=5.13, SD=2.53; p=.002). There were no significant differences between any other blocked stages, showing a pattern of 1=2=3<4. The data did fit both a linear (F(1,70)=16.80, p<.001, η_p^2=.19) and quadratic trend (F(1,70)=6.78, p=.011, η_p^2=.09), though the linear trend shows a stronger effect based on F-ratio and effect size. See Figure 15 for mean frustration ratings per condition and individual data points.

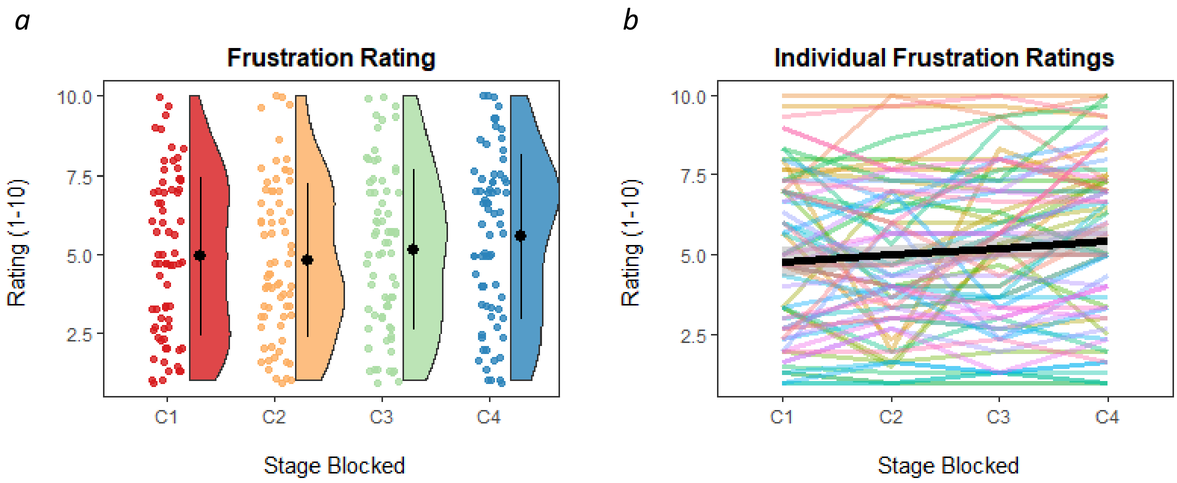


Figure 15. a) Raincloud plot of in-task frustration ratings for each of the blocked conditions (C1-C4) representing stage blocked. b) Plot of individual participants' data to illustrate the change in the frustration response across the four blocked conditions.

4.3.3 Contributing factors in the frustration response: Age and individual differences

Initial analyses to test the linear relationship between frustration and age found no significant correlation between age and participants' overall mean frustration across stages (r(69)= -.16, p>.05) or frustration sensitivity (r(67)=.08, p>.05). Regression analysis to test the quadratic term of age and overall mean frustration found a marginally significant model (F(2,68)=2.81, p=.068) which explained 4.9% of the variance (R^2=.05). Since the model was marginally significant individual predictors were examined. The linear term of age was non-significant (β= -.19, p=.101) and the quadratic term of age was marginally significant (*β*=.21, *p*=.073), showing a quadratic 'U'-shaped trajectory (see Figure 16). Regression analysis to test the quadratic term of age and frustration sensitivity found a non-significant model (*F*(2,66)=.52, *p*=.60).

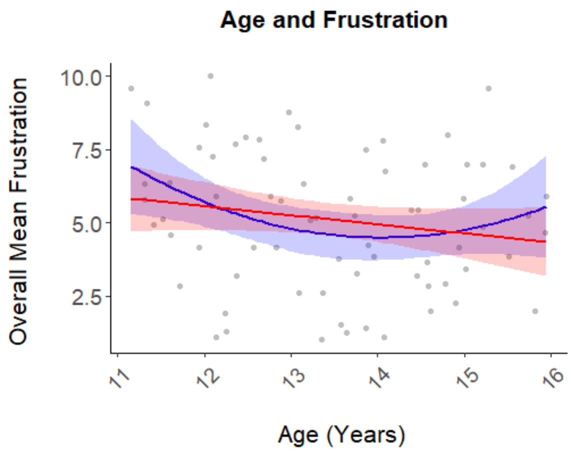


Figure 16. Scatter plots show individual data points of overall mean frustration showing the linear term of age (red line) and the quadratic term of age (blue line), with the shaded area representing the confidence interval at 95%, i.e. there is 95% confidence the true regression line lies within the shaded area. Results for overall mean frustration were at trend for the overall model (*p*=.068) and quadratic trend (*p*=.073).

As an exploratory analysis to explore whether age or age^2 provided any *unique* contributions when accounting for individual difference factors, and to explore the relative unique contributions of these factors themselves in the frustration response, any individual differences variables that were significantly correlated with either age or overall mean frustration were identified. Reactive aggression, anxiety[8] and socio-economic status were all significantly correlated with overall mean frustration, while

[8] Total internalising score was also significantly correlated with overall mean frustration, however this was not included in the regression model since this was driven by anxiety score; depression was not significantly correlated with overall mean frustration.

pubertal status was significantly correlated with age (see Table 7). These were then placed into a linear regression as predictors, with overall mean frustration as the outcome variable. The model was significant ($F(6,53)=4.56$, $p=.001$), explaining 34% of the variance ($R^2=.34$). Two predictors were significant: SES ($\beta= -.28$, $p=.022$) and reactive aggression ($\beta= .28$, $p=.031$). These predictors were not correlated with each other (Table 7). Neither age nor age^2 remained marginally significant when these additional variables were included.

4.3.4 Frustration and individual differences: Reactive aggression

There was a significant positive correlation between overall mean frustration (*M*=5.11, *SD*=2.37) and reactive aggression (*M*=8.24, *SD*=4.14; $r(69)=.33$, $p=.005$; see Figure 17), however there was no significant correlation between frustration sensitivity (*M*=0.22, *SD*=0.60) and reactive aggression ($r(67)= -.30$, $p>.05$).

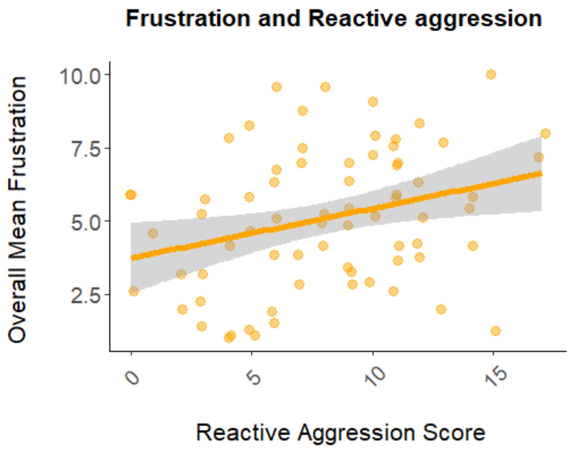


Figure 17. Scatterplot with line of best fit showing positive correlation (*r(*69)=.33) between overall mean frustration (Y-axis) and reactive aggression score (X-axis).

4.3.5 Frustration, inhibitory control and reactive aggression

There was no significant relationship between percentage commission errors and overall mean frustration ($r(59)=.11$, $p=.505$), nor was there a significant relationship between percentage commission error and frustration sensitivity ($r(57)=-.04$, $p=.708$). Additionally, there were no significant correlations between inhibitory control ability and reactive aggression ($r(59)=.02$, $p=.901$).

	Mean frustration	Frustration sensitivity	Commission errors (%)	Age (Years)	SES (% rank)[1]	Pubertal status[2]	Reactive aggression[3]	Anxiety[4]	Depression[4]	Internalising behaviours[4]
Mean frustration	–									
Frustration sensitivity	-0.01	–								
Commission errors (%)	0.09	-0.05	–							
Age (Years)	-0.15	0.09	-0.35 **	–						
SES (% rank)[1]	-0.29 *	0.14	0.19	0.06	–					
Pubertal status[2]	0.01	0.11	0.06	0.43 ***	-0.16	–				
Reactive aggression[3]	0.29 *	-0.08	0.02	-0.05	0.07	0.055	–			
Anxiety[4]	0.29 *	0.18	-0.13	0	0.05	0.077	0.43 ***	–		
Depression[4]	0.12	0.12	-0.1	0.14	0.16	0.059	0.41 ***	0.69 ***	–	
Internalising behaviours[4]	0.24 *	0.17	-0.13	0.06	0.1	0.077	0.46 ***	0.96 ***	0.87 ***	–

**p<.05   **p<.01   ***p<.001*

Table 7. Table of correlations for all variables of interest.

[1]SES (socio-economic status; percentile rank), [2]Pubertal status (Tanner stage), [3]RPQ reactive aggression subscale, [4]RCADS anxiety subscale, depression subscale and RCADS total score (internalising behaviours).

4.4 Discussion

This study investigated the development of the frustration response across adolescence and whether developmental differences in the frustration response may be related to individual differences in trait-like reactive aggression behaviours and inhibitory control ability. Consistent with the general trend in previous Chapters and Yu et al. (2014), frustration increased linearly across the four stages of blocking (question one), though the predicted modularity of frustration across the stages (1<2<3<4) was not found. Rather, adolescents were more frustrated when blocked directly preceding reward attainment compared to any other stage of blocking only (broadly replicating Chapter 2, Pilot Study Two). The relationship between frustration and age (question two) was not significant for either the linear or quadratic terms of age when correlated with either overall mean frustration or frustration sensitivity. Frustration (overall mean but not sensitivity) was positively related to trait-like reactive aggression in line with the hypothesis (question three) but was not related to inhibitory control abilities (question four). Additionally, the relative contribution of potential impellence factors, i.e. age and individual differences (reactive aggression, anxiety and SES), in predicting the frustration response found that age did not explain the frustration response but individual differences did, such that reactive aggression was positively associated while SES was negatively associated with the frustration response.

Frustration increased linearly as predicted, however this was not as neatly parametrically modulated as hypothesised based on Yu et al. (2014) or was previously reported in Pilot Studies One and Three using adult samples (see Chapter 2). However, the pattern that adolescents were more frustrated when blocked directly prior to the reward (stage 4) compared to any other stage is consistent with results found in the previous adolescent sample (Chapter 2, Pilot Study Two). As was discussed in Chapter 2, this may be because adolescents are typically more ‘present-oriented’ favouring immediate rewards over delayed rewards (Steinberg et al, 2009; Whelan & McHugh, 2009). Applied to the frustration paradigm, adolescents may not differentiate the effects of being blocked at stages 1-3 as much as adults as they are not as proximate to the reward, whereas stage 4 immediately precedes the reward. As such, adolescents compared to adults may find goal-blocking less frustrating at stages 1-3, therefore showing less modulation of the frustration response. Another possibility is that the data may be generally more noisy in the adolescent sample than the previous adult samples. For example, in the current study, standard deviations for the in-task ratings ranged from 2.44-2.61, whereas in the adult sample in Chapter 3, the standard deviations ranged from 1.95-2.33. As such, the increased variation at each stage in the adolescent sample compared to an adult sample may explain why there was less parametric modulation of frustration between stages 1-3 when frustration ratings are generally lower than at stage 4.

That there were no age effects in the frustration response is not consistent with either the linear or quadratic predictions made for age, i.e. that the development of the frustration response may mirror age effects in emotion regulation improvements (linear term) or the trajectory of 'peaking' reactive aggression in mid-adolescence (quadratic term). However, the pattern of responding appears to be different between adolescents and adults, with adult samples showing a stronger parametric modulation of the frustration response. This may be indicative of more subtle developmental differences between groups as opposed to within groups. However, it was not possible to directly test this comparison statistically. Indeed, the sample tested in this study do not cover the entire range of adolescence and so it is possible that results may have differed had a wider age range spanning more of the adolescent period been included.

The null findings between age and overall mean frustration may have occurred for a number of reasons. Previous research reported developmental differences in the neural frustration response in adolescents compared to adults (Ernst et al. 2005) and within adolescence (Lewis et al. 2006). However, Ernst et al. did not see differences in behavioural ratings of frustration, and these were not measured directly by Lewis et al. (2006). It is possible that while the implicit neural response to frustration shows developmental differences, that these do not directly translate into consciously perceived (explicit) affect. Indeed, Lewis et al. (2006) reported a weak relationship between neural activity and negative emotion ratings, though this improved when removing the youngest participants. Similarly, a study investigating emotion regulation differences across adolescence (8-15 years) found no differences in self-reported appraisal but did find increased amplitude of a neural marker of emotion regulation in the older group (12-15 years) compared to the younger group (8-11; van Cauwenberge, van Leeuwen, Hoppenbrouwers & Wiersema, 2017).

Related emotion regulation research has also found a null age effect across development when using self-report measures on experimental tasks. For example, temporal distancing ability was stable across adolescence (12-22 years; Ahmed et al. 2018), as was cognitive reappraisal success and spontaneous use of emotion regulation related language (10-23 years; Nook, Vidal Bustamante, Cho & Somerville, 2019). While the current study was not an emotion regulation task, these are related processes that are likely engaged during frustrating episodes (e.g. Lewis et al. 2006) and may in part explain the null developmental differences in the frustration response.

Additionally, a recent review paper of adolescent development has suggested that individual differences are as important as age in explaining trends in adolescent behaviours and their neural substrates (Foulkes & Blakemore, 2018). Reviewing a number of longitudinal MRI studies of adolescent development, Foulkes and Blakemore reveal that while most studies demonstrate adolescent development or maturation in brain areas related to the frustration response (e.g. amygdala) at the sample mean, individual developmental trajectories show large variation. In the current study, both overall mean frustration and frustration sensitivity were not significantly associated with age, but both show large individual differences, i.e. both the magnitude of the frustration response and the change in the frustration response across the four blocked stages shows a large amount of variance (see Figure 15). Indeed, when looking at the unique contribution of age and individual differences factors, the frustration response did not vary with age but did appear to vary with unique variance associated with reactive aggression and socio-economic status.

Methodological limitations of the study may also shed light on the null results. As in previous studies in this thesis, overall mean frustration was reported as being moderately frustrating (5-6 on a 10-point scale). The mean may not be particularly representative of individual differences in *change* across the four stages, which in previous Chapters was speculated to provide additionally meaningful information about the development of the frustration response. Therefore, the current study also used a measure of frustration sensitivity, but this similarly showed no association with age. However, the frustration sensitivity variable may not be an appropriate measure. It was calculated at an individual participant level as the value of the slope of the frustration response across the four blocked stages. However, this relies on a linear trajectory of participants' responses across the four stages which not all participants displayed (see Figure 15b). As such, the frustration sensitivity measure could not adequately capture the change in frustration for participants *without* a linear frustration response, and therefore cannot accurately characterise the sample's mean frustration sensitivity.

In contrast to age, two individual difference factors, namely reactive aggression and SES, were found to significantly predict mean frustration response (both in simple correlations, and uniquely when age, age^2, pubertal status and anxiety were included in the model). In line with the second hypothesis and consistent with previous literature (e.g. Yu et al. 2014; Deater-Deckard et al., 2010; Harrington, 2006; Little et al., 2003), mean frustration response (but not frustration sensitivity) was positively related to trait-like reactive aggression, such that increased frustration responses (higher ratings) were associated with increased frequencies of reactive aggressive behaviours in day-to-day life. These results suggest that individual differences in the frustration response are related to individual differences in reactive aggression. On the one hand, the Frustration-Aggression hypothesis and the I^3 model would predict that the frustration response should precede the aggressive response. On the other hand, the General Aggression Model considers aggressive personalities, such as may be captured using a trait-like measure of reactive aggression as in the current study, to be distal factors that are both influenced by individual episodes of aggression and influence individual episodes of aggression as a distal factor, suggesting a more cyclical relationship between these two variables.

Applied to the frustration response as operationalised in the present study, it is possible that increased trait-like reactive aggression as measured by the Reactive Proactive Aggression Questionnaire serves as an 'impellence' factor in the likelihood of frustrating occurrences resulting in a stronger mean frustration response. Indeed, regression results found that trait-like reactive aggression positively predicted the frustration response, which suggests the relationship between the frustration response and trait-like reactive aggression may be more akin to the ‘aggressive personality’ or knowledge structures proposed in the General Aggression Model. The present study did not include a reactive aggression outcome variable such as response force, measured in Chapter 3. In light of the present findings, a future study could test the hypothesis that the frustration response mediates the relationship between trait-like reactive aggression and aggressive responding.

The final pre-registered hypothesis, that inhibitory control ability would be related to the frustration response and reactive aggression was not confirmed. Inhibitory control ability improved linearly with age ($r(59)= -.35$, $p=.006$), in line with previous literature, and provided a validation of the task (e.g. Aite et al. 2016). However, inhibitory control ability was not associated with overall mean frustration or reactive aggression, which is inconsistent with predictions, and with previous studies that have found a negative relationship between inhibitory control and frustration (Muris, Meesters & Blijlevens, 2007; Lewis et al., 2006) and reactive aggression (Hecht & Latzmann, 2017; Finkel et al., 2009).

Discrepancies between the current results regarding frustration and previous findings may at least partly be explained by methodological differences. The Go/No-Go design used in this study assessed inhibitory control in an affectively neutral context, i.e. assessed 'cold' inhibitory control, whereas previous literature has primarily assessed 'hot' inhibitory control. For example, the task used in Lewis et al. (2006) was a frustration induction paradigm within an emotion-induction inhibitory control task. As such, the EEG results demonstrating increased activation in areas related to inhibitory control would be in response to an affectively charged inhibitory control task, as is demonstrated by increased ratings of 'mad' and 'upset'. Similarly, the questionnaire items of inhibitory control used in Muris, Meesters & Blijlevens (2007) were akin to 'hot' inhibitory control, e.g. 'has a hard time waiting his/her time to speak when excited'. Both the frustration response and reactive aggression are inherently affectively charged, as both are characterised by negative affect. As such, individual differences in both the frustration response and reactive aggression may be better explored by using an inhibitory control task that captures 'hot' inhibitory control abilities. This is particularly relevant when exploring the relationship between the frustration response, reactive aggression and inhibitory control during adolescence as while 'cold' inhibitory control improved linearly with age, 'hot' inhibitory control appears to improve quadratically with age (Somerville, Hare & Casey, 2011), whereby adolescents demonstrate worse inhibitory control ability than do children and adults. Additionally, 'cold' and 'hot' inhibitory control abilities do not appear to be correlated with each other during adolescence and adulthood, suggesting 'cold' and 'hot' inhibitory control abilities draw upon distinct processes (Aite et al., 2016). Given all the evidence suggesting that it is specifically hot inhibitory control that is important, this might be an important refinement of the I^3 model that hot, not cold or general inhibitory control, serves as an 'Inhibition' factor in the likelihood of frustration or reactive aggressive behaviours occurring.

Finally, exploratory results revealed a non-predicted unique relationship between the frustration response and socio-economic status. Socio-economic status was intended as a control variable across age. However, as it was unrelated to age but did relate to the frustration response, it warrants a brief discussion. Individuals from lower SES backgrounds reported higher levels of overall mean frustration on the task. Previous research has found lower SES to be associated with impaired cognitive and socio-emotional development (Hackman, Farah & Mearey, 2010; McLoyd, 1998). As such, individuals with lower SES may have greater difficulty in regulating their frustration response, though this warrants more research (outside of the scope of the thesis). Interestingly, SES was not significantly correlated with reactive aggression, suggesting that this effect may be relatively subtle and, at least in this sample, does not 'spill over' into real-world aggressive behaviour.

Overall, these results suggest that mean frustration response does not vary with age across adolescence or with inhibitory control ability but is related to individual differences in reactive aggressive behaviours. From the perspective of aggression models, age in-and-of-itself may therefore not be a strong impellence factor to reactive aggression, at least via the frustration response. Previous research did, however, find age-related differences in the frustration response at the neural level (Ernst et al. 2005; Lewis et al. 2006), in regions overlapping with the aggression network. As such, the neural mechanisms underlying the frustration response also warrant investigation during adolescence, as few studies to date have characterised the frustration response at this level of explanation or explored whether age-related variation in the neural response may be related to individual differences in reactive aggression. That the frustration response was related to individual differences in trait-like reactive aggression suggests that predisposition towards reactive aggression may also be an impellence-like factor in the frustration response (which in turn may impel further reactive aggression). Regarding inhibition factors, inhibitory control ability may still serve as a mediating role in the frustration response and reactive aggressive behaviours when measured using 'hot' inhibitory control tasks.

The next Chapter therefore investigates the neural bases of the frustration response for the reasons discussed above. Namely, the frustration response has not been well characterised in the extant frustration literature, though some research suggests there are potential developmental differences relating to adolescence. Given the previously evidenced overlap between the frustration response and aggression network, developmental differences during adolescence in the neural underpinnings of the frustration response may be related to individual differences in reactive aggression which may not be seen at the behavioural level at moderate levels of frustration as are elicited in the current paradigm.

Chapter 5: The Neural Bases of Frustration

The previous Chapters have so far characterised the frustration response at two levels of explanation: behavioural (e.g. grip force; Chapter 3) and self-report (Chapters 2, 4), and have related the frustration response to individual differences pertinent to the broader context of the thesis, reactive aggression and adolescence respectively. In Chapter 3, results demonstrated that while aggressive responding to frustration (i.e. grip force) significantly increased across the four blocked conditions, overall grip force was not significantly correlated with the overall mean level of frustration reported. These data suggest that increasing levels of frustration provoke increasing levels of physiological aggressive responding, or perhaps a preparedness to respond aggressively. In Chapter 4, results demonstrated that the frustration response in a sample of adolescents (11-16 year olds) did not significantly vary as a function of age, contrary to predictions. Rather, individual differences (i.e. reactive aggression, SES) were stronger in explaining variation within the frustration response. In both studies the frustration response was measured by behavioural variables, i.e. grip force or self-report ratings, but these data reveal little regarding the underlying mechanisms of the frustration response. In the current study therefore, the frustration response was examined using fMRI to garner further understanding of the frustration response at the neural level.

5.1 Introduction

Understanding the neural underpinnings of the frustration response will provide an additional level of explanation that has not yet been covered by previous Chapters and may provide a measure that is able to capture subtle individual differences (e.g. in age or reactive aggressive responding) that the grip force and self-report ratings measures may otherwise not be sensitive enough to detect. Additionally, the frustration measures used so far used only capture the end point of an entire process of the frustration response, i.e. the surface level behavioural outcomes. However, different cognitive and affective processes that can be differentiated using neuroimaging may exert the same effect on performance in behavioural measures (Wilkinson & Halligan, 2004; Keightley et al. 2003). The current study will also provide evidence regarding the neural mechanisms underpinning the frustration response in typically developing adolescents, which is currently lacking in the extant literature. To date, the majority of studies exploring the frustration response have been in healthy adult samples, children or youth with clinical diagnoses.

In studies using adult samples, comparing frustration (e.g. reward omission or rigged negative feedback) to no frustration (e.g. reward or accurate/positive feedback) has revealed increased activation in regions of the limbic system including the anterior cingulate cortex (ACC; Yu et al. 2014; Abler et al. 2005), posterior cingulate cortex (PCC; Yu et al. 2014; Bierzynska et al. 2016) and anterior insula (Bierzynska et al. 2016; Yu et al. 2014; Abler et al. 2005), and in regions of the

PFC including ventral/ventral-lateral PFC (v/vlPFC; Ihme, Unni, Zhang, Rieger & Jipp, 2018; Abler et al. 2005) and dorsolateralPFC (dlPFC; Bierzynska et al. 2016; Yu et al. 2014). There is also some evidence, though not as commonly reported, of increased activation in the amygdala and periaqueductal gray (PAG; Yu et al. 2014) and in the ventral striatum including the caudate and putamen (Bierzynska et al. 2016). For example, Yu et al. (2014) found increased activation in the amygdala and PAG when participants were blocked compared to an affect-neutral baseline, and also found that activation within these areas was significantly positively correlated with the stage participants were blocked at, i.e. the closer the participant was to the reward the greater the increase in the BOLD signal in these brain regions.

A small number of studies have begun to refine our understanding of the brain regions associated with the frustration response by comparing neural activation during frustration between individuals with high and low levels of: frustration tolerance (Bierzynska et al. 2016), susceptibility to frustration (i.e. the inverse of frustration tolerance; Siegrist et al. 2005) and aggression (Pawliczek et al. 2013). A study by Bierzynska et al. (2016) found that only the PCC differentiated groups during frustration (negative feedback on a difficult tactile task), with individuals low on frustration tolerance showing increased activation in comparison to individuals high on frustration tolerance.

Another study by Siegrist et al. (2005), however found multiple regions with differentiated activation during frustration. In this study, participants with high levels of susceptibility to frustration showed increased activation of the ACC, vlPFC and dlPFC compared to their low susceptibility to frustration counterparts. In contrast, a recent study by Pawliczek et al. (2013) found individuals with high levels of aggression compared to individuals with low levels of aggression (characterised by aggression scores >85th percentile and <15th percentile respectively of the total sample) showed reduced activation in the dorsal ACC, vlPFC and dlPFC. Particularly for the ACC, vlPFC and dlPFC, these findings appear contradictory, though they are not directly comparable due to the different measures used. Given these regions are associated with emotional processing and emotion regulation, it may be reflective of the underlying processes involved in both frustration and aggression, such as decreased self-regulation/increased impulsivity in individuals with increased aggression (Pawliczek et al. 2013) and extended processing of emotional or salient stimuli in individuals with low frustration tolerance (Bierzynska et al. 2016).

In children and adolescents, similar brain regions have been reported in relation to the frustration response. In studies of children for example, frustration was induced via reward-omission and was associated with increased activation in the dlPFC (3-6 year olds, Perlman, Luna, Hein & Huppert, 2014; 6-9 year olds, Perlman et al. 2015) and in the caudate and putamen (ventral striatum; 6-9 year olds, Perlman et al. 2015). Another study found increased activation in the vPFC/OFC and mid cingulate cortex (MCC)/PCC during a frustration-induction as determined by source analyses of EEG electrode activation (5-16 year olds, Lewis et al. 2006). This finding is perhaps the most relevant to the adolescent developmental period, as the increase in the vPFC was only found in the 9-12 and 13-16 year olds (i.e. not the younger children), and the increase in MCC/PCC was only found in the 13-16 year olds for the frustration block only (it was also found in the reward block for younger age groups).

Furthermore, exploring the differences between healthy control youth and clinical samples of youth with diagnoses that include either frustration or reactive aggression as a hallmark characteristic (e.g. irritability and relatedly, bipolar disorder), allows investigation into aberrant processing of the frustration response. In studies comparing clinical and non-clinical groups during frustration, the evidence is mixed. Youth with severe irritability in comparison to healthy controls have shown both hypoactivation and hyperactivation in the ACC. For example, hypoactivation was seen in youth with irritability compared to healthy controls during ‘lose’ (i.e. frustration) trials compared to ‘win’ trials in a rigged reaction time task (Perlman et al. 2015). Conversely, hyperactivation was seen in youth with irritability compared to healthy controls while completing an affective Posner task following frustration-inducing rigged feedback, i.e. responding accurately but receiving negative feedback (occurred on 60% correct trials), compared to positive, i.e. accurate feedback (occurred on 40% correct trials), from the previous trial (Tseng et al. 2019). It should be noted though that evidence of hyperactivation was only found in the 8-14 year olds and not in the 14-18 year olds in this study. Youth with bipolar disorder also show hyperactivation in the ACC (Rich et al. 2010) in comparison to typically developing controls during an affective Posner task with rigged feedback on one of the three blocks, such that on 56% of correct responses participants would receive negative feedback ('Too slow!') and lose money earned in the task. A small number of studies have also reported aberrant processing in the amygdala and ventral striatum (hypoactivation, Deveney et al. 2013) and the PCC (hyperactivation; Perlman et al. 2015) in youth with severe irritability compared to healthy controls. Additionally, activation in the dlPFC and caudate (ventral striatum) were positively related with level of irritability in a sample of 8-18 year olds (Tseng et al. 2019).

While these disorders are related to frustration and/or reactive aggression, Conduct Problems/Disorder (CP/CD) and Disruptive Behavioural Disorders (DBD) are the only disorders *defined* by antisocial and aggressive behaviour, and so may provide additional insight into the neural underpinnings associated with frustration. For example, a study by White et al. (2016) compared groups of youth with DBD to typically developing controls using the Social Fairness Game, a provocation (not frustration but related) task, using fMRI (see Chapter 1.2.5 for details of the study). On some trials, participants would receive a fair split of an amount of money (low provocation) and on other trials would receive an unfair split (high provocation), which they could either accept or reject. fMRI results found DBD youth compared to controls showed greater amygdala and PAG activity, reduced attenuation of vmPFC activation, and reduced amygdala-vmPFC connectivity during high provocation trials. These results suggest that in youth with clinically relevant levels of reactive aggression, provocation was related to both hypo-activation and decreased functional connectivity between PFC and limbic regions, which may result in impaired emotion regulation (though frustration was not studied directly).

Taken together, these studies in both adults and youths suggest that the ACC, dlPFC and vPFC are implicated in the frustration response, with some indication that the anterior insula, amygdala, PCC and ventral striatum may also play a role. These brain regions have previously been implicated in emotion processing and subsequent emotional reactivity (amygdala), particularly negative emotions (anterior insula), emotion regulation (vlPFC, dlPFC), rewards and error processing (ventral striatum) and conflict control between affect and cognition (ACC, PCC). Given that the frustration response has been described as an energising emotion and one that generates a preparatory response (Yu et al. 2014) and the processes associated with these brain regions would likely serve this function, it makes sense for these regions to be increasingly active during an escalating frustration response.

Though any conclusions regarding developmental differences in the frustration response across adolescence are necessarily tentative given the limited literature addressing this question, the studies presented provide some evidence of a developmental trend of increasing vlPFC and dlPFC activity with age, though this appears to only occur until mid-adolescence (Tseng et al. 2019; Lewis et al. 2006). Neurobiological development during adolescence includes the maturation of the PFC and areas relevant to emotion regulation as well as a reorganisation of the reward system including the ventral striatum (see Chapter 1.2.4), so these findings are in line with known structural and functional developmental trends.

Additionally, the brain regions associated with the frustration response were also implicated as sites of aberrant processing in individuals with behaviours associated with reactive aggression such as youth with irritability (ACC, amygdala, dlPFC), and within typical adult populations when comparing individuals on high and low extremes of aggressive behaviours (e.g. ACC, vlPFC, dlPFC). This suggests that these regions may be of relevance to associations between individual differences in frustration processing and reactive aggression. These regions also overlap with brain regions involved in reactive aggression (e.g. amygdala, PAG, insula and dlPFC; Lickley & Sebastian, 2018) suggesting the frustration response may represent the preparation for a possible aggressive response, in line with models of aggression (e.g. I^3 and GAM; Finkel, 2014; Allen et al. 2018). In particular, the ACC showed decreased activation in typical adults with high compared to low trait aggression (Pawliczek et al. 2013) and hypoactivation in youth with irritability compared to typically developing youth (Perlman et al. 2015; Deveney et al. 2013). The ACC has previously been associated with conflict control, error processing and emotion regulation (Ahmed et al. 2015), suggesting that these areas keep the frustration response in check and prevent an override into an aggressive response until it is further pushed beyond a certain threshold.

However, the extant literature does not have a body of evidence sufficient to draw strong conclusions on the characterisations of the neural bases of the frustration response. In particular, there is a lack of a developmental aspect in understanding the frustration response for two reasons. Firstly, there are very few existing studies examining this relationship. Secondly, the studies presented in this Chapter are limited as they have used samples of children only or have combined child and adolescent groups such that the results cannot be accurately extrapolated to adolescence. Additionally, some studies have investigated which regions show differences in activation between clinical and non-clinical groups, i.e. are not characterising the frustration response per se. As such, there is little empirical work on the development of the neural bases of the frustration response across adolescence, nor how these relate to reactive aggression.

The aim of the current study is therefore three-fold: to elucidate the neural correlates of the frustration response; to investigate whether the identified neural correlates show developmental changes with age across adolescence, and; whether individual differences within the neural correlates of the frustration response are associated with individual differences in reactive aggression. Specifically, it is predicted that a) the neural bases of frustration will show some overlap with those implicated in reactive aggression, particularly in regions identified above including the ACC, anterior insula, amygdala and vlPFC/dlPFC; b) there will be developmental change in the neural bases of the frustration response, specifically increasing engagement of PFC (vlPFC/dlPFC) coupled with decreasing self-reported frustration with age; c) individual differences in the neural responses to frustration will be correlated with differences in reactive aggression such that greater frustration responses will be associated with greater levels of reactive aggression. These findings would suggest that development in the ability to manage frustration during adolescence may be underpinned by the continuing maturation of emotion regulation abilities which may have implications for reactive aggression.

5.2 Methods

5.2.1 Participants

A total of 40 adolescents aged 11-18 years (Age_{M}=14.85 years, Age_{SD}=2.40 years) were recruited from a community opportunity sample via advertisements in mainstream secondary and sixth form schools and to public groups such as youth groups and social media. Participant characteristics are displayed in Table 8. Participants were invited to take part in the fMRI study after being screened for eligibility including a) being able to undergo an MRI scan and b) no current diagnoses of psychological, psychiatric or neurological disorders, excluding mild learning difficulties such as dyslexia. A final sample of 39 were included in the subsequent analyses due to one exclusion. Predetermined exclusion criteria were consistent with previous studies. These were ±3SD in: task errors collapsed across conditions (N=0); confirmation errors (N=1); or questionnaire subscales (N=0). One participant did meet the exclusion criteria for +3SD on questionnaire subscales (RCADS: anxiety) but removing them from the sample had no effect on the behavioural data therefore they were not excluded to retain power in the fMRI analyses. Additional exclusion criteria included: >5% volumes with motion exceeding a determined threshold (N=0; see 'Data Analyses' for more information). Ethical approval was granted for this study by Royal Holloway University of London ethics committee.

Measure	Demographics	
	M	SD
Age (Years)	14.85	2.4
	N	%
Gender		
Male	18	46%
Female	21	54%
Handedness		
Left	7	18%
Right	32	82%
Special Educational Needs		
Yes	1	3%
	Dyslexia (N=1)	
No	37	95%
Don't Know	1	3%
Socio-Economic Status		
10% most deprived	0	0%
20% most deprived	1	3%
30% most deprived	1	3%
40% most deprived	0	0%
50% most deprived	3	8%
50% least deprived	4	10%
40% least deprived	6	15%
30% least deprived	4	10%
20% least deprived	10	26%
10% least deprived	10	26%

Table 8. Demographic characteristics of the analysed sample (N=39).

5.2.2 Materials

5.2.2.1 Frustration task

The adapted frustration paradigm as described in Chapter 2 (see section 2.1.2) was optimised for use within an MRI environment, with a specific focus on addressing the additional difficulties of scanning an adolescent sample (see Figure 18 for adapted task timeline).

One of the main difficulties in scanning adolescents relative to adults is the participants' ability to stay engaged with the task and the increased likelihood of motion (e.g. Yuan et al. 2009). To retain participant engagement and to minimise motion as much as possible the task was split into two consecutive runs (42 trials per run) each lasting approximately 13-18 minutes (self-paced) as participant engagement has been previously found to decrease in a stepwise manner after two runs of a task (Engelhardt et al. 2017) and run length has been found to increase motion in children (Meissner, Walbrin, Nordt, Koldewyn & Weigelt, 2019 [pre-print]). Additionally, within each run, participants were given a 15 second half-way break, as having inside-scanner breaks has been found to decrease motion (Meissner et al. 2019 [pre-print]). To avoid adding undue motion during the break, participants were instructed prior to scanning, and reminded at the beginning of each run, to remain as still as possible during the break. Reward tokens earned in the first run were carried over to the second run to ensure continuity of the task and to keep task structure consistent with the version of the task used in the preceding studies. Trial order for the entire task was pseudo-randomised prior to run one and was carried over into the second run (see Chapter 2 for pseudo-randomisation details).

The main effect of interest was the parametric modulation of frustration, therefore a linear pattern of increasing activation related to frustration with stage blocked as participants get closer to the reward was predicted. However, the task design also represents a linear progression in the change of visual stimuli with stage, i.e. the squares representing each stage turn from white to green or red (completed stage or blocked stage respectively) as they progress. Therefore, to avoid potential confounds from systematic differences in visual stimulation (e.g. red or green squares), three further modifications to the task were made.

Firstly, the white squares (representing the number of stages left to complete in a given trial) were changed to grey as grey is less salient than white and is generally better for participant comfort as white is very bright when inside the scanner. Secondly, the luminance of the squares showing number of stages left to be completed (grey) were matched to the luminance of the squares denoting the number of stages completed successfully (green) as closely as possible using a photometer (grey=59.08 cd/m^2; green=58.76 cd/m^2). It was particularly important that luminance was matched to ensure that the saliency of the visual information did not vary systematically with the manipulation of the task, i.e. stage blocked. By ensuring this, any activation reported could be more confidently interpreted as a result of parametrically modulated frustration and not visual differences in task design. Thirdly, the reward progress bar was presented on both sides of the screen to ensure it was presented bilaterally to the left and right hemispheres and should therefore not interfere with any lateralised effects of interest.

A jittered-length fixation cross replaced a fixed-duration fixation cross between the feedback stage (‘WIN’ or ‘BLOCKED’) and the confirmation stage ([did you…] ‘win or blocked’). This allowed the BOLD response at these two stages to be decorrelated such that the main regressor of interest (feedback) can be measured independently from the next stage in the task (confirmation) as these were always presented in the same order. Additionally, this provided a potential avenue to explore brain activation during a ‘reactivity’ state (feedback) and a ‘recovery’ state (confirmation). Jitter lengths were randomised to range between 1.5-4 seconds, with the total mean jitter lasting approximately 2.5 seconds to match that of the scanner repetition time (TR).

Additionally, the confirmation screen was reduced from a 3 second to a 2 second duration, as participants were responding to the confirmation stage well within 2 seconds (Chapter 4: M=908ms, SD=219ms). Reducing the confirmation stage to 2 seconds reduced scanning time and assisted with overall task engagement.

Finally, to simplify in-scanner responses and to allow participants to respond with a single five-key response pad, the possible responses to the in- and end-task ratings were changed from 1-10 to 1-5, while retaining the descriptive categories to be consistent with previous studies (see Figure 19).

Very slightly or not at all		A Little		Moderately		Quite a lot		Extremely	
1	2	3	4	5	6	7	8	9	10

Very slightly or not at all	A Little	Moderately	Quite a lot	Extremely
1	2	3	4	5

Figure 19. Top: 1-10 ratings used in the original Yu et al. (2014) version and previous iterations of the adapted versions (Chapters 2-4). Bottom: 1-5 rating scale used in the MRI study of the adapted task (Chapter 5).

5.2.2.2 Additional measures

As part of the larger fMRI battery participants also completed a Gender Decision task consisting of emotional and neutral faces. However, this is not discussed further. Participants also completed the Go/No-Go task used in previous studies (used in both Chapters 3 and 4) outside of the scanner, but this is also not discussed further.

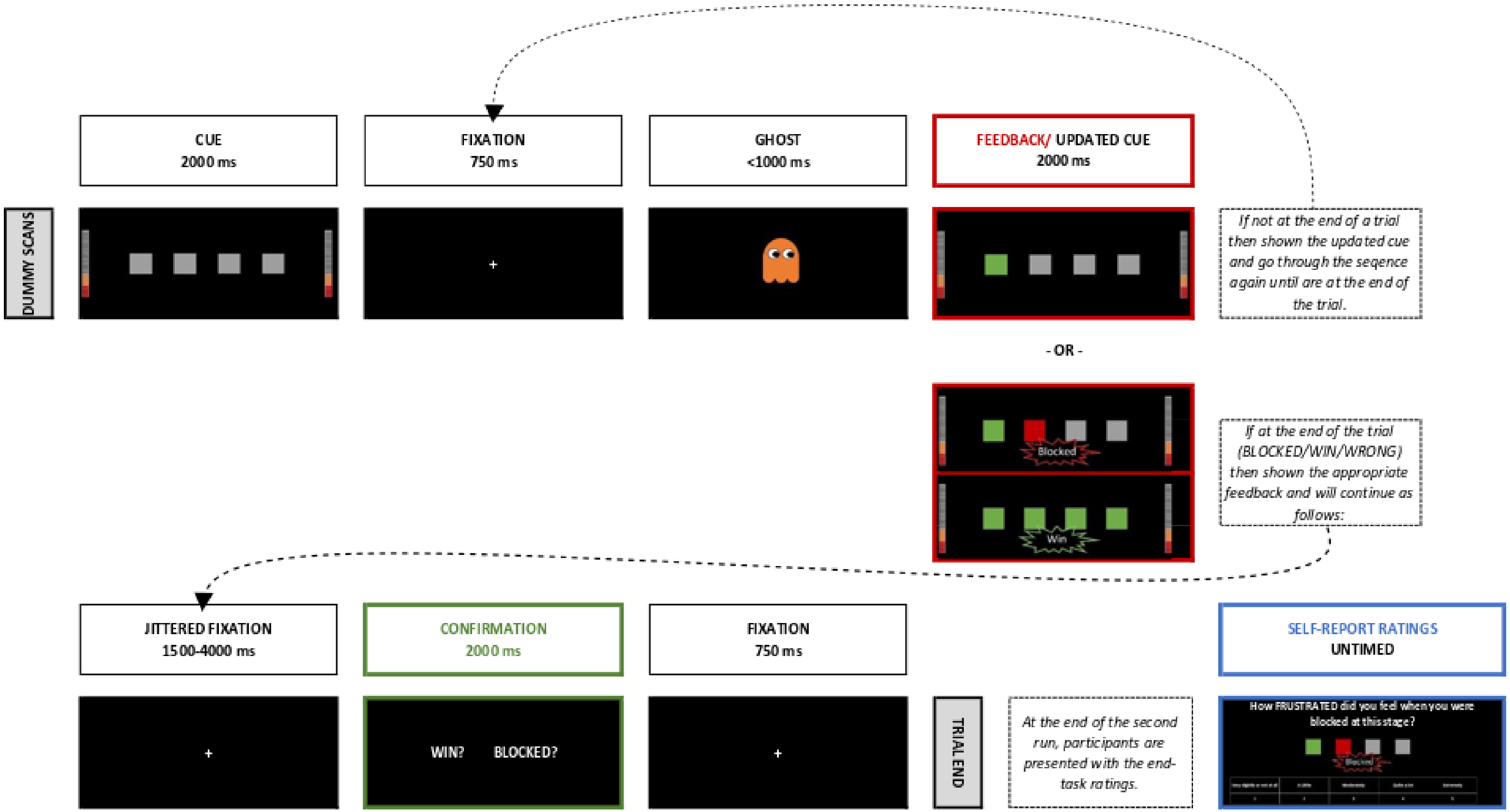


Figure 18. MRI adapted frustration paradigm timeline, showing contingencies depending on stage completed and participant responses.

5.2.2.3 Questionnaire battery

The questionnaire battery was largely the same as detailed in Chapter 4 (4.2.2). Demographics included age, handedness, ethnicity, presence of special educational needs and postcode in order to obtain a measure of socio-economic status using the English indices of multiple deprivation (see English Indices of Deprivation, 2019). Note, in Chapter 4 SES was based on the UK indices of multiple deprivation from 2015 whereas the current study is based on the 2019 measure. Other questionnaire measures included internalising symptoms (anxiety and depression; Revised Child Anxiety and Depression Scale, Ebesutani et al., 2012); frustration tolerance (Frustration Discomfort Scale, Harrington, 2005), reactive aggression (Reactive-Proactive Aggression Questionnaire, Raine et al. 2006); ADHD (from the Strengths and Difficulties Questionnaire, Goodman et al. 1998) and affective reactivity (Affective Reactivity Index, Stringaris et al., 2012), and; a measure of pubertal status (Pubertal Development Scale) (see Appendix 2 for all measures). The current study also included a measure of situations that trigger aggression (Situational Triggers of Aggressive Responding scale, Lawrence, 2006) and intelligence quotient (Weschler Abbreviated Scale of Intelligence, WASI-II; The Psychological Corporation, 1999).

Situational Triggers of Aggressive Responses Scale (STARS)

The STAR scale is a 23-item measure of level of aggression typically triggered by different events which can be split into two factors (subscales): frustration and provocation. Participants were instructed that they would be presented with a number of scenarios in which they might feel aggressive, with each item preceded by the statement ‘I feel aggressive when…’. Items were scored using a five-point Likert scale 1 (very inaccurate for them) – 5 (very accurate for them), with high scores representing typically feeling aggressive in that given situation. The frustration subscale (10-items) was related to situations participants found frustrating and where they felt they had a lack of control, e.g. 'I am frustrated', while the provocation subscale (13-items) was related to items where participants felt they had been directly provoked, e.g. 'I am goaded or provoked by someone'. However, as this scale was designed for adults, two items were removed as they did not pertain to the adolescent sample of the current study. These items were both from the provocation subscale: 'Someone is drunk and is inconsiderate towards me' and 'Another driver commits a traffic violation'.

The STAR scale was included in the current study as an additional measure of individual differences in the frustration response and whether these may be related to how likely frustrating events may lead to reactive aggression. As the STAR scale explicitly asks participants to rate how likely it is frustration would make them feel aggressive, scores on the STAR scale can be correlated with the frustration response to explore the relationship between frustration and aggression in an alternative way.

Weschler Abbreviated Scale of Intelligence (WASI-II)

The WASI-II provides a brief measure of intelligence and was included in the current study to control for a possible confounding effect of IQ on age. The current study opted for the two-subset form which measures both verbal (vocabulary test) and non-verbal (matrix reasoning) cognitive abilities, providing a research estimate of full-scale IQ. Scores are converted to normed values by age.

5.2.3 Procedure

Participants were invited to the Combined Universities Brain Imaging Centre (CUBIC) centre located at Royal Holloway University of London to take part in a single testing session lasting approximately 2.5-3 hours in total. Participants were given study-specific and MRI information sheets and provided informed assent plus parental consent if under 18, and informed consent if aged 18+. Participants were given opportunities to ask questions and received full instructions and the chance to practice the fMRI tasks. Task order inside the scanner was fixed such that participants would first complete the two runs of the frustration task followed by the Gender Decision task. This was to ensure that the main task of interest (frustration task) was completed while participants were still engaged in the session, and to avoid any 'spill-over' effects from the presentation of emotional expressions in the latter task. Outside the scanner, participants completed the questionnaire battery, WASI and Go-No/Go task.

5.2.4 fMRI data acquisition

MRI scanning was conducted using a Siemens Tim Trio 3T scanner with 32 channel head-coil. Anatomical data were acquired using a 5.5-minute 3-dimensional T1-weighted structural MPRAGE anatomical scan. Functional data were acquired using multi-slice T2-weighted echo-planar imaging with blood oxygenation level-dependent contrast. The echo-planar imaging sequence was designed to optimise signal detection and reduce drop-out in the amygdala and orbitofrontal cortex (Weiskopf, Hutton, Josephs & Deichmann, 2006) and used the following acquisition parameters: 35 3-mm slices acquired using a sequential descending sequence; echo time=30 milliseconds; repetition time=2500 milliseconds; slice tilt =~20°; flip angle=78°; field of view=192x192-mm; matrix size=64x64. Functional data for the frustration task were acquired across two runs (run one: *M*=328 volumes [*SD*=10]; run two: *M*=374 volumes [*SD*=17]). Note, run two was longer and more variable than run one as end-task self-report ratings were taken during this run and these were also self-paced. Stimuli were projected to the back of the scanner, and participants viewed these using a backwards facing mirror attached to the head coil. Fieldmaps were also acquired to be used in the unwarping step during pre-processing.

5.2.5 Data analyses

5.2.5.1 Behavioural data analyses

Behavioural data were analysed as detailed in Chapter 4 (4.2.4). The task manipulation to increase frustration was checked using one-way ANOVA of mean in-task frustration across each blocked condition (four stages). To investigate individual differences in frustration and how they might be associated with related constructs (e.g. frustration tolerance, internalising behaviours and aggression), an overall mean of in-task frustration self-report was generated by collapsing across the four blocked conditions and was correlated with each of the questionnaire subscales. As with previous studies we explored the relationship between self-reported frustration, motivation and surprise. Finally, to ensure that results relating to age did not differ with IQ or with pubertal status, a correlation was run between age and WASI score, and this was non-significant ($r(37)= -.20$, $p=.221$), and pubertal status was included as a control variable in any behavioural analyses pertaining to age.

5.2.5.2 Imaging data analyses

Imaging data were analysed using Automatic Analysis (AA; Cusack et al. 2015) and using Statistical Parametric Mapping software (SPM12; http://www.fil.ion.ucl.ac.uk/spm). Data were pre-processed in line with standard sequences. To allow for scanner equilibrium, the first four volumes of data (10 seconds) were discarded. Data were realigned and unwarped using acquired fieldmaps, normalised using 2x2x2 millimetre voxel size, and finally smoothed using an 8-mm full-width half maximum Gaussian filter. Data was then passed through a high-pass filter at 128-sec to account for low frequency drift. The time series was modelled using an event-related design which included 22 regressors (see Figure 20). Of these, five regressors of interest were modelled as events with duration of 2 seconds: BLOCKED feedback for each of the four blocked conditions (when participants learned they were blocked at stages 1, 2, 3 & 4) and WIN feedback for win conditions. Note, the BLOCKED feedback regressors only included trials where the blocked feedback was shown because of the hidden feedback structure rather than task errors, i.e. a 'true' block pre-determined in line with the task manipulation. Trials where the BLOCKED feedback was shown due to participants incorrectly responding to the task, i.e. 'false' blocks, were excluded as 'false' blocks may engage different processes than 'true' blocks. Additionally, the six realignment parameters were included as regressors of no interest for every participant, plus regressors corresponding to any volumes that exceeded a threshold of movement (1.5-mm translation, 1 degree of rotation), to account for individual differences in motion. In total, 90% of participants had volumes regressed out due to excessive motion (whole sample: *M*=7.35 volumes, *SD*=5.78 volumes), but no participants were excluded as the total number of volumes regressed out never exceeded 5% of the total number of volumes.

Event	Duration (seconds)	Interest
Cue	2	Baseline
Fixation cross (combined across fixed and jittered)	fixed: 0.75; Jittered: 1.5-4	No
Ghost presentation of correct responses	response time - presentation time	No
Ghost presentation of incorrect responses	response time - presentation time	No
Ghost response	0	No
Presentation of the frustration rating	response time - presentation time	No
Presentation of the motivation rating	response time - presentation time	No
Presentation of the surprise rating	response time - presentation time	No
Presentation of the pleasant rating	response time - presentation time	No
Rating response (collapsed across all ratings)	0	No
Presentation of feedback - condition 1	2	Yes
Presentation of feedback - condition 2	2	Yes
Presentation of feedback - condition 3	2	Yes
Presentation of feedback - condition 4	2	Yes
Presentation of feedback - condition 5 (WIN)	2	Yes
Presentation of confirmation - WIN condition and responded correctly (respond WIN)*	response time - presentation time	No
Presentation of confirmation - WIN condition and responded incorrectly (respond BLOCKED)*	response time - presentation time	No
Presentation of confirmation - BLOCKED condition (true block) and responded correctly (respond BLOCKED)*	response time - presentation time	No
Presentation of confirmation - BLOCKED condition (true block) and responded incorrectly (respond WIN)*	response time - presentation time	No
Presentation of confirmation - BLOCKED condition (task incorrect) and responded correctly (respond BLOCKED)*	response time - presentation time	No
Presentation of confirmation - BLOCKED condition (task incorrect) and responded incorrectly (respond WIN)*	response time - presentation time	No
Confirmation response	0	No

Figure 20. Table depicting the regressors used to model the time series and their respective durations.

*Modelled as presentation time to response time for correct and incorrect as opposed to modelling presentation and correct/incorrect response independently because the neural processes behind a correct/incorrect response would occur between the presentation to the response, not from the response itself.

At the first level two contrasts of interest were created (in addition to contrasts to check the task manipulation at the neural level which are not reported in the main text, see Appendix 5). The first contrast was a theoretically driven contrast of interest to map the parametric modulation of the frustration response. The parametric modulation contrast looks for brain regions that show parametrically modulated neural activity with increasing or decreasing task stage, and was modelled using the event-related point at which BLOCKED feedback was delivered at each of the four blocked stages (duration=2 seconds; contrast weightings [-1.5 -0.5 0.5 1.5] representing a parametric modulation of 1<2<3<4).

The second contrast was an exploratory data-driven contrast of interest representing a high>low frustration response. This contrast was driven by the self-report ratings of frustration, therefore is modelled to explore which brain regions show a pattern of neural activity that matches the pattern seen in the behavioural data (1=2=3<4). As with the parametric contrast, this contrast uses the time at which BLOCKED feedback is delivered at each of the four stages as the event-related regressor of interest (duration = 2 seconds).

The resulting contrast images generated at the first level were entered into second level (group level) models. To test for the main effects of a) parametric modulation of frustration and b) high>low frustration response a 'simple' ANOVA model was generated which included just the contrast of interest. These models provide data on which brain regions across the sample vary in line with the contrast. Additionally, a number of exploratory regression models were generated to include both covariates of interest (linear age which will be referred to simply as age, quadratic age and reactive aggression) and covariates of no interest (i.e. confounds). These were: a) age; b) age controlling for reactive aggression; c) reactive aggression, d) reactive aggression controlling for age, and e) quadratic term of age. Including the covariates of interest as regressors into the second level models provides data on which brain regions vary in response to the contrast *and* vary significantly with regressor across the participants, i.e. high variation across the sample. Note, the quadratic age analysis was conducted by including the linear term of age in the model as a regressor of no interest, as is done in the behavioural analyses to attain the quadratic effect.

Finally, two sets of subsidiary analyses were run. The first was to ensure brain regions showing activation were a result of frustration and not driven by motivation or surprise, two regression models were runs to explore the main effect of the parametric modulation contrast while controlling for a) overall mean motivation and b) overall mean surprise from participants self-report ratings, modelled as covariates of no interest. The second explored the neural activation related to blocked compared to win (blocked>win; blocked defined by all four blocked conditions) and the inverse (win>blocked). This was done to characterise the neural underpinning of frustration relative to reward, i.e. a comparison of negative and positive.

All whole brain results are reported at a cluster-corrected level of $p<.05$ family-wise error corrected. For completeness and to avoid type II errors for exploratory analyses, we also report results at an uncorrected (*p*<.001) threshold with an extent threshold of 10 voxels (*k*>10).

The above second level models were also run using region of interest (ROI) analyses, using uncorrected whole brain results (*p*<.001) which were small volume corrected using family-wise error correction (SVC-FWE) at *p<.05* across the number of voxels within the ROI mask (see below for ROI definition). Additionally, to test whether individual differences in BOLD signal change in response to the contrast were related to individual differences in either age or reactive aggression, mean activation in significant clusters for ROIs showing significant activation in the 'simple' models were extracted using FSL and then correlated with both age and reactive aggression scores.

ROIs were generated for regions related to frustration, aggression or more broadly related to reactivity or regulation. These were defined anatomically, primarily using bilateral Automatic Anatomical Labelling (AAL) masks and were generated in MarsBar. Where anatomical AAL masks were unavailable, a priori regions of interest were defined using an 8mm sphere around co-ordinates reported in Yu et al. (2014) for the effect of proximity to reward. ROI results are reported at the peak-level FWE-correction (*p*<.05) with small volume corrections applied and are labelled as to whether they were derived from the AAL map or from functionally defined spheres (see Table 9).

Region of Interest	AAL	Sphere	L/R
Amygdala	✓		Bilateral
Anterior cingulate cortex	✓		Bilateral
Mid cingulate cortex	✓		Bilateral
Posterior cingulate cortex	✓		Bilateral
Anterior insula	✓		Bilateral
Periaquaductal gray		✓ (-10 -28 -14)	L
Dorsolateral PFC	✓		Bilateral

Table 9. Region of interest (ROI) masks used in the analyses and whether they were defined as bilateral masks using Anatomical Labelling (AAL) or 8mm spheres around co-ordinates reported to show activation in response to blocking (proximity effect) in Yu et al. (2014). Note, the dorsolateral PFC was defined using the AAL label of 'middle frontal gyrus' since the dlPFC is situated within the middle frontal gyrus.

5.3 Results

5.3.1 Behavioural data

5.3.1.1 Task manipulation check

Repeated measures ANOVA of in-task self-report data found a significant main effect of blocked condition ($F(3,144)=10.11$, $p<.001$, $\eta_p^2=.21$). Post-hoc analyses found frustration ratings were significantly higher after being blocked at stage 4 ($M=3.41$, $SD=1.09$) than when blocked at stage 3 ($M=2.98$, $SD=1.01$; $p<.001$), stage 2 ($M=2.82$, $SD=1.00$; $p<.001$) and stage 1 ($M=2.95$, $SD=1.12$, $p=.006$). Results show a significant linear and quadratic trend (both *p's*=.001; see Figure 21).

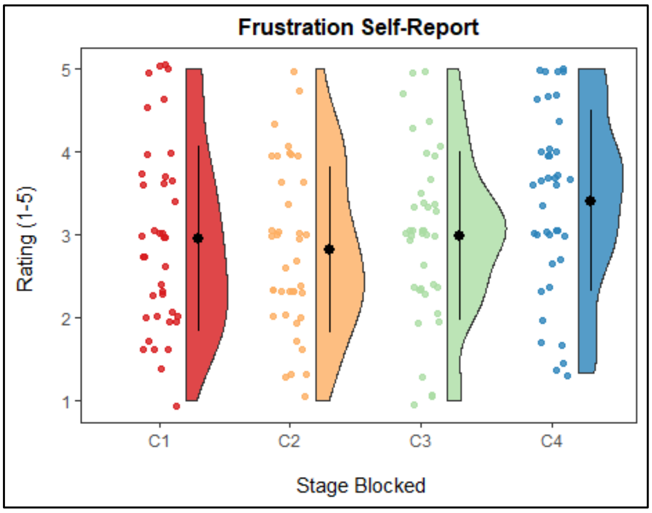


Figure 21. Plot of the mean in-task self-report ratings of frustration (1-4) on y-axis by blocked condition, denoted as C (condition) 1-4 (i.e. blocked ay stages 1-4 respectively) on the x-axis.

5.3.1.2 Frustration and age

The relationship between overall mean frustration (*M*=3.04, *SD*=.96) and age was assessed using linear regression to model both linear effect of age (Age) and the quadratic effect of age (Age^2). This was not a significant model ($F(2,36)=.28$, $p=.759$, $R^2=.012$; see Figure 22). The beta values for each age term were also non-significant (Age: β =-.12, $p=.476$; Age^2: β =.04, $p=.803$). Controlling for pubertal status in this regression did not alter the results as the model was still non-significant ($F(3,35)=0.91$, $p=.445$).

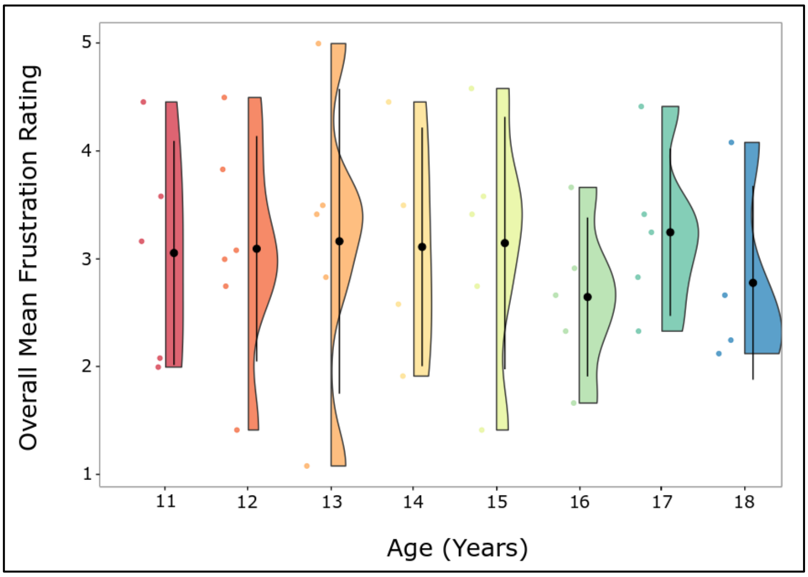


Figure 22. Overall mean frustration ratings plotted per age group (years) for ease of visualising the data. Data show no relationship between mean frustration and age.

5.3.1.3 Frustration and reactive aggression

There was no significant correlation between overall mean frustration and reactive aggression (*M*=7.31, *SD*=2.97; *r*(37)=.18, *p*=.262).

5.3.1.4 Frustration and questionnaire measures

Overall mean frustration was significantly positively correlated with two of the questionnaire measures, the Frustration Discomfort Scale Fairness subscale (FDS; *r*(37)=.40, *p*=.013) and the Situational Triggers of Aggressive Responses Scale frustration subscale (STARS; *r*(37)=.36, *p*=.025). There were no other significant correlations between overall mean frustration and questionnaire measures (remaining FDS subscales, STARS provocation subscale or the Revised Child Anxiety and Depression Scale subscales).

5.3.1.5 Self-report motivation and surprise

Repeated measures ANOVA of in-task self-report motivation found a significant main effect of blocked condition ($F(3,144)=15.23$, $p<.001$, $\eta_p^2=.29$; Greenhouse-Geisser corrected due to violated Mauchly's sphericity [$X^2(5)=35.82$, $p<.001$]). Post-hoc analyses found motivation ratings were significantly higher before being blocked at stage 4 (*M*=3.09, *SD*=1.07) than when blocked at stage 3 (*M*=2.62, *SD*=0.88; *p*=.011), stage 2 (*M*=2.32, *SD*=0.86; *p*<.001) and stage 1 (*M*=2.24, *SD*=0.78, *p*<.001). Results show a significant linear (*p*<.001) and quadratic trend (*p*=.033). Repeated measures ANOVA of in-task self-report surprise, however, found no significant main effect of blocked condition ($F(3,144)=2.02$, $p=.115$, $\eta_p^2=.05$).

Correlational analyses between overall mean frustration, motivation (*M*=2.57, *SD*=.73) and surprise (*M*=2.60, *SD*=.69) revealed significant positive correlations between frustration and motivation (*r*(37)=.43, *p*=.006), frustration and surprise (*r*(37)=.55, *p*<.001) and motivation and surprise (*r*(37)=.49, *p*=.002). Correlations between blocking at individual stages of the task (see Table 10 for correlation matrix) show that both motivation and surprise ratings had significant moderate positive correlations with frustration ratings at stages 2, 3 and 4, but only surprise had a significant moderate positive correlation with frustration rating at stage 1. Surprise and motivation ratings also have significant moderate positive correlations with each other at stages 2, 3 and 4 but not stage 1.

Frustration, Motivation and Surprise Self-report Ratings by Condition Blocked

		Frustration				Motivation				Surprise			
		C1	C2	C3	C4	C1	C2	C3	C4	C1	C2	C3	C4
Frustration	C1	–											
	C2	0.76***	–										
	C3	0.77***	0.79***	–									
	C4	0.75***	0.78***	0.83***	–								
Motivation	C1	0.12	0.40*	0.27	0.29	–							
	C2	0.19	0.42**	0.32	0.37*	0.83***	–						
	C3	0.18	0.27	0.32*	0.39*	0.46**	0.68***	–					
	C4	0.42**	0.35*	0.35*	0.44**	0.33*	0.41**	0.61***	–				
Surprise	C1	0.43**	0.29	0.31	0.21	0.02	0.09	0.25	0.40**	–			
	C2	0.35*	0.56***	0.41**	0.42**	0.34*	0.48**	0.51**	0.19	0.49**	–		
	C3	0.44**	0.35*	0.45**	0.32*	0.24	0.41**	0.54***	0.40*	0.62***	0.49**	–	
	C4	0.48**	0.36*	0.58***	0.60***	0.12	0.26	0.46**	0.49**	0.56***	0.41*	0.66***	–

df=37 **p<.05* ***p<.01* ****p<.001*

Table 10. Correlation matrix of the self-report ratings of frustration, motivation and surprise at each of the four blocked conditions (blocked at stages 1-4 respectively).

5.3.2 fMRI data

5.3.2.1 Parametric modulation of frustration

5.3.2.1.1 Main effects

Region of interest analyses revealed significant activation in response to the main effect of parametric modulation (increase: 1<2<3<4) in right ACC (*k*=100*,* t=4.7, *p*<.001*,* SVC-FWE) and marginally significant in the right MCC (*k*=6*,* t=3.9, *p*=.058, SVC-FWE). No significant activation was seen in any other ROIs (see Table 11). Given the proximity of the peak voxel for each cluster these two ROI analyses were deemed to reflect one contiguous cluster on the ACC/MCC border. As the MCC cluster was only marginally significant, correlations with individual differences were only run with the ACC cluster. Extracting the mean activation across the ACC (peak: 4 16 28, *k*=100) clusters using FSL, a significant positive correlation were found with reactive aggression scores (*r*(37)=.46, *p*=.003, see Figure 23).

At the whole brain level, there was also a significant main effect of the parametric modulation, with significantly increased BOLD signal with increasing blocked condition (1<2<3<4) primarily in the right cuneus and bilateral lingual gyrus (*p*<.05, whole brain FWE-corrected at the cluster level; see Table 12). For completeness, the reverse contrast (4<3<2<1) revealed no brain regions surviving cluster-level FWE-corrections, but activations were seen in the right precuneus, left cuneus and left posterior cingulate cortex at a *p*<.001 uncorrected threshold (see Table 12).

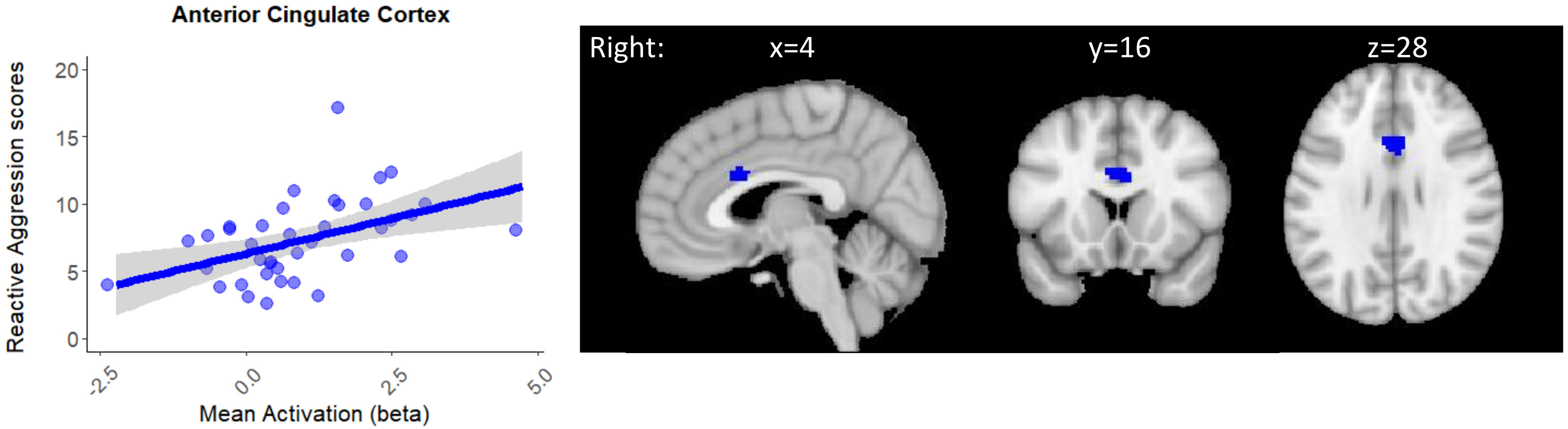


Figure 23. Left: correlational plots between mean activation of significant ACC clusters in ROI analyses and reactive aggression scores. Right: brain plot of where the significant cluster of activation in the ROI analyses was located.

5.3.2.1.2 Individual differences

5.3.2.1.2.1 Age

Looking at the ROI analyses, there were no significant positive correlations between age and activation in any ROI, but there were significant negative correlations between age and activation in the amygdala (*k*=9, t=4, *p*<.01, SVC-FWE) and periaqueductal gray (*k*=87, t=5, *p*=.001, SVC-FWE) ROIs. That is, the parametric modulation becomes less steep in the amygdala and periaqueductal gray activation with age (see Figure 24). Visual inspection of the figure suggests these results may be driven by an outlier in both amygdala and PAG activation. Excluding this participant did not change the significance (SVC-FWE corrected) of the results and so were included. When controlling for reactive aggression, there were no significant negative correlations with age in any ROIs. Age and reactive aggression scores were also not correlated with each other (*r*(27)=.03, *p*=.851). Finally, ROI analyses on the quadratic age covariate of interest revealed no significant clusters of activation.

At the whole brain level, including age as a covariate of interest in the second level regression revealed no regions showing significant positive correlations with age, at either FWE-corrected or uncorrected levels. Additionally, no regions showed significant negative correlations with age that survived FWE-corrections. Controlling for reactive aggression scores by including it as a covariate of no interest in the second level regression model revealed significant activation with decreasing stage in the right insula at the uncorrected threshold, but otherwise did not alter the results.

Exploring the quadratic term of age as a covariate of interest in the second level regression revealed no regions showing significant positive or negative correlations with the parametric modulation at the FWE-corrected level. However, there were significant positive correlations at an uncorrected level within the right anterior orbital gyrus and left inferior frontal gyrus, but no significant negative correlations at an uncorrected level.

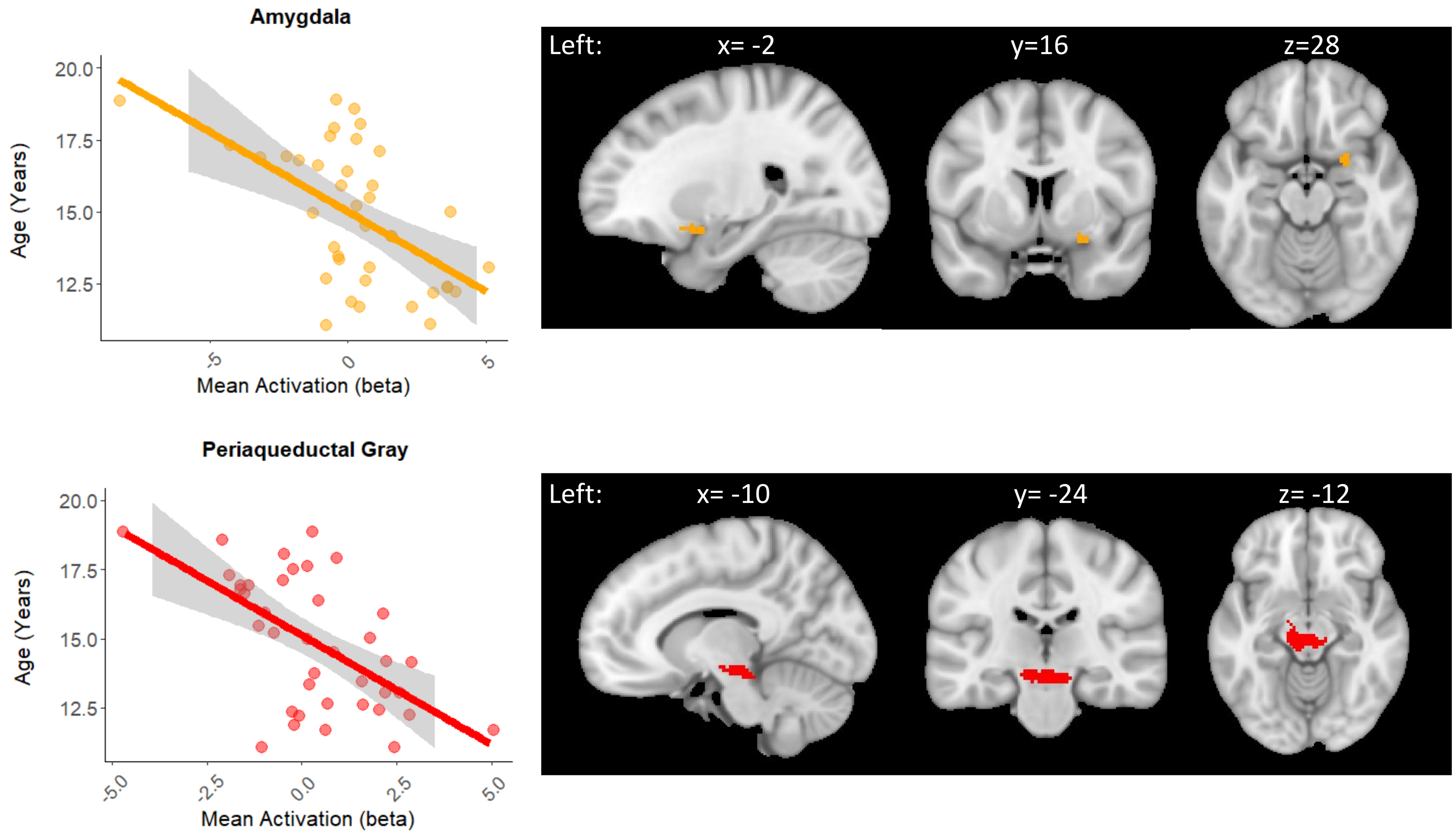


Figure 24. Left: correlational plots between mean activation of significant amygdala and PAG clusters in ROI analyses and age. Right: brain plot of where the significant cluster of activation in the ROI analyses was located.

5.3.2.1.2.2 Reactive aggression

ROI analyses of the second level whole brain data revealed significant positive correlations between BOLD signal in the PCC (t=4.2, *p<.01,* SVC-FWE) with reactive aggression scores, but found no significant negative correlations between reactive aggression in any ROIs (see Table 11). Controlling for age also revealed no significant activations in any ROIs for either increasing or decreasing reactive aggression scores.

Whole brain analyses of the parametric modulation contrast with reactive aggression scores as a covariate of interest revealed significant positive correlations between activation in the right superior occipital gyrus (FWE-corrected; see Table 12). There were no clusters of significant activation showing a negative relationship between reactive aggression and BOLD signal at either FWE-corrected or uncorrected thresholds. Controlling for age as a covariate of no interest revealed no significant positive correlations with reactive aggression scores but did reveal significant negative correlation in the right insula with reactive aggression scores, which was not present when not controlling for age (a suppressor effect; Cohen & Cohen, 1975; see Table 12).

Region of interest (ROI) Results								
Brain Region	**AAL/ Sphere**	**L/R**	**Peak Voxel**			**k**	**z**	**Peak *p-value***
Parametric Modulation contrast								
Increasing proximity to reward (1<2<3<4)								
Anterior cingulate cortex	AAL	R	4	16	28	100	4.13	*0.008*
		L	-2	16	28		4.05	*0.011*
Mid cingulate cortex	AAL	R	4	14	30	6	3.56	*0.058*
Decreasing proximity to reward (4<3<2<1)								
Posterior cingulate cortex	AAL	L	-4	-38	21	1	3.34	*0.042*
Parametric Modulation with Age covariate of interest								
Increasing proximity to reward: negative relationship with age								
Amygdala	AAL	R	24	6	-16	9	3.59	*0.010*
		L	-24	-8	-16	1	3.09	*0.045*
Periaqueductal gray	Sphere	L	-10	-24	-12	87	4.12	*0.001*
Parametric Modulation with Reactive Aggression covariate of interest								
Increasing proximity to reward: positive relationship with reactive aggression								
Anterior cingulate cortex	AAL	R	6	10	28	9	3.47	*0.073*
Mid cingulate cortex	AAL	R	6	0	34	24	3.48	*0.075*
		R	6	8	30		3.48	*0.076*
Posterior cingulate cortex	AAL	L	-8	-40	26	20	3.81	*0.010*
		R	12	-42	26	29	3.75	*0.012*
		R	8	-40	26		3.55	*0.022*
		R	12	-46	24		3.42	*0.034*

Table 11. Region of interest (ROI) results for the parametric contrast (1<2<3<4), including main effects results and covariates of interest: age and reactive aggression. Results show brain regions surviving peak-level FWE-correction (*p<.05*) with small volume corrections applied. AAL/Sphere=ROI mask defined anatomically using the AAL atlas or as an 8-mm sphere centred around co-ordinates from Yu et al. (2014); L/R=laterality (left/right); peak voxel co-ordinates are reported in Montreal Neurological Institute (MNI) standard space; k=cluster size; z=z-value for peak voxel.

Whole Brain Results

Brain Region	L/R	Peak Voxel			k	z	Cluster *p-value*	Peak *p-value*
Parametric Modulation contrast								
Increasing proximity to reward (1<2<3<4)								
Cuneus	R	16	-90	8	72	5.65	*<0.05*	*<0.001*
Lingual gyrus	L	-22	-74	-8	12	4.89	*<0.05*	*0.016*
Lingual gyrus	R	12	-64	-4	2	4.69	*<0.05*	*0.035*
Parametric Modulation with Reactive Aggression covariate of interest								
Increasing proximity to reward: positive relationship with reactive aggression								
Superior occipital gyrus	R	24	-76	24	2	4.63	*<0.05*	*0.047*

Table 12. Whole brain results for the parametric modulation (1<2<3<4) contrasts. Results show brain regions surviving cluster-level FWE-correction and corresponding FWE-corrected peak p-value if $p<0.05$. L/R=laterality (left/right); peak voxel co-ordinates are reported in Montreal Neurological Institute (MNI) standard space; k=cluster size; z=z-value for peak voxel.

5.3.2.2 High versus low frustration

5.3.2.2.1 Main effects

ROI analyses of these whole brain results revealed no significant BOLD signal activations or deactivations. The anterior insula showed marginally significant (*p*>.085) BOLD signal increase, but these are not reported further.

For neural responses following the high>low (4>3=2=1) pattern which mirrored the behavioural data at the whole brain level, significantly increased BOLD signal was found in the right calcarine fissure, left and right lingual gyrus and right superior occipital gyrus at FWE-corrected (*p*<.05) threshold. Additionally, increased BOLD signal was seen in the left middle occipital gyrus at the uncorrected threshold (*p*<.001; *k*>10). Whole brain analyses revealed no significant BOLD signal mean deactivation (i.e. the reverse contrast 1=2=3>4) at either the corrected or uncorrected threshold.

5.3.2.2.2 Individual differences

5.3.2.2.2.1 Age

ROI analyses revealed significant negative correlation between high versus low frustration activity in the amygdala (*k*=11, t=4.00, *p*=.019, SVC-FWE) and PAG (*k*=14, t=4, *p*=.01, SVC-FWE) with age (Table 13), suggesting less steep increase in amygdala and PAG activation with age. Similar to the whole brain results there were no significant BOLD signal changes when controlling for reactive aggression. Additionally, ROI analyses revealed no significant correlations with the quadratic age covariate of interest.

At the whole brain level, there were no brain regions revealing significant positive correlations with age, however there were significant negative correlations in regions related to reactivity including the left thalamus, right caudate nucleus, right calcarine fissure and fornix (uncorrected threshold only, see Table 14). Inclusion of reactive aggression as a covariate of no interest revealed no regions with significant positive or negative correlations of the BOLD signal with age.

Exploring the quadratic term of age as a covariate of interest in the second level regression revealed no regions showing significant positive or negative correlations with the parametric modulation at the FWE-corrected level. However, there were significant positive correlations at an uncorrected level within the right superior temporal gyrus and right cerebellum, but no significant negative correlations at an uncorrected level.

5.3.2.2.2.2 Reactive aggression

ROI analyses revealed no significant activations within any ROI. Whole brain analyses, however, revealed positive correlation between reactive aggression scores and the left middle temporal lobe activation (uncorrected threshold). No other regions showed significant correlations with reactive aggression or with reactive aggression when controlling for age.

ROI Results								
Brain Region	**AAL/ Sphere**	**L/R**	**Peak Voxel**			**k**	**z**	**Peak *p-value***
High>Low with Age covariate of interest								
High>Low: negative relationship with age								
Amygdala	AAL	R	26	2	-16	11	3.37	*0.019*
Periaqueductal gray	Sphere	L	-8	-26	-14	14	3.42	*0.010*

Table 13. Region of interest (ROI) results for the high>low contrast (4>3=2=1), including main effects results and covariates of interest: age and reactive aggression. Results show brain regions surviving peak-level FWE-correction (*p<.05*) with small volume corrections applied. AAL/Sphere=ROI mask defined anatomically using the AAL atlas or as an 8-mm sphere centred around co-ordinates from Yu et al. (2014); L/R=laterality (left/right); peak voxel co-ordinates are reported in Montreal Neurological Institute (MNI) standard space; k=cluster size; z=z-value for peak voxel.

Whole Brain Results								
Brain Region	**L/R**	**Peak Voxel**			**k**	**z**	**Cluster *p-value***	**Peak *p-value***
High>Low contrast								
High>Low (4>3=2=1)								
Calcarine fissure	R	14	-86	8	70	5.39	*<0.05*	*0.001*
Lingual gyrus	L	-12	-78	-4	90	5.21	*<0.05*	*0.003*
	L	-24	-76	-6		4.9		*0.013*
Superior occipital gyrus	R	18	-94	20	2	4.74	*<0.05*	*0.025*
Lingual	R	14	-70	-2	4	4.67	*<0.05*	*0.034*
Superior occipital gyrus	R	18	-94	14	1	4.6	*<0.05*	*0.044*

Table 14. Whole brain results for the High>Low (4>3=2=1) contrasts. Results show brain regions surviving cluster-level FWE-correction and corresponding FWE-corrected peak p-value if *p*<0.05. L/R=laterality (left/right); peak voxel co-ordinates are reported in Montreal Neurological Institute (MNI) standard space; k=cluster size; z=z-value for peak voxel.

5.3.2.3 Blocked versus win

As a subsidiary analysis, we explored the neural underpinnings of the frustration response when compared to winning as a direct comparison between negative and positive affect. ROI analyses revealed no regions of interest showing any significant activation for the Blocked>Win contrast, but the Win>Blocked contrast was associated with significantly increased activation in the anterior, mid and posterior cingulate cortex as well as the dlPFC (see Table 15).

Whole brain analyses revealed the Blocked>Win showed no clusters of activation that survived FWE-corrected threshold or surpassed the uncorrected threshold. In contrast, the Win>Blocked contrast revealed significantly increased activations in the ventral striatum (right caudate and left caudate/putamen) at the FWE-corrected threshold. At the uncorrected threshold, there were also clusters of increased activation within the right insula (see Table 16).

Region of interest (ROI) Results								
Brain Region	**AAL/ Sphere**	**L/R**	**Peak Voxel**			**k**	**z**	**Peak *p-value***
Win>Blocked contrast								
Anterior cingulate cortex	AAL	L	-10	36	-8	1045	5.05	*<.001*
		R	8	26	-6		5.01	*<.001*
		L	-8	38	-4		4.89	*<.001*
		L	-4	38	2		4.87	*<.001*
		L	-2	52	-2		4.74	*0.001*
		R	14	42	18		4.74	*0.001*
		R	8	38	-6		4.63	*0.001*

		L	-4	48	-4		4.63	*0.001*
		R	2	54	10		4.57	*0.001*
		R	14	50	10		4.39	*0.003*
		R	10	32	-10		4.17	*0.007*
		R	16	44	10		3.81	*0.023*
		R	14	44	4		3.68	*0.035*
Mid cingulate cortex	AAL	R	8	-50	34	373	4.57	*0.001*
		R	8	-44	36		4.42	*0.003*
		L	-2	-40	34		4.15	*0.008*
		L	-2	-34	40		3.58	*0.052*
Posterior cingulate cortex	AAL	R	10	-50	30	239	4.46	*0.001*
		R	12	-48	22		4.23	*0.002*
		L	-12	-50	20		4.09	*0.003*
		L	-6	-42	32		3.94	*0.006*
		R	8	-42	30		3.86	*0.007*
		R	10	-42	8	1	3.4	*0.033*
		L	-8	-44	8	1	3.23	*0.054*
dlPFC	AAL	L	-22	30	42	28	3.84	*0.039*
		R	24	34	42	49	3.81	*0.043*

Table 15. Region of interest (ROI) results for the Blocked>Win and Win>Blocked contrasts. Results show brain regions surviving peak-level FWE-correction (*p<.05*) with small volume corrections applied. AAL/Sphere=ROI mask defined anatomically using the AAL atlas or as an 8-mm sphere centred around co-ordinates from Yu et al. (2014); L/R=laterality (left/right); peak voxel co-ordinates are reported in Montreal Neurological Institute (MNI) standard space; k=cluster size; z=z-value for peak voxel. dlPFC=dorsolateral prefrontal cortex.

Whole Brain Results

Brain Region	L/R	Peak Voxel			k	z	Cluster *p-value*	Peak *p-value*
Win>Blocked contrast								
Medial frontal gyrus, orbital	R	4	48	-10	603	5.5	*<0.05*	*0.001*
	L	-14	36	-10		5.41		*0.001*
	R	8	58	0		5.38		*0.002*
Caudate	R	10	12	-8	28	5.16	*<0.05*	*0.004*
Vermis 4/5/Lingual	R	6	-52	4	31	5.1	*<0.05*	*0.006*
Anterior cingulate cortex	R	8	26	-6	7	5.01	*<0.05*	*0.008*
Caudate/Putamen	L	-12	10	-8	9	4.95	*<0.05*	*0.011*
Anterior cingulate cortex	R	14	42	18	5	4.74	*<0.05*	*0.026*
Precuneus	R	12	-50	22	2	4.72	*<0.05*	*0.028*

Table 16. Whole brain results for the Blocked>Win and Win>Blocked contrasts. Results show brain regions surviving cluster-level FWE-correction and corresponding FWE-corrected peak p-value if $p<0.05$. L/R=laterality (left/right); peak voxel co-ordinates are reported in Montreal Neurological Institute (MNI) standard space; k=cluster size; z=z-value for peak voxel.

5.4 Discussion

The current study aimed to characterise the neural underpinnings of the frustration response in a sample of adolescents using the adapted frustration paradigm developed in Chapter 2 with fMRI. Further, the current study sought to extend the understanding of the frustration response by relating it to age and reactive aggression, two factors of interest to the broader thesis goal and that are related to frustration.

5.4.1 Behavioural correlates of the frustration response

Behavioural results largely replicated findings reported in previous Chapters. The level of frustration induced significantly increased as a result of the task manipulation, showing the same pattern of increasing frustration as in previous studies in this thesis using adolescent samples (1=2=3<4; Chapters 2 and 4).

As in previous Chapters, ratings of frustration were significantly positively correlated with both motivation and surprise. This suggests that participants show individual differences in the level of generalised emotional reactivity, i.e. individuals reporting high levels of frustration were also likely to report higher levels of other affective states. It is likely that frustration and motivation are 'opposite sides of the same coin' and are inherently linked, as previously demonstrated (e.g. Buss, 1963). Surprise on the other hand, may not have as much of an impact, as while it was correlated with frustration ratings it did not vary with stage blocked (no significant differences), unlike motivation.

Self-report frustration was also positively related to the fairness and frustration subscales of two frustration tolerance measures (Frustration Discomfort Scale and Situational Triggers of Aggressive Responses Scale respectively), suggesting participants were frustrated to a degree that showed construct validity with existing frustration measures, including one (STARS) that links frustration to reactive aggressive outcomes.

5.4.2 Neural bases of the frustration response

At the neural level, parametrically increasing levels of frustration (parametric modulation contrast) was primarily associated with activation in the anterior cingulate cortex (whole brain uncorrected and ROI analyses) extending to mid cingulate cortex (ROI analyses). Modelling the neural response of increasing frustration to mirror the behavioural pattern (high>low contrast) however did not find activation in the same regions as the parametric modulation. Rather, the high>low contrast revealed activation in the anterior insula, though this should be taken tentatively as this was found at uncorrected threshold but did not come out in ROI analyses. Additionally, when comparing frustration to reward (blocked>win contrast) there were no significant activations in relation to frustration as had been found in previous research using similar contrasts (e.g. Abler et al. 2005). Rather, reward was related to increased activations in all of the regions predicted to be involved in the frustration response but also associated with reward responses: the anterior, mid and posterior cingulate cortex, the insula and dlPFC, in addition to related regions including the caudate and putamen which are typical reward related regions.

The activations reported during frustration are consistent with some of the study predictions and activations reported in prior studies (ACC: Yu et al. 2014; Abler et al. 2005; Siegrist et al. 2005; MCC: Lewis et al. 2006; anterior insula: Yu et al. 2014; Bierzynska et al. 2016; Abler et al. 2005), though they do not cover the same extent of those reported in the literature, i.e. there were no significant activations found in the amygdala (Yu et al. 2014) or the dlPFC (Bierzynska et al. 2016; Yu et al. 2014) in response to frustration only.

With regard to the ACC result, Yu et al. concluded the increased ACC activation was reflective of executing goal-directed behaviours, in that the ACC may underpin the necessary 'increased vigour' to achieve goals that have been thwarted, and to control any subsequent frustration-induced aggression due to the ACC's broader involvement with the aggression network. Relatedly, Pawliczek et al. (2013) found decreased ACC activation in (healthy) adults with high compared to low trait aggression during a frustrating event (unsolvable anagrams). The authors interpreted this to be an impaired ability to control and regulate frustration from escalating into aggression due to the decreased recruitment of the ACC, hence the higher propensity for aggressive outbursts in individuals with high trait aggression.

In the current study, the increased activation in the ACC reported in the parametric modulation contrast may therefore reflect greater engagement with goal-directed behaviours in order to overcome obstacles to pursue the goal in mind, and to control and regulate any subsequent frustration (as demonstrated by the generally increasing frustration ratings) or aggression elicited by the increasing frustration-induction. Indeed, by regulating the frustration response and controlling any aggressive urges would also be beneficial in pursuing a goal as it allows more resources to be allocated to the task at hand. This is particularly relevant given the ACC results emerged only in the parametric modulation, i.e. increasing frustration-induction, but not the high versus low contrast.

This interpretation would also be consistent with broader roles associated with the ACC, such as regulation of emotion and emotional conflict (Etkin, Egner & Kalisch, 2011; Etkin, Egner, Peraza, Kandel & Hirsch, 2006), though these studies relate to emotional Stroop tasks and not frustration specifically. Frustration was previously defined as a negatively valenced energising or approach motivation to overcome obstacles to achieve a goal (Yu et al. 2014). This interpretation of the ACC as playing a role in emotion regulation in pursuit of a goal would therefore be consistent with this definition of frustration.

In relation to the win>blocked findings, previous research has also found increased ACC activation during win or reward trials (Perlman et al. 2015). Perlman et al. (2015) concluded this may represent alterations in the reward expectancy and reward updating. This would be consistent with the task design that participants are blocked on two thirds of the trials collapsed across blocked conditions, making winning perhaps unexpected. Another possibility is that the ACC has been linked with processing self-relevant stimuli (Yu et al. 2011; Vogt, 2005).

5.4.3 Frustration response and age

Consistent with the findings from previous Chapters, frustration ratings did not vary with age, even when controlling for pubertal status. At the neural level however, age was negatively correlated with the amygdala and periaqueductal gray (ROI analyses) in both the parametric modulation and the high>low contrasts. The quadratic term of age however revealed no significant correlations in either ROI or FWE-corrected whole brain analyses. These results suggest that adolescents are processing the frustrating events differently as a linear function of age despite behavioural responses being non-distinguishable, providing some support to the hypothesis of developmental changes in the neural bases of frustration.

Relative to frustration, this pattern of decreasing activation in the amygdala with age has been found previously between adults and adolescents in response to reward omission, with adults showing larger decreases in amygdala activity than adolescents (Ernst et al. 2005). These results may demonstrate general age-related decreasing activation in the amygdala. This study extends these findings to show a negative relationship between the amygdala and age in response to *increasing* frustration, suggesting participants are showing a less steep escalation in amygdala response with age.

Across adolescence, there is ongoing maturation of the limbic system, such as amygdala grey matter volume increase (Mills, Goddings, Clasen, Giedd & Blakemore, 2014) and in the connectivity between the limbic regions and other regions such as the prefrontal cortex, driven by the amygdala to help reorganise subcortical-cortical networks (Scherf et al. 2013). A such, the inverse relationship between age and amygdala/PAG activity may represent these ongoing neurobiological changes. This would also be consistent with more recent developmental ‘imbalance’ models (Casey, Galván & Somerville 2016) which suggest that subcortical-subcortical connectivity development must occur before subcortical-cortical and cortical-cortical connectivity can mature and become effective networks which are needed for emotion regulation.

Both the amygdala and the PAG have long been associated with the detection and processing of salient information (Saxbe et al. 2018; Phan, Wager, Taylor & Liberzon, 2002) and as part of the rage and aggression network (Yu et al. 2014). The amygdala in particular has been associated with processing salience (Adolphs, 2008) and recent research suggests that the amygdala sends information about the expected (usually aversive) outcome to the PAG (Fadok, Markovic, Tovote & Lüthi, 2018). The PAG in the animal literature has been associated with the generation of aggressive responses (Siegal et al. 1999). This is consistent with other recent research that suggests the PAG plays a particularly active role in the resolution of avoidance-approach conflicts (Silva & McNaughton, 2019). As such, both the amygdala and PAG have been associated with generating defensive and aversive/avoidant motivational responses (Blakemore, Reiger & Vuilleumier, 2016). Together, this network begins the process of generating the appropriate behavioural response.

The activation within the amygdala and PAG linearly decreased with age in response to increasing frustration-induction (parametric modulation contrast), which suggests a less steep neural response to increasing levels of frustration with age. Given the roles of these regions in approach/avoidance behaviours, less pronounced parametric modulation with age may reflect more efficient salience processing in the amygdala. In the PAG, a reduction in how steeply activation escalates could reflect increasing maturity in terms of frustration becoming less likely to escalate into aggression with age.

These results suggest a reduced escalation of the response to increasing frustration-induction with linear age, and are at least partially supportive of the hypothesis of developmental change across adolescence in the neural response to frustration-induction. These results may reflect ongoing maturation of the limbic system (e.g. Gogtay et al. 2004) or potentially maturation of the connectivity between regions of the limbic system and regulatory regions (e.g. Scherf et al. 2013). Given there were significant clusters of activation for the quadratic term of age suggests the results more closely reflect the maturation or development of emotion regulation abilities during adolescence as opposed to the 'peaking' trajectory hypothesised to reflect trajectories of reactive aggression during adolescence. However, these differences in the neural responses did not map onto the behavioural ratings of frustration.

5.4.4 Frustration response and reactive aggression

At the behavioural level there was no significant relationship between frustration and trait-like reactive aggression. At the neural level however, increasing frustration was associated with increased activation in the ACC, MCC and PCC. In particular, activation within the ACC, MCC and PCC were positively correlated with individual differences in trait-like reactive aggression. Similar results were found in the high>low contrast of increased activation within the MCC and PCC. These results suggest that individuals with higher reactive aggression scores had greater increases in activation within these regions in response to increasing frustration. These results provide support for the hypothesis that individual differences in the frustration response would be associated with individual differences in reactive aggression. The previous research was somewhat mixed regarding the association between the neural bases of the frustration response and reactive aggression. The current results are in line with the (majority) of studies showing hyperactivation in the ACC (Siegrist et al. 2005; Rich et al. 2010) and PCC (Perlman et al. 2015) in youth with severe irritability or bipolar disorder, both clinical diagnoses closely related with reactive aggression.

One interpretation of these results may be that individuals with increased trait-like reactive aggression have to ‘work harder’ and subsequently show increased engagement from these regions in order to manage the conflict between emotionally salient information (i.e. negative feedback) and task performance (Ghostie response) to achieve the same behavioural outcome. Increased activation as being reflective of ‘working harder’ or increased recruitment of the ACC in a regulatory role comes from the neural efficiency hypothesis (Neubauer & Fink, 2009) which suggests individuals that perform better would show reduced activation due to increased efficacy of the related networks involved. This would also be consistent with the associated roles of the ACC described above, i.e. the integration and regulation of emotional state to maintain task performance. This interpretation is also consistent with results showing increased ACC activation in individuals with high compared to low levels of behaviours related to reactive aggression (e.g. severe irritability; Siegrist et al. 2005; Tseng et al. 2019).

Perhaps the most interesting element to these results is that the relationship with trait-like reactive aggression occurred in response to *increasing* frustration, not just frustration per se (or frustration relative to a neutral control condition). This suggests that reactive aggression (or lack thereof) may be associated with the ability to appropriately titrate the frustration response under increasingly frustrating situations. That is, the results suggest that activity in ACC increases more steeply in response to the task manipulation in individuals with higher levels of reactive aggression.

Individual differences in reactive aggression therefore appear to be related to the ability to manage increasing levels of frustration, as increasing levels of frustration require individuals with high levels of reactive aggression to work harder to attain the same behavioural outcome (Pawliczek et al. 2013). This could have potential implications for everyday occurrences of frustration accumulating over time not captured in the current study. Whilst having to work harder to maintain performance during the mild evocation of frustration in a controlled, one-off situation of the testing environment may not have any behavioural consequences, in everyday life where both the magnitude and frequency or accumulation of frustration is unconstrained may contribute to behavioural differences in the ability to tolerate frustration and exaggerate reactive aggressive behaviours. This would be consistent with models of aggression which suggest increasing exposure to frustration could result in a higher likelihood of responding aggressively (e.g. General Aggression Model; Anderson & Bushman, 2002). It is also consistent with the findings from the current study that individuals reporting higher levels of self-report frustration also reported a decreased tolerance to unfair situations (FDS fairness subscale) and an increased likelihood of becoming aggressive in response to frustrating situations (STARS frustration subscale).

5.4.5 Limitations

Controlling for overall mean motivation and surprise did not affect the results, suggesting that the imaging results appear specific to frustration despite a potentially increased generalised emotional reactivity as shown in the ratings. It is worth mentioning however that controlling for the overall mean does not allow the more fine-grained parametric modulation of motivation or surprise to be controlled. Given surprise did not vary with stage blocked it is unlikely that this would be problematic, however motivation showed the same pattern exhibited by the frustration response across the four stages (1=2=3<4). However, since frustration and motivation are so intrinsically linked, controlling for this same motivation pattern would likely be overconservative (Miller and Chapman, 2001).

Relatedly, it was not possible to partition out the effects of prediction error response, i.e. responses associated with the omission of an expected reward (Schultz, 1998) within the activation seen in the parametric modulation contrast. Each blocking event signals the loss of the same reward regardless of stage, which partially controls for this possibility. However, as participants progress through the task the probability of winning the overall trial increases with each stage. If participants are implicitly tracking these probabilities (itself not a given), this might lead to some confounding between affective frustration response and prediction error signalling. However, the ACC activation was significantly correlated with reactive aggression scores suggesting that it may be less reflective of prediction errors but of frustration or negative affect more broadly.

5.4.6 Conclusions

Overall, the regions implicated in the frustration response are in line with previous studies. Increasing levels of frustration-induction (parametric modulation) were associated with activation in the ACC, suggesting the ACC is quite precisely tracking the escalating frustration-induction. Based on previous interpretations of this activation, the ACC activity may reflect increasing engagement in emotion regulation and control in pursuit of a goal. This would be consistent with the function of frustration as an approach motivation and energising emotion that occurs to aid in overcoming the obstacles or obstructions that have caused the frustration, despite the negative affect it elicits.

There also appear to be individual differences in how the frustration response is processed with age in the amygdala and PAG, and trait-like reactive aggression in the ACC. These results suggest that both age during adolescence and trait-like reactive aggression contribute to variance in the frustration response. The direction of effects suggest that the frustration response may mature during adolescence, at least at the neural level, with activation becoming less steep with age. Since this effect was not seen at behavioural levels, this highlights the importance of studying maturation at multiple levels of explanation. The frustration response also increased more steeply with levels of reactive aggression at the neural level, suggesting individuals with increased levels of reactive aggression may have to 'work harder' to regulate frustration to keep it from escalating into aggressive behaviours.

Chapter 6: General Discussion

6.1 Research questions explored in this thesis

The aims and research questions of the thesis were as follows: 1) to develop an adolescent age-appropriate frustration induction paradigm; 2) examine individual differences in the frustration response and whether these are related to individual differences in engagement in reactive aggressive behaviours, and 3) explore the behavioural and neural development of frustration in a typically developing sample. Each of these aims and questions will be addressed.

6.1.1 Development of a frustration-induction paradigm

In Chapter 2, an age-appropriate frustration induction paradigm was developed for adolescents. This was adapted from an existing paradigm in adults (Yu et al. 2014) that parametrically manipulated the level of frustration induced. Across three pilot studies (including two adult and one adolescent sample), frustration was successfully induced and generally increased with the task manipulation of purposefully blocking participants' progress to a reward at different proximities to the reward. Frustration was measured using self-report ratings both during and at the end of the task. In subsequent Chapters, the in-task ratings were used as the primary outcome measure of frustration as these appeared to represent a more methodologically sound approach, both because affect ratings were taken immediately following the emotion-eliciting event (goal-blocking) and because the approach reduced potential demand characteristics. In Chapters 3, 4 and 5 this adapted paradigm was used in adults (Chapter 3) and adolescents (Chapters 4 and 5) and again found increased frustration as a result of task manipulation (stage blocked). This suggested validity and reliability of the adapted version to induce and manipulate frustration in both adult and adolescent samples, completing the first research aim of the thesis.

6.1.2 Characterising the frustration response

6.1.2.1 Behavioural correlates

To characterise individual differences in the frustration response, overall mean frustration was related to a number of other affective states during the task (motivation and surprise) and to self-report measures including frustration tolerance (Frustration Discomfort Scale [FDS]; Situational Triggers of Aggressive Responses [STARS]), internalising behaviours (Revised Child Anxiety and Depression Scale [RCADS]) and socio-economic status (SES).

Across all studies, motivation followed the same pattern of responding as frustration, and these were significantly positively correlated with each other at the overall mean level. Surprise on the other hand was not as consistently associated with frustration as motivation, suggesting motivation is more closely associated with the frustration response. Indeed, it is possible that motivation is a key feature of the frustration response (i.e. motivation to achieve a goal is required in order for goal-blocking to be frustrating), which would be consistent with prior research (Yu et al. 2014; Buss, 1963; Dollard et al. 1939).

Frustration was also positively associated with the Fairness subscale of the Frustration Discomfort Scale (Harrington, 2005) in Chapter 2 (Pilot Study Three) and Chapter 5, but this relationship was not found in Chapter 2 Pilot Study One or in Chapter 4. The Fairness subscale, e.g. 'I can't stand having to change when other people are at fault', is a subset of items taken from the Entitlement subscale. The broader factor of Entitlement centred around the belief that one's goals need to be met and that others should not interfere, obstruct or frustrate them in any way, and the Fairness scale hones in on items relating to fairness. This would be consistent with the experience of frustration, i.e. having a goal blocked (Dollard et al. 1939), and there may be an exaggerated effect when this is related to intention and perhaps lack of control, i.e. 'when other people are at fault'. Indeed, in Chapter 5 frustration was also positively associated with the frustration subscale of the Situational Triggers of Aggressive Responses Scale (Lawrence, 2006). This scale assesses the likelihood of situations that are frustrating or where participants feel they have a lack of control would result in participants feeling aggressive. The association with lack of control in the STARS frustration subscale and the element of lack of control in the FDS Fairness subscale therefore suggest individual differences in the tolerance toward frustration and would be an interesting avenue to further understand this relationship.

In Chapter 4, frustration was positively related to anxiety and negatively related to socio-economic status (SES). The comorbidity between externalising problems and anxiety has been well established (Haller, 2017; Card & Little, 2006), so it makes sense that frustration as a hallmark characteristic of other externalising disorders (e.g. irritability; Leibenluft, 2017) would also be positively correlated with anxiety. The relationship with SES, however, has not been well established in the frustration literature. Lower SES has been associated with decreased emotion regulation ability (Hackman, Farah & Mearey, 2010; McLoyd, 1998). It is possible therefore that frustration-induction is not efficiently down-regulated in these individuals, though this is speculative and not assessed in the current thesis.

To summarise, there appear to be individual differences in the frustration response related to general levels of emotional reactivity, i.e. if an individual shows increases in motivation and to a degree surprise they are also likely to show increases in frustration. Additionally, participants' showed individual differences in level of frustration tolerance, which may be driven by how easily frustrated an individual becomes when goals are unfairly blocked (FDS Fairness) or when individuals lack control (STARS Frustration).

6.1.2.2 Neural correlates of frustration

Parametrically increasing levels of frustration-induction were associated with increased activation in a region of interest on the ACC border. Previous frustration literature that has found ACC activation has interpreted it in two ways: engaging with goal-directed behaviours and emotion regulation and/or control of aggressive impulses (Yu et al. 2014; Pawliczek et al. 2013). Frustration is a negatively valenced approach motivation, an energising emotion that occurs to aid in overcoming the obstacles or obstructions that have caused the frustration (Yu et al. 2014). As such, the increased ACC activation during frustration-induction would be consistent with these interpretations, particularly in response to increasing frustration-induction (parametric modulation). When modelling the imaging data of the frustration response to the self-report ratings of frustration, however, very little activation was reported other than the anterior insula, though this should be taken tentatively as it was at uncorrected levels only and did not survive SVC correction in the ROI analyses.

6.1.3 Individual differences: Frustration response and reactive aggression

The frustration response in Chapters 3-5 were all measured using overall mean in-task ratings collapsed across the four stages blocked and were correlated with either a trait-like measure of reactive aggression (Reactive-Proactive Aggression Questionnaire, Raine et al. 2006) or an 'outcome' measure of reactive aggression (response force).

Trait-like reactive aggression was positively correlated with overall mean frustration in adults in Chapter 2 (Pilot Study Three) and with the sample of adolescents in Chapter 4 (behavioural study), but not in the sample of adolescents tested in Chapter 5 (MRI study; behavioural results). Additionally, trait-like reactive aggression was found to be predictive of the level of frustration reported by adolescents in Chapter 4.

At the neural level, activation within the ACC in response to increasing frustration-induction (parametric modulation) was positively associated with reactive aggression scores. This suggests that individuals whose frustration response increased more steeply with stage blocked (i.e. increasingly frustrating event), also show increased levels of trait-like reactive aggressive behaviours. In Chapter 5 therefore, the pattern of the change in frustration response was related to trait-like reactive aggression.

A similar relationship was found in Chapter 3 when using an outcome measure of aggressive responding, i.e. response force at stage blocked. Though the magnitude of the frustration response (overall mean) did not correlate with the magnitude of the aggressive response, both showed parametric increases with task manipulation, i.e. the closer to the reward when blocked, the more frustrated participants reported themselves to be, and the stronger the force of response. Increasing levels of frustration-induction therefore resulted in both increased affective frustration and aggressive responding, though the data do not show that frustration induction and aggressive responding was mediated by affective frustration (not correlated).

Across all three levels of explanation tested in this thesis, individual differences in self-report frustration were positively related to individual differences in reactive aggression. The two types of relationship seen, the overall mean correlations in self-report data and the neural patterns in the ACC to increasing frustration, capture different things. Overall mean data demonstrate individual differences between the magnitude of the frustration response and trait-level reactive aggression. The degree of change across the four stages on the other hand suggests that the titration of the frustration response relative to the frustrating event is related to reactive aggressive behaviours displayed in day-to-day life.

These results converge with the two main aggression models used to guide the research in this thesis, the I^3 theory and General Aggression Model. These theories posit that frustration is an 'impellence' factor, such that one's susceptibility to or tolerance of frustration may increase the likelihood of an aggressive response occurring. In both theories, and in line with the Frustration-Aggression Hypothesis (Dollard et al. 1939), frustration precedes aggression. Additionally, in Chapter 4 reactive aggression was predictive of the level of frustration elicited, suggesting that trait-like reactive aggression may also influence the level of frustration elicited. This is particularly consistent with the General Aggression Model which suggests that 'aggressive personalities' may serve as a distal factor to increase (or decrease) the likelihood of an aggressive act occurring. We extend this idea to suggest that distal factors such as 'aggressive personalities' may also influence the severity of the frustration response. Together, these results suggest that frustration and reactive aggression are perhaps more cyclically related; frustration may precede single episodes of aggression, but the occurrence of aggression builds these trait-like or personality schemas of aggression, which in turn may influence how frustrated an individual becomes and so on. However, this was not tested directly but future longitudinal studies would be valuable to test this potential bidirectional relationship. Similarly, since frustration appears to be part of the process of reactive aggression, these models may also be useful in mapping the frustration response itself, with the frustration response being the ‘outcome’ factor and other impellence and inhibition factors (e.g. the factors associated with frustration such as frustration tolerance, anxiety and SES) could influence the likelihood of becoming *frustrated*.

To summarise, individual differences in the frustration response were positively associated with the level of reactive aggressive behaviours, even in in typically developing samples. These results support the second research question and suggest that individual differences in the frustration response may contribute to our understanding of why some individuals might display increased levels of reactive aggression. As discussed, this would be consistent with models of aggression which describe frustration as a precursor or trigger to aggressive responding, but extends this to include level of frustration tolerance as an impellence factor and frustration as an outcome which may also be influenced by impellence factors. This is a novel aspect of this thesis, as there is a paucity of research linking frustration and aggression, with the majority of empirical studies demonstrating links between threat or provocation and reactive aggression.

6.1.4 Development of the frustration response in adolescence

In Chapters 4 and 5 the frustration response was examined in two samples of adolescents (11-16 and 11-18 years respectively) to explore a) whether there are age-related differences in the frustration response, and b) whether these changes may contribute to age-related differences in reactive aggression during adolescence.

In both Chapters 4 and 5, the affective frustration response as measured by self-report did not vary as a function of age, whether this was defined as a linear term (age) or a quadratic term (age^2). The two terms of age were included to be able to test the two competing developmental hypotheses. First, that frustration would linearly decrease with age, which would be consistent with improving emotion regulation abilities seen more broadly across adolescence (Silvers et al. 2017; Silvers et al. 2012). Alternatively, frustration might follow an inverted 'U' shape trajectory across adolescence that peaked around mid-adolescence and would mirror the adolescent-peaking trajectory of reactive aggression (e.g. Moffitt, 1993; Jennings & Reingle, 2012).

While the overall mean frustration did not vary with age, the adolescent samples throughout the thesis (Chapters 1, 4 and 5) have shown a different pattern of responding to the increasing frustration-induction (1=2=3<4), showing a generally increasing but less parametric modulation compared to adults. Though this was not empirically tested, the consistency in the pattern of responding in adolescence suggests adolescents are perhaps processing frustration-induction differently to adults and warrants further investigation (see 6.3).

At the neural level, age was negatively associated with amygdala and periaqueductal gray (PAG) activation in response to the parametric modulation of frustration and the high versus low contrast of frustration. These results suggest a reduced escalation of the response to increasing frustration-induction with age, and are at least partially supportive of the hypothesis of developmental change across adolescence in the neural response to frustration-induction. These results may reflect ongoing maturation of the limbic system (e.g. Gogtay et al. 2004) or potentially maturation of the connectivity between regions of the limbic system and regulatory regions (e.g. Scherf et al. 2013).

To summarise, age-related changes in the neural frustration response appear to mirror general development of emotional reactivity and the underlying neurobiological changes during adolescence. However, the (self-report) frustration response shows no association with age at the behavioural level when using the overall mean, (though the pattern of frustration-increase does appear to differ subtly from adults). This may be because adolescents are not as accurate as introspecting or reporting their response as adults (see Chapter 4 for discussion). Alternatively, it may represent differed processing of the frustration response (i.e. less parametric in nature) in adolescents compared to adults that may be indicative of broader developmental differences only seen when comparing across developmental age groups. These results suggest that age may be a less important factor in the self-reported frustration response compared to individual differences measures such as reactive aggression within adolescence. However, at the neural level there was an effect of age showing maturation in the processing of the frustration response. Neuroimaging provides a more sensitive measure looking at underlying mechanisms. As such, the effect of age may be of a small effect size related to a generalised window of vulnerability within typically developing adolescence, but the development of the frustration response may not be the most fruitful factor in understanding adolescent vulnerability to developing clinically relevant reactive aggression. However, age may interact to play a role in the frustration response in adolescents with clinically significant reactive aggressive behaviours.

6.3 Limitations and future directions

One of the main limitations of the studies presented in this thesis is that the frustration response was not able to be disentangled from the effects of motivation or prediction errors. This thesis and previous literature (e.g. Dollard et al. 1939; Buss, 1963) have found that frustration and motivation were positively related. This might suggest individual differences in generalised emotional reactivity, however motivation may be more aptly characterised as an approach behaviour (Wright et al. 2009) than an affective state per se. Given this positive relationship and that the frustration response has also been described as an approach behaviour or energising emotion (Yu et al. 2014) it may be the case that motivation is part of the frustration response. Indeed, going back to the definitions of frustration (e.g. De Botton, 2011; Dollard et al. 1939), a frustration response is elicited when a desire or goal has been obstructed. That is to say, when goal-directed, i.e. motivated, behaviours are thwarted. Motivation, therefore, may be an inherent factor of the frustration response.

Relatedly, the design of the frustration paradigm used throughout the thesis means that prediction error signalling is a potential confound. However, this is potentially a weaker signal than the effects of goal-blocking, as the probabilities of winning a given stage in a trial or the entire trial would be difficult to work out and continue to engage in the task. The blocked outcomes on the other hand are much more explicit and are very salient to the participant. Yet, as with motivation, the nature of frustration is related to reward omission, which is inherently tied to prediction errors. Therefore, it is not possible to conclude that the frustration response is not in part explained by prediction errors and may be very difficult to disentangle these concepts without looking at time course data or using a paradigm that is better able to dissociate these effects.

Another limitation of this thesis is related to the analyses of the frustration response. Across the studies presented, the frustration response showed individual differences in both magnitude (overall mean) and trajectory (change across four stages). Given the main analyses of this thesis were correlational which require a single score per participant, overall mean was the primary measure used. This may be a cruder measure than the trajectory of the frustration response as it collapses across the four blocked stages. In Chapter 4 a measure of the trajectory of the frustration response was attempted by calculating a beta score of the slope of frustration ratings across the four stages, however this was found to be an inappropriate measure given it assumes a linear trajectory which not all participants responses fitted.

Including a measure of the rate of change across the four stages may provide richer information about individual differences and provide a more nuanced understanding of the relationship of the frustration response to reactive aggression and its development across adolescence. For example, the change in frustration response in both Chapters 3 and 5 were related to reactive aggression, whereas in Chapter 3 the overall mean of the frustration response was not. In Chapter 3, both the frustration response (frustration ratings) and aggressive responding (response force) increased parametrically, but there was no correlation between overall results. In Chapter 5, the parametric modulation contrast revealed regions of significant change in activation in response to increasing frustration and this activation was positively related to reactive aggression, yet there was no correlation between overall mean results when measured behaviourally (though this was not tested at the neural level). Similarly, adolescents showed a different pattern of escalating frustration compared to adults, with adolescents being significantly more frustrated when blocked at stage 4 only whereas adults showed a more stepwise increase across the four stages. This suggests that adolescents show a different *pattern* of frustration response to adults, which may be meaningful regarding the developmental question of the frustration response. Indeed, age related changes in the neural response to frustration were found to be more strongly associated with the parametric modulation contrast which models change across the four blocked stages.

There are also two limitations relating to the relationship between the frustration response and reactive aggression. First, this thesis primarily focused on physical reactive aggression, guided by the longitudinal trajectory studies showing the adolescent-peaking patterns of physical aggression (e.g. Moffitt, 1993; Jennings & Reingle, 2012) and based on the measures available (e.g. Reactive-Proactive Aggression Questionnaire; Raine et al. 2006). However, there are other types of reactive aggression, e.g. social or relational reactive aggression, which was found to be more strongly associated with frustration tolerance than physical aggression in a sample of adolescents (Dane & Marini, 2014). By exploring the relationship between the frustration response and other types of reactive aggression, a broader picture or how individual differences may interact to provide possible explanations for the adolescent vulnerability to increased reactive aggression, whether this is characterised by physical or relational reactive aggression.

Secondly, this thesis only examined typically developing samples whose reactive aggression scores were within normative ranges (Raine et al. 2006; Brugman et al. 2017). It is possible that the frustration response is characterised differently in individuals with clinically relevant levels of reactive aggression. The frustration response may be exaggerated in clinical groups, both in magnitude and escalation to increasingly frustrating events, or the pattern may be differently characterised. In irritability for example, Grabell et al. (2017) found there was a linear relationship between irritability scores and frustration-related activation in the lateral PFC in youth with irritability scores within normative ranges, but this pattern was reversed in in youth with irritability scores above clinical thresholds. Rather, the overall trend across all participants showed an inverted 'U' shaped quadratic trend, with the peak at the pre-clinical end of the normative range.

Future work should explore the frustration response in non-typical groups, i.e. clinical groups relevant to reactive aggression such as youths with irritability, Disruptive Behaviour Disorders and Conduct Problems. By examining the frustration response in both typically developing and clinical groups, aberrant processing of the frustration response can be identified, along with potential relationships with reactive aggressive behaviours. This thesis has begun to lay out the groundwork within typical adolescents using appropriate paradigms so that comparisons between typical and clinical groups can be made. Further, this thesis has demonstrated that individual differences in the frustration response (magnitude and titration of response) is positively related to individual differences in reactive aggression in typically developing individuals. As such, this should be further investigated in clinical groups.

Relatedly, the thesis only examined developmental differences within adolescence and did not compare across different developmental groups, e.g. compare the frustration response between children, adolescents and adults. While some of the studies presented in this thesis used adult samples, these were primarily undergraduate students (Age_{M}=20.91 years; Age_{SD}=4.11) and so would not provide a comparison group per se. Rather, these samples would represent an extension of the adolescent group, given late adolescence (or 'emerging adulthood') is now thought to continue until ~24 years of age (Sawyer et al. 2018) based on biological (Gogtay et al. 2004) and social definitions of adolescence (Damon, 2004). As such, comparing the two would not necessarily overcome this limitation. The second recommendation for future studies is to compare the frustration response *between* children, adolescents and adults. This between-subjects comparison will allow the development of the frustration response to be more holistically investigated as it covers the developmental period in question and provides distinct developmental comparison groups. The results presented in this thesis only provide tentative support for a developmental effect across adolescence based on within-adolescent samples. It may be that the development of the frustration response is of a small effect size and more strongly observable when compared across different age groups. If age effects were found, this would be consistent with the idea that adolescent development is a window of vulnerability in that adolescents might be processing the frustration response differently to children and/or adults, but that this effect may only be relevant (or potentiated) when it is combined with other individual differences factors.

Finally, the frustration response was primarily investigated in this thesis as a precursor to reactive aggression specifically. However, the frustration response in and of itself is also worth exploring how it relates to a host of outcome measures such as well-being or achievement. There are a number of reasons for frustration being a worthwhile affective reaction to explore more thoroughly. Related constructs e.g. irritability and reactive aggression, are also highly correlated with internalising disorders (Haller, 2017; Card and Little, 2006); irritability and reactive aggression lie on a spectrum (Leibenluft, 2017) and frustration is related to both; frustration was also related to anxiety but not depression (Chapter 4), suggesting differentiation within internalising behaviours; and, frustration is a more common occurrence than, for example, reactive aggression, which is only present in a (significant) minority of adolescents and generally desists thereafter into adulthood. As such, the frustration response may be a useful measure for understanding other behaviours.

6.4 Conclusions

To conclude, this thesis has demonstrated that the frustration response can be elicited in adults and adolescents using an adolescent age-appropriate adaptation of a frustration induction task which utilises the parametric manipulation of goal-blocking relative to the proximity to a reward. It has also characterised the frustration response across multiple levels of explanation, including self-report, behavioural, neural, and in terms of relationships with individual differences of interest (age and reactive aggression). The frustration response was found to be positively associated with trait-like reactive aggressive behaviours, particularly when operationalised as the change in frustration response (fMRI data, Chapter 5). Additionally, the frustration response and aggressive responding show similar patterns of increase with proximity to reward, suggesting an association between the two (Chapter 3). The frustration response does not seem to vary strongly with age during adolescence at the behavioural level (Chapters 4 & 5), however there does appear to be maturation in the processing of the frustration response across adolescence at the neural level. This suggests that both age and individual differences factors are related to the frustration response and is consistent with the idea that both age and individual differences factors are important in understanding the frustration response (Foulkes & Blakemore, 2018). Together, these results suggest that the frustration response is a fruitful avenue for understanding individual differences in reactive aggression. Future research should extend this work to a greater range of ages and age groups, and to adolescents exhibiting clinically significant levels of reactive aggression.

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Appendix 1: Rating scales for adapted frustration task

The rating scales were kept consistent with the ratings used in Yu et al. (2014) across Chapters 2-4 of a 10-point Likert scale, but were adapted for use in Chapter 5 to a 5-point Likert scale.

Very slightly or not at all		A Little		Moderately		Quite a lot		Extremely	
1	2	3	4	5	6	7	8	9	10

Very slightly or not at all	A Little	Moderately	Quite a lot	Extremely
1	2	3	4	5

Top: 1-10 ratings used in the original Yu et al. (2014) version and previous iterations of the adapted versions (chapters 2-4).

Bottom: 1-5 rating scale used in the MRI study of the adapted task (chapters 5).

Appendix 2: Self-report questionnaires

Throughout the thesis a number of questionnaires were used. These will be listed below in full and noted for which Chapter they were used.

2a) Frustration-Discomfort Scale (9-items). This was a shortened version of the full Frustration-Discomfort Scale (Harrington, 2005) as a measure of frustration tolerance. Only 9-items were used based on a review by Bebane et al. (2015) which identified these items as most closely resembling frustration. Used in Chapter 2, Pilot Study One.

2b) Frustrative Non-Reward. This was a subscale of the BIS/BAS scale (Wright, Lam & Brown, 2009) to measure an individual's propensity for low levels of 'approach' motivation following non-reward. Used in Chapter 2, Pilot Study One and Three.

2c) Frustration-Discomfort Scale (five-factor scale). The full five-factor Frustration-Discomfort Scale (Harrington, 2005) was used as a broader measure of frustration tolerance. The five factor version was used as opposed to the four factor version as the five factor version split the 'Entitlement' scale in to two further factors and it was the 'Entitlement' scale that was positively associated with anger (Harrington, 2006) and hostility (Jibeen, 2013). Used in Chapter 2 Pilot Study Three and Chapters 4 and 5.

2d) Reactive-Proactive Aggression. This 23-item questionnaire is a measure of frequency of reactive and proactive aggressive behaviours in everyday life. Participants are asked to rate the frequency of such behaviours in the last six months. Used in Chapter 2 Pilot Study Three and in Chapters 3-5.

2e) State-Trait Anxiety Inventory: Trait form. The STAI trait form (Spielberger et al. 1983) is a 20-item measure of trait anxiety and was used in secondary analyses to control for the possible comorbidity between anxiety symptoms and reactive aggression as has previously been reported in the literature (Card & Little, 2006). Used in Chapter 3 only.

2f) Revised Child Anxiety and Depression Scale (RCADS; short form). The RCADS short form (Ebesutani et al. 2012) is a 25-item scale of anxiety and depression suitable for use with children and adolescents. The scale was included again as a control for the possible comorbidity between internalising symptoms and reactive aggression. Used in Chapter 4 and 5.

2g) Pubertal Development Scale. This is a 5-6 items scale that assesses the pubertal status of children and adolescents (Carskadon & Acebo, 1993) to control for differences in pubertal status in chronological age analyses. The scale is comprised of three questions to be answered by both male and female participants, then a further two questions specifically for male pubertal development and a further two or three questions specifically for female pubertal development. Used in Chapters 4 and 5.

2h) Situational Triggers of Aggressive Responses (STAR) Scale. The STAR scale (Lawrence, 2006) is a 23-item measure o level of aggression typically triggered by frustrating or provoking events, creating two subscales. The frustration subscale (10-items) was related to situations participants found frustrating and where they felt they had a lack of control. This scale was designed for adults and so two items were removed as they did not pertain to an adolescent sample. The scale was included as an additional measure of individual differences in the likelihood of frustrating events resulting in aggression. Used in Chapter 5.

2a) Frustration-Discomfort Scale (9-items)

The next few statements are beliefs that some people hold.
Please rate how strongly each belief applies to you by ticking the circle that most applies to you.

I can’t stand doing things that involve a lot of hassle
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't bear it if other people stand in the way of what I want
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't tolerate being overlooked
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't stand having to change when others are at fault
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't tolerate being treated with disrespect
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't tolerate being taken for granted
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't tolerate other people's bad or stupid behaviour
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can’t stand being left in the dark with no explanations
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't bear to have been treated unjustly
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

Scoring: *Sum items to create total score. No items are reverse scored. Scoring scale is 1 (Absent) – 5 (Very Strong).*

Items come from three of the five factors: Discomfort Intolerance (item 1), Gratification (items 2 & 3) and Fairness (items 4, 5, 6, 7, 8 & 9).

2b) Frustrative Non-Reward

Please rate how much each statement is true to you by ticking the circle that most applies to you.

When circumstances prevent me from achieving my goal, I find it hard to keep trying
◯ Very true for me ◯ Somewhat true for me ◯ Somewhat false for me ◯ Very false for me

When an event I am looking forward to is cancelled, I lose the energy to find an alternative
◯ Very true for me ◯ Somewhat true for me ◯ Somewhat false for me ◯ Very false for me

When I don't get what I want, I lose interest in my day-to-day tasks
◯ Very true for me ◯ Somewhat true for me ◯ Somewhat false for me ◯ Very false for me

If I have been working hard at something, I lose motivation if I don't get the reward I deserve
◯ Very true for me ◯ Somewhat true for me ◯ Somewhat false for me ◯ Very false for me

When something good I am expecting doesn't happen, I feel less enthusiastic about it for a while
◯ Very true for me ◯ Somewhat true for me ◯ Somewhat false for me ◯ Very false for me

Scoring: *Sum items to create a total score. All items should be reverse scored. Scoring scale is 1 (Very true for me) – 4 (Very false for me).*

2c) Frustration-Discomfort Scale (five-factor)

The next few statements are beliefs that some people hold. Please rate how strongly each belief applies to you by ticking the circle that most applies to you.

I need the easiest way around problems; I can't stand making a hard time of it
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't stand having to wait for things I would like now
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I must be free of disturbing feelings as quickly as possible; I can't bear if they continue
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't stand being prevented from achieving my full potential
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't stand doing tasks that seem too difficult
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't stand it if other people act against my wishes
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't bear to feel that I am losing my mind
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't bear the frustration of not achieving my goals
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't stand doing tasks when I'm not in the mood
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't bear it if other people stand in the way of what I want
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can’t bear to have certain thoughts
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't tolerate lowering my standards even when it would be useful to do so
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't stand having to push myself at tasks
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't tolerate being taken for granted
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can’t stand situations where I might feel upset
◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

Please continue over the page

I can't bear to move on from work I'm not fully satisfied with

◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't stand the hassle of having to do things *right now*

◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can’t stand having to give in to other people's demands

◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't bear disturbing feelings

◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can’t stand doing a job if I'm unable to do it well

◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can’t stand doing things that involve a lot of hassle

◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't stand having to change when others are at fault

◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't get on with life, or be happy, if things don't change

◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't stand feeling that I am not on top of my work

◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't stand having to persist at unpleasant tasks

◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't tolerate criticism, especially when I know I'm right

◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't stand to lose control of my feelings

◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't tolerate any lapse in my self-discipline

◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't tolerate being overlooked

◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't bear to have been treated unjustly

◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can’t stand being left in the dark with no explanations

◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

Please continue over the page

I can't stand giving up immediate pleasures for the sake of a distant goal

◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't tolerate being treated with disrespect

◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't bear being deprived now of things I lacked in the past

◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

I can't tolerate other people's bad or stupid behaviour

◯ Absent ◯ Mild ◯ Moderate ◯ Strong ◯ Very Strong

Scoring: *Sum items to create subscale scores. No items are reverse scored. Scoring is 1 (Absent) – 5 (Very Strong).*

Subscales:

Discomfort Intolerance: 1, 5, 9, 13, 17, 21, 25

Emotional Intolerance: 3, 7, 11, 15, 19, 23, 27

Fairness: 14, 22, 26, 30, 31, 33, 35

Gratification: 2, 6, 10, 18, 29, 32, 34

Achievement: 4, 8, 12, 16, 20, 24, 28

2d) Reactive-Proactive Aggression Questionnaire

There are times when most of us feel angry, or have done things that we should not have done.

These next few statements will ask you to rate how often you have done them.

Don't spend too long thinking about them, just give your first response by ticking the circle of the most appropriate answer.

Remember - your answers are anonymous and confidential.

Please answer honestly!

Yelled at others when they have annoyed you
○ Never ○ Sometimes ○ Often

Had fights with others to show who was on top
○ Never ○ Sometimes ○ Often

Reacted angrily when provoked by others
○ Never ○ Sometimes ○ Often

Taken things from others
○ Never ○ Sometimes ○ Often

Become angry when frustrated
○ Never ○ Sometimes ○ Often

Vandalised something just for fun
○ Never ○ Sometimes ○ Often

Had temper tantrums
○ Never ○ Sometimes ○ Often

Damaged something because you felt mad
○ Never ○ Sometimes ○ Often

Had a fight just to be cool
○ Never ○ Sometimes ○ Often

Hurt others to win a game
○ Never ○ Sometimes ○ Often

Become angry when you don't get your way
○ Never ○ Sometimes ○ Often

Used force to get others to do what you want
○ Never ○ Sometimes ○ Often

Become angry or mad when you lost a game
○ Never ○ Sometimes ○ Often

Please continue over the page

Become angry when others threatened you

◯ Never ◯ Sometimes ◯ Often

Used force to obtain money or things from others

◯ Never ◯ Sometimes ◯ Often

Felt better after hitting or yelling at someone

◯ Never ◯ Sometimes ◯ Often

Threatened and bullied someone

◯ Never ◯ Sometimes ◯ Often

Made obscene (rude) phone calls just fun

◯ Never ◯ Sometimes ◯ Often

Hit others to defend yourself

◯ Never ◯ Sometimes ◯ Often

Got others to gang up on somebody else

◯ Never ◯ Sometimes ◯ Often

Carried a weapon to use in a fight

◯ Never ◯ Sometimes ◯ Often

Become angry or mad or hit others when teased

◯ Never ◯ Sometimes ◯ Often

Yelled at others so they would do things for you

◯ Never ◯ Sometimes ◯ Often

Scoring: *Sum items to create subscales. No items are reverse scored. Scoring scale is 0 (Never) – 2 (Often).*

Subscales:

Reactive Aggression: 1, 3, 5, 7, 8, 11, 13, 14, 16, 19, 22.

Proactive Aggression: 2, 4, 6, 9, 10, 12, 15, 17, 18, 20, 21, 23.

2e) State Trait Anxiety Inventory (Trait form)

A number of statements which people have used to describe themselves are given below.
Read each statement and then select the box that best indicates how you generally feel.
Make sure you answer all the items.

Remember - your answers are stored anonymously and confidentially.
Please answer honestly!

I feel pleasant
○ Almost never ○ Sometimes ○ Often ○ Almost always

I feel nervous and restless
○ Almost never ○ Sometimes ○ Often ○ Almost always

I feel satisfied with myself
○ Almost never ○ Sometimes ○ Often ○ Almost always

I wish I could be as happy as others seem to be
○ Almost never ○ Sometimes ○ Often ○ Almost always

I feel like a failure
○ Almost never ○ Sometimes ○ Often ○ Almost always

I feel rested
○ Almost never ○ Sometimes ○ Often ○ Almost always

I am "calm, cool and collected"
○ Almost never ○ Sometimes ○ Often ○ Almost always

I feel that difficulties are piling up so that I cannot overcome them
○ Almost never ○ Sometimes ○ Often ○ Almost always

I worry too much over something that really doesn't matter
○ Almost never ○ Sometimes ○ Often ○ Almost always

I am happy
○ Almost never ○ Sometimes ○ Often ○ Almost always

I have disturbing thoughts
○ Almost never ○ Sometimes ○ Often ○ Almost always

I lack self-confidence
○ Almost never ○ Sometimes ○ Often ○ Almost always

I feel secure
○ Almost never ○ Sometimes ○ Often ○ Almost always

I make decisions easily
○ Almost never ○ Sometimes ○ Often ○ Almost always

I feel inadequate
○ Almost never ○ Sometimes ○ Often ○ Almost always

Please continue over the page

I am content

◯ Almost never ◯ Sometimes ◯ Often ◯ Almost always

Some unimportant thoughts run through my mind and bothers me

◯ Almost never ◯ Sometimes ◯ Often ◯ Almost always

I take disappointments so keenly that I can't put them out of my mind

◯ Almost never ◯ Sometimes ◯ Often ◯ Almost always

I am a steady person

◯ Almost never ◯ Sometimes ◯ Often ◯ Almost always

I get in a state of tension or turmoil as I think over my recent concerns and interests

◯ Almost never ◯ Sometimes ◯ Often ◯ Almost always

Scoring: *Sum items to create total score. Items 1, 3, 6, 7, 10, 13, 14, 16 & 19 are reverse scored. Scoring scale is 1 (Almost never) – 4 (Almost always).*

2f) Revised Child Anxiety and Depression Scale

The next few questions ask you about your day-to-day emotions.
Please select the answer that shows how often each of these things happen to
There are no right or wrong answers.

I feel sad or empty
◯ Never ◯ Sometimes ◯ Often ◯ Always

I worry when I think I have done poorly at something
◯ Never ◯ Sometimes ◯ Often ◯ Always

I would feel afraid of being on my own at home
◯ Never ◯ Sometimes ◯ Often ◯ Always

Nothing is much fun anymore
◯ Never ◯ Sometimes ◯ Often ◯ Always

I worry that something awful will happen to someone in my family
◯ Never ◯ Sometimes ◯ Often ◯ Always

I am afraid of being in crowded places, like shopping centres, the movies, buses, busy playgrounds
◯ Never ◯ Sometimes ◯ Often ◯ Always

I worry what other people think of me
◯ Never ◯ Sometimes ◯ Often ◯ Always

I have trouble sleeping
◯ Never ◯ Sometimes ◯ Often ◯ Always

I feel scared if I have to sleep on my own
◯ Never ◯ Sometimes ◯ Often ◯ Always

I have problems with my appetite
◯ Never ◯ Sometimes ◯ Often ◯ Always

I suddenly become dizzy or faint when there is no reason for this
◯ Never ◯ Sometimes ◯ Often ◯ Always

I have to do some things over and over again, like washing my hands, cleaning, or putting things in a certain order
◯ Never ◯ Sometimes ◯ Often ◯ Always

I have no energy for things
◯ Never ◯ Sometimes ◯ Often ◯ Always

I suddenly start to tremble or shake when there is no reason for this
◯ Never ◯ Sometimes ◯ Often ◯ Always

Please continue over the page

I cannot think clearly
◯ Never ◯ Sometimes ◯ Often ◯ Always

I feel worthless
◯ Never ◯ Sometimes ◯ Often ◯ Always

I have to think of special thoughts (like numbers or words) to stop bad things from happening
◯ Never ◯ Sometimes ◯ Often ◯ Always

I think about death
◯ Never ◯ Sometimes ◯ Often ◯ Always

I feel like I don't want to move
◯ Never ◯ Sometimes ◯ Often ◯ Always

I worry that I will suddenly get a scared feeling when there is nothing to be afraid of
◯ Never ◯ Sometimes ◯ Often ◯ Always

I am tired a lot
◯ Never ◯ Sometimes ◯ Often ◯ Always

I feel afraid that I will make a fool of myself in front of people
◯ Never ◯ Sometimes ◯ Often ◯ Always

I have to do some things in just the right way to stop bad things from happening
◯ Never ◯ Sometimes ◯ Often ◯ Always

I feel restless
◯ Never ◯ Sometimes ◯ Often ◯ Always

I worry that something bad will happen to me
◯ Never ◯ Sometimes ◯ Often ◯ Always

Scoring: *Sum items to create subscales. No items are reverse scored. Scoring scale is 0 (Never) – 3 (Always).*

Subscales:

Anxiety: 2, 3, 5, 6, 7, 9, 11, 12, 14, 17, 18, 20, 22, 23.

Depression: 1, 4, 8, 10, 13, 15, 16, 19, 21, 24, 25.

2g) Pubertal Development Scale: Boys form

The next questions are about changes that may be happening to your body. These changes normally happen to different young people at different ages. If you do not understand a question, please ask. If you do not know the answer, just select 'I don't know' – but please ask first as we may be able to help!

Would you say that your growth in height…

- ◯ Has not yet begun to spurt
- ◯ Has barely started
- ◯ Is definitely underway
- ◯ Seems completed
- ◯ Don't know

How about the growth of your body hair? (Body hair means hair any place other than your head, such as under your arms)

- ◯ Has not yet begun to spurt
- ◯ Has barely started
- ◯ Is definitely underway
- ◯ Seems completed
- ◯ Don't know

Have you noticed any skin changes, especially pimples or spots?

- ◯ Has not yet begun to spurt
- ◯ Has barely started
- ◯ Is definitely underway
- ◯ Seems completed
- ◯ Don't know

Have you noticed a deepening of your voice?

- ◯ Voice has not yet started changing
- ◯ Voice has barely started changing
- ◯ Voice changes are definitely underway
- ◯ Voice changes seem complete
- ◯ Don't know

Have you begun to grow hair on your face?

- ◯ Facial hair has not yet started growing
- ◯ Facial hair has barely started growing
- ◯ Facial hair growth has definitely started
- ◯ Facial hair growth seems completed
- ◯ Don't know

2g) Pubertal Development Scale: Girls form

The next questions are about changes that may be happening to your body. These changes normally happen to different young people at different ages. If you do not understand a question, please ask. If you do not know the answer, just select 'I don't know' – but please ask first as we may be able to help!

Would you say that your growth in height…

- ◯ Has not yet begun to spurt
- ◯ Has barely started
- ◯ Is definitely underway
- ◯ Seems completed
- ◯ Don't know

How about the growth of your body hair? (Body hair means hair any place other than your head, such as under your arms)

- ◯ Has not yet begun to spurt
- ◯ Has barely started
- ◯ Is definitely underway
- ◯ Seems completed
- ◯ Don't know

Have you noticed any skin changes, especially pimples or spots?

- ◯ Has not yet begun to spurt
- ◯ Has barely started
- ◯ Is definitely underway
- ◯ Seems completed
- ◯ Don't know

Have you noticed your breasts have begun to grow?

- ◯ Have not yet started growing
- ◯ Have barely started growing
- ◯ Breast growth is definitely underway
- ◯ Breast growth seems complete
- ◯ Don't know

Have you begun to menstruate (started your period)?

- ◯ Yes
- ◯ No

If YES, how old were you when you began to menstruate (have your period)?

_________ Years _________ Months

Scoring: *Items are not summed to create a total score but depending on the scores for each item a category score is created using the Tanner stages. No items are reverse scored. Scoring scales differ for each item and form.*

Boys:

Items 1, 2 & 3: 1 (… not yet begun to spurt) – 4 (… seems completed).

Item 4: 1 (… not yet started changing) – 4 (… seems completed).

Item 5: 1 (… not yet started growing) – 4 (… seems completed).

Girls:

Items 1, 2 & 3: 1 (… not yet begun to spurt) – 4 (… seems completed).

Item 4: 1 (… not yet started growing) – 4 (… seems completed).

Item 5: 1 (No) or 4 (Yes).

Item 6 is not scored.

2h) Situational Triggers of Aggressive Responses

The following is a list of situations in which you may have felt aggressive. Please indicate, as honestly as possible, how accurate they are for you, in terms of whether you feel aggressive in these situations.

I feel aggressive when…

A friend betrays me

- ◯ Very Accurate
- ◯ Moderately Accurate
- ◯ Neither accurate nor inaccurate
- ◯ Moderately Inaccurate
- ◯ Very Inaccurate

I am the subject of a practical joke

- ◯ Very Accurate
- ◯ Moderately Accurate
- ◯ Neither accurate nor inaccurate
- ◯ Moderately Inaccurate
- ◯ Very Inaccurate

People I live with show a lack of consideration

- ◯ Very Accurate
- ◯ Moderately Accurate
- ◯ Neither accurate nor inaccurate
- ◯ Moderately Inaccurate
- ◯ Very Inaccurate

Someone steals something from me

- ◯ Very Accurate
- ◯ Moderately Accurate
- ◯ Neither accurate nor inaccurate
- ◯ Moderately Inaccurate
- ◯ Very Inaccurate

I feel frustrated

- ◯ Very Accurate
- ◯ Moderately Accurate
- ◯ Neither accurate nor inaccurate
- ◯ Moderately Inaccurate
- ◯ Very Inaccurate

More questions over the page!

Someone insults me

- ◯ Very Accurate
- ◯ Moderately Accurate
- ◯ Neither accurate nor inaccurate
- ◯ Moderately Inaccurate
- ◯ Very Inaccurate

I have academic/school or work problems

- ◯ Very Accurate
- ◯ Moderately Accurate
- ◯ Neither accurate nor inaccurate
- ◯ Moderately Inaccurate
- ◯ Very Inaccurate

I experience a family dispute or argument

- ◯ Very Accurate
- ◯ Moderately Accurate
- ◯ Neither accurate nor inaccurate
- ◯ Moderately Inaccurate
- ◯ Very Inaccurate

I feel hot and crowded

- ◯ Very Accurate
- ◯ Moderately Accurate
- ◯ Neither accurate nor inaccurate
- ◯ Moderately Inaccurate
- ◯ Very Inaccurate

Someone ignores me

- ◯ Very Accurate
- ◯ Moderately Accurate
- ◯ Neither accurate nor inaccurate
- ◯ Moderately Inaccurate
- ◯ Very Inaccurate

Someone behaves in an inconsiderate manner towards me

- ◯ Very Accurate
- ◯ Moderately Accurate
- ◯ Neither accurate nor inaccurate
- ◯ Moderately Inaccurate
- ◯ Very Inaccurate

More questions over the page!

I am in pain

- ◯ Very Accurate
- ◯ Moderately Accurate
- ◯ Neither accurate nor inaccurate
- ◯ Moderately Inaccurate
- ◯ Very Inaccurate

I am goaded or provoked by someone

- ◯ Very Accurate
- ◯ Moderately Accurate
- ◯ Neither accurate nor inaccurate
- ◯ Moderately Inaccurate
- ◯ Very Inaccurate

I've been let down by someone

- ◯ Very Accurate
- ◯ Moderately Accurate
- ◯ Neither accurate nor inaccurate
- ◯ Moderately Inaccurate
- ◯ Very Inaccurate

I feel stressed

- ◯ Very Accurate
- ◯ Moderately Accurate
- ◯ Neither accurate nor inaccurate
- ◯ Moderately Inaccurate
- ◯ Very Inaccurate

I hear a noise that I cannot control

- ◯ Very Accurate
- ◯ Moderately Accurate
- ◯ Neither accurate nor inaccurate
- ◯ Moderately Inaccurate
- ◯ Very Inaccurate

I am frustrated with services

- ◯ Very Accurate
- ◯ Moderately Accurate
- ◯ Neither accurate nor inaccurate
- ◯ Moderately Inaccurate
- ◯ Very Inaccurate

More questions over the page!

Others around me are becoming aggressive

- ◯ Very Accurate
- ◯ Moderately Accurate
- ◯ Neither accurate nor inaccurate
- ◯ Moderately Inaccurate
- ◯ Very Inaccurate

Someone makes offensive remarks to me

- ◯ Very Accurate
- ◯ Moderately Accurate
- ◯ Neither accurate nor inaccurate
- ◯ Moderately Inaccurate
- ◯ Very Inaccurate

I argue with a friend

- ◯ Very Accurate
- ◯ Moderately Accurate
- ◯ Neither accurate nor inaccurate
- ◯ Moderately Inaccurate
- ◯ Very Inaccurate

Scoring: *Sum items to create subscale scores. No items are reverse scored. Scoring scale is 1 (Very accurate) – 5 (Very inaccurate).*

Subscales:

Frustration: 5, 7, 8, 9, 10, 12, 14, 15, 16, 17.

Provocation: 1, 2, 3, 4, 6, 11, 13, 18, 19, 20.

Appendix 3: Pre-registration of Chapter 3

This pre-registration was created using the asPredicted.org template and can be found on the Open Science Framework at this link: https://osf.io/yc6wa/

1) Data collection. Have any data been collected for this study already?

- ○ Yes, we already collected the data.
- ◉ No, no data have been collected for this study yet.
- ○ It's complicated. We have already collected some data but explain in Question 8 why readers may consider this a valid **pre**-registration nevertheless.

2) Hypothesis. What's the main question being asked or hypothesis being tested in this study?

Question One: Is grip force (an outcome measure of reactive aggression) related to the level of frustration displayed by participants?

We predict that participants will show greater levels of self-reported frustration (measured in-task) when they are blocked closest to the potential reward (e.g. Yu et al., 2014). We also predict a positive correlation between self-reported levels of frustration and 'of-the-moment' reactive aggression response (grip force), also demonstrated by Yu et al., (2014).

Question Two: Is grip force associated with individual differences in trait reactive aggression?

We predict that there will be a positive correlation between the overall relative mean 'of-the-moment' reactive aggression (grip force) with the level of trait-like reactive aggression. Further we predict that, everyday or trait-like reactive aggression may play a mediating role in the relationship between frustration (self-report) and ‘of-the-moment’ reactive aggression (grip force).

Question Three: Is grip force associated with individual differences in inhibitory control?

We anticipate inhibitory control ability will be negatively correlated with overall mean grip force whereby greater levels of inhibitory control will be associated with lower levels of ‘of-the-moment’ reactive aggression (grip force). We predict that inhibitory control will ‘protect’ against self-reported frustration being translated into an aggressive force response.

3) Dependent variable. Describe the key dependent variable(s) specifying how they will be measured.

The current study consists of two computerised tasks and a series of questionnaires. The first computerised task aims to induce frustration by preventing participants from receiving rewards. Participants will be blocked at one of four stages. As demonstrated by previous research by Yu et al., (2014) and adapted pilot and study data, participants show greater frustration when blocked closer to the potential reward (i.e. at stage four when they are closest to receiving a reward compared with previous stages). The dependent variables are ‘of-the-moment’ reactive aggression (measured by relative mean grip force) and self-reported frustration (measured in-task, using a 10-point Likert Scale).

Relative mean grip force is calculated by dividing the maximum force of a response during the task by the mean of their response during a calibration stage (pre-task). This accounts for each participants strength, resulting in a relative score. This measurement is taken when participants are asked to confirm whether they were blocked in the trial (N=56 Blocked trials). Additionally, we will measure ‘baseline’ grip force in response to a neutral question.

Interspersed within the task are also self-reported ratings of frustration. Using a 10-point Likert Scale, participants indicate their level of frustration (1 =’Very slightly or not at all’; 10 = ‘Extremely’). For the main analyses we will be using the overall mean frustration score (collapsed across conditions).

A second computerised task will be used to measure inhibitory control using a Go/No-Go Task. Here, commission errors (e.g. going on a no-go trial) will be used to measure inhibitory control.

As well as demographic information, a series of questionnaires will be used. These include: The Reactive Proactive Aggression Questionnaire (RPQ; Raine et al., 2006), and State-Trait Anxiety Inventory (STAI; Spielberger et al., 1983). The RPQ provides a measure of trait-like reactive aggression to be used in the individual differences analyses. The STAI will provide a measure of anxiety to be used in secondary analyses as a control variable.

4) Conditions. How many and which conditions will participants be assigned to?

As this study is a within-subjects design, all participants will complete all the conditions. This includes the two computerised tasks and the questionnaires. The Go/No-Go Task will be counterbalanced with the go and no-go stimuli varying across participants (e.g. if the participants go for a circle or square).

In the Frustration task there are 5 task conditions, and these represent which stage of each trial the participant will become blocked, if at all. Conditions 1-4 represent the levels 1-4 respectively of the trial at which participants will be blocked, and condition 5 represents a 'WIN' level whereby participants will not be purposefully blocked, but may still be blocked if they respond incorrectly or do not respond.

5) Analyses. Specify exactly which analyses you will conduct to examine the main question/hypothesis.

Analyses by which research question they will help answer.

Question One: Is grip force (an outcome measure of reactive aggression) related to the level of frustration displayed by participants?

To check the frustration induction was successful, a repeated measures ANOVA with 4 levels (each of the blocked stages) and post-hoc planned contrasts to test the pattern that frustration induced at stage 4>3>2>1. Multiple comparison corrections will be used for the planned comparisons (3 comparisons) therefore p should be less than or equal to 0.016, (p = 0.05/3).

Similarly, to investigate the change in response force across the 4 conditions a repeated measures ANOVA with 4 levels (each of the blocked stages) and post-hoc planned contrasts to test the pattern of response at stage 4>3>2>1. Multiple comparison corrections will be used for the planned comparisons (3 comparisons) therefore p should be less than or equal to 0.016, (p=0.05/3).

Pearson's Correlations will be used to observe the relationship between the overall mean frustration (self-report) and overall relative 'of-the-moment' reactive aggression (grip force) measures.

Question Two: Is grip force associated with individual differences in trait reactive?

Pearson's Correlation will be used to investigate the relationship between trait-like reactive aggression (questionnaire) and 'of-the-moment' reactive aggression (grip force measure).

Question Three: Is grip force associated with individual differences in inhibitory control?

Inhibitory control will be calculated using commission errors. A Pearson's Correlation will be used to test the relationship between overall relative mean 'of-the-moment' reactive aggression (grip force measure) and inhibitory control (commission errors).

6) More analyses. Any secondary analyses?

Should the above ANOVA analyses demonstrate a linear pattern of change in frustration/grip force we will use a regression to create a beta value of the slope of change across the 4 blocked conditions for each participant for both self-report frustration and ‘of-the-moment’ reactive aggression (grip-force measure). The frustration beta will provide a measure of frustration sensitivity.. In the case of the reactive aggression grip force measure, this may provide a measure of the degree to which frustration is *translated* into aggression. A Pearson’s correlation will then be used to explore whether reactivity to frustration follows a linear relationship with frustration sensitivity.

A regression analysis will be used to explore the extent to which overall mean frustration and inhibitory control can predict ‘of-the-moment’ reactive aggression (grip force).

Aggressive personalities are thought to increase the likelihood of a frustrating event resulting in aggression whereby inhibitory control is thought to play a protective role in the translation of frustration to reactive aggression. Therefore, inhibitory control and trait-like reactive aggression may mediate the relationship between overall mean frustration and 'of-the-moment' reactive aggressive behaviours (grip force).

Mediation analyses a) trait-like reactive aggression as a mediator between the frustration response and 'of-the-moment' reactive aggression, and b) inhibitory control as a mediator between the frustration response and reactive aggression.

7) Sample Size. How many observations will be collected or what will determine sample size?

Fourty adult participants will be recruited for this study. The sample size was determined using GPower using 80% power at alpha level (0.05) with a moderate effect size of d = 0.4-0.5 (N=35-45).

8) Other. Anything else you would like to pre-register?

A measure of trait anxiety will be taken and may be used as a control variable in the analyses to ensure results are not driven by anxiety.

Exclusion criteria will be ±3SD for: task errors collapsed across conditions (1-5); confirmation errors; commission errors; or questionnaire subscales.

9) Name. Give a title for this AsPredicted pre-registration.

Frustration and Reactive Aggression: A Response Force Measure

10) Finally. For record keeping purposes, please tell us the type of study you are pre-registering.

Experiment.

Appendix 4: Pre-registration Chapter 4

This pre-registration was created using the asPredicted.org template and can be found on the Open Science Framework at this link: https://osf.io/7ser3/

1) Data collection. Have any data been collected for this study already?

○ Yes, we already collected the data.

◉ No, no data have been collected for this study yet.

○ It's complicated. We have already collected some data but explain in Question 8 why readers may consider this a valid **pre**-registration nevertheless.

2) Hypothesis. What's the main question being asked or hypothesis being tested in this study?

Question One: Are there developmental changes across adolescence (age 9-18) in a) the overall mean extent to which frustrating non-reward events elicit a frustration response and b) sensitivity to gradually escalating levels of frustration events, i.e. greater difference in level of frustration induced across the 4 stages of frustration induction?

We predict a change in the overall mean level of induced frustration across age, however this may either follow a linear decrease with age, or follow an inverted 'U' shape as has been found for other related constructs such as reactive aggression, which peaks around 13-15 years. We predict there will be developmental differences in the sensitivity or tolerance to frustration, i.e. difference in level of frustration induced across 4 levels, where each level increases the amount of induced frustration.

Question 2: Is overall mean level of frustration and/or sensitivity to frustration related to individual differences, particularly focusing on reactive aggression, i.e. aggression in response to provocation or threat?

Level of reactive aggression to change with age. The shape of the trajectory is uncertain, however previous studies have found reactive aggression followed an inverted 'U' shape.

Predict that a higher overall mean level of induced frustration will be positively correlated with level of reactive aggressive behaviours

Those with greater sensitivity to frustration, will have greater levels of reactive aggression, i.e. positive correlation, and that the frustration response may mediate any relationship between age and aggression.

Question Three: How do inhibitory control abilities change across adolescence? Are these related to ability to deal with frustration?

Inhibitory control is predicted to increase with age. Changes in inhibitory control will be correlated with changes in overall mean level of frustration and frustration sensitivity.

3) Dependent variable. Describe the key dependent variable(s) specifying how they will be measured.

The study comprises two computerised tasks and a battery of questionnaires. The first task induces frustration by blocking participants from a reward at one of 4 stages (the higher the stage the closer to the reward, therefore the greater the frustration induced when blocked, as demonstrated in the original task by Yu et al., (2014) and our pilot data from an adapted version). Self-report ratings of frustration at being blocked is taken 3 times during the task and once at the end of the task for each stage at which participants are blocked. The key dependent variables therefore are the self-report ratings of frustration, including mean self-report rating of frustration across all tasks, and the beta of the slope of frustration for each individual across the 4 conditions, as an index of frustration sensitivity or frustration tolerance. The two scores of frustration are separate as an overall mean may mask variations in ability to tolerate escalating frustration, i.e. some participants may only become extremely frustrated at the most frustrating stages, whereas others may find the lower levels of frustration induction as equally frustrating as the higher levels. This measure of frustration sensitivity therefore is another way of investigating developmental effects/individual differences in terms of frustration response.

The second task is a classic inhibition task (go/no-go), which will use d' to take a measure of inhibition, as this takes into account both omission and commission errors to account for response bias.

There will also be a number of questionnaires: Reactive and Proactive Aggression, Revised Child Anxiety and Depression Scale, pubertal status, research-estimated IQ

(WASI-II short form) and demographics. The main DVs are age and level of reactive aggression; the remaining measures will be used as control variables.

4) Conditions. How many and which conditions will participants be assigned to?

The whole battery (including the two computerised tasks and questionnaires) uses a within-subjects design, therefore all participants will complete all conditions. The Go/No-Go task will counterbalance go and no-go stimuli across participants, stratified by age.

In the Frustration task there are 5 task conditions, and these represent which stage of each trial the participant will become blocked, if at all. Conditions 1-4 represent the levels 1-4 respectively of the trial at which participants will be blocked, and condition 5 represents a 'WIN' level whereby participants will not be purposefully blocked, but may still be blocked if they respond incorrectly or do not respond.

5) Analyses. Specify exactly which analyses you will conduct to examine the main question/hypothesis.

Question One: Are there developmental changes across adolescence in a) the overall mean frustration response and b) frustration sensitivity?

To check the frustration induction was successful, a repeated measures ANOVA with 4 levels (each of the blocked stages) and post-hoc planned contrasts to test the pattern that frustration induced at stage 4>3>2>1. Multiple comparison corrections will be used for the planned comparisons (3 comparisons) therefore p should be less than or equal to 0.016, ($p = 0.05/3$).

For the prediction that overall mean frustration will change with age, we will conduct

Pearson's product moment correlation between mean rating of frustration (across all levels) and age to test the linear decrease prediction

Regression with age and age^2 as predictors of overall mean frustration and frustration sensitivity to test the prediction that there will be an inverted 'U' quadratic trajectory of age on both frustration measures. This will be two tailed as there is not enough prior literature to make a clear prediction on the direction of change with age.

To analyse the prediction that frustration sensitivity will change with age, a regression analysis will be conducted within each participant's data to calculate a beta score of the slope/trajectory of change in frustration across the 4 levels of blocking. This will provide a measure of each participant's sensitivity to frustration, e.g. a steeper (positive) slope would suggest that participants have a higher sensitivity to escalating frustration.

Following the above analyses we will conduct a Pearson's product moment correlation between frustration sensitivity measure (i.e. beta value for each participant) and age.

Question Two: Is overall mean level of frustration and/or sensitivity to frustration related to individual differences, particularly focusing on reactive aggression?

To assess the prediction that levels of reactive aggression will change with age, we will conduct a Pearson's product moment correlation between age and reactive aggression scores.

To address the predictions that overall mean frustration and frustration sensitivity are related to levels of reactive aggression two Pearson's product moment correlations, correcting for multiple comparisons (x2; therefore $p \leq 0.025$):

Reactive Aggression scores and mean rating of frustration.

Reactive Aggression scores and Frustration slope beta to gauge the association between reactive aggression and frustration sensitivity.

Question Three: How do inhibitory control abilities change across adolescence? Are these related to ability to deal with frustration?

A d' score will be calculated for each participant as a measure of inhibitory control. As this is a relatively novel way of analysing inhibitory control percentage of commission errors will also be calculated, as is standard practice, to check that d' is an adequate measure.

To test the prediction that inhibitory control will improve with age a Pearson's product moment correlation between d' and age will be conducted.

To test the predictions that overall mean frustration and frustration sensitivity are related to inhibitory control we will conduct two Pearson's product moment correlations, correcting for multiple comparisons (x2; therefore $p \leq 0.025$):

a) d-Prime and overall mean frustration

b) d-Prime and frustration sensitivity

6) More analyses. Any secondary analyses?

Frustration is thought to be a precursor to reactive aggression, therefore overall mean frustration/frustration sensitivity should predict level of reactive aggression. However, inhibitory control may mediate the translation of frustration to aggressive behaviours, therefore this may also be a predictor.

Regression: do age, frustration sensitivity, mean frustration and/or inhibitory control predict reactive aggression?

Mediation analyses a) frustration and/or inhibitory control as a mediator between age and reactive aggression, and b) inhibitory control as a mediator between the frustration response and reactive aggression.

To further test the prediction that there might be a quadratic trajectory of frustration response across adolescence, we will be conducting the 'two lines test' (see http://datacolada.org/62) to follow up any regressions showing a significant quadratic effect of age. This test estimates two regression lines, one with low values and one with high values of *x*, in this case overall mean frustration (or frustration sensitivity) with age. The test states that a quadratic effect has only been found if these two regression lines have opposite signs and are individually significant, and has been devised to address high false positive rates for concluding U-shaped relationships exist when relying on quadratic regression alone.

7) Sample Size. How many observations will be collected or what will determine sample size?

No need to justify decision, but be precise about <u>exactly</u> how the number will be determined.

Given our main research question is how age changes with frustration we calculated the required N for a correlation between two continuous variables (mean frustration and age).

Sample size was determined using GPower using 80% power at alpha level of 0.05 with an effect size of r = 0.3 (r^2 equating to 9% of total variance). This power calculation indicated an N of 84 participants was necessary (for r = 0.2-0.3 respectively).

Furthermore, given that a quadratic relationship may exist, we also provide a power analysis for a quadratic regression (two-tailed) with two predictors, age and age squared. Using 80% power, alpha level 0.05 and effect size of $r^2 = 0.09$ (to coincide with r=0.3), the estimated sample size was between 104 participants.

The overall sample size for this study is 135 as a lower limit, with the aim of testing 15-20 participants for each school year group (year 9 - year 13; roughly ages 9-18 years). This number is well within the range suggested by GPower to detect an effect size of 0.3.

8) Other. Anything else you would like to pre-register?

(e.g., data exclusions, variables collected for exploratory purposes, unusual analyses planned?)

NA.

9) Name. Give a title for this AsPredicted pre-registration

Frustration during adolescence: Associations with age and reactive aggression.

10) Finally. For record keeping purposes, please tell us the type of study you are pre-registering.

Experiment.

Appendix 5: Blocked>Baseline contrast

One additional contrast was created to check the task manipulation at the neural level, i.e. participants showed increased frustration response at the neural level after being blocked, therefore a blocked>baseline contrast was generated. This contrast modelled neural activity that was greater during the BLOCKED feedback (collapsed across the 4 blocked conditions) compared to neural activity in response to the cue/updated cue stimuli (collapsed across presentations prior to the 4 blocked conditions). Both cue and updated cue stimuli were included to account for the increased number of stages completed by collapsing neural activity during the feedback across the 4 blocked conditions.

During blocked feedback in comparison to cue stages there were large clusters of significant increases in BOLD signal in the predicted region of the insula (bilateral), as well as in the lingual gyrus, middle occipital gyrus, hippocampus and thalamus (*p<.05, FWE-corrected*). At the uncorrected threshold (*p<.001, k>10*) there were additional increased activations in regions of interest including the anterior and mid cingulate cortices (see Table). As this analysis was intended as a manipulation check at the neural level, no further analyses were conducted.

Whole Brain Results								
Brain Region	**L/R**	**Peak Voxel**			**k**	**z**	**Cluster *p-value***	**Peak *p-value***
Blocked>Baseline								
Mean activation								
Lingual gyrus	L	-16	-84	8	3230	7.39	*<0.001*	*<0.001*
	L	22	-82	-8		7.12		*<0.001*
	L	-30	-82	-10		7.00		*<0.001*
Middle occipital gyrus	L	-18	-98	10	183	6.32	*<0.001*	*<0.001*
	L	-28	-90	8		5.75		*<0.001*
	L	-10	-100	10		5.40		*0.001*
Insula	L	-38	16	8	547	6.01	*<0.001*	*<0.001*
	L	-32	16	-8		5.73		*<0.001*
	L	-32	28	4		5.48		*0.001*
Insula	R	34	22	8	499	5.75	*<0.001*	*<0.001*
	R	30	22	-8		5.35		*0.002*
	R	34	26	-2		5.27		*0.003*
Hippocampus	L	-22	-30	-2	17	5.28	*0.005*	*0.003*
Thalamus	R	22	-30	0	11	4.96	*0.009*	*0.011*

Whole brain results for the Blocked>Baseline contrast. Results show brain regions surviving cluster-level FWE-correction and corresponding FWE-corrected peak p-value if p<0.05. L/R=laterality (left/right); peak voxel co-ordinates are reported in Montreal Neurological Institute (MNI) standard space; k=cluster size; z=z-value for peak voxel.

Appendix 6: Whole brain results at uncorrected threshold

a) **Whole brain results at an uncorrected threshold for the parametric modulation contrast, including covariates of age and reactive aggression.**

Whole Brain Results: Parametric Modulation Contrast							
Brain Region	**L/R**	**Peak Voxel**			**k**	**z**	**Peak *p-value***
Parametric Modulation contrast							
Increasing proximity to reward (1<2<3<4)							
Cuneus	R	16	-90	8	924	5.65	*<0.001*
	R	12	-64	-4		4.69	*<0.001*
	R	26	-62	-4		3.73	*<0.001*
Lingual gyrus	L	-22	-74	-8	432	4.89	*<0.001*
	L	-12	-78	-4		4.52	*<0.001*
	L	-28	-58	-6		3.98	*<0.001*
Anterior cingulate cortex	R	4	16	28	107	4.13	*<0.001*
Calcarine fissure	R	16	-86	-2	10	3.63	*<0.001*
Fusiform gyrus	R	28	-78	-6	16	3.38	*<0.001*
Calcarine fissure	L	-20	-60	12	38	3.36	*<0.001*
	L	-20	-70	12		3.36	*<0.001*
	L	-20	-52	6		3.22	*<0.001*
Middle occipital gyrus	L	-28	-82	22	56	3.36	*<0.001*
Decreasing proximity to reward (4<3<2<1)							
Precuneus	R	20	-52	34	156	4.21	*<0.001*
	R	22	-48	26		3.69	*<0.001*
	R	28	-52	30		3.64	*<0.001*
Cuneus	L	-26	-52	24	81	3.56	*<0.001*
	L	-34	-58	30		3.4	*<0.001*

	L	-20	-50	34		3.36	*<0.001*
Posterior cingulate cortex	L	-4	-38	12	16	3.34	*<0.001*

Parametric Modulation with Age covariate of interest

Increasing proximity to reward: negative relationship with age

Periaquaductal gray	L	-10	-24	-12	309	4.12	*<0.001*
	R	2	-26	-14		3.69	*<0.001*
	R	10	-28	-16		3.51	*<0.001*
Hippocampus	L	-32	-12	-16	55	3.83	*<0.001*
Amygdala	R	24	8	-14	39	3.66	*<0.001*
Caudate nucleus	R	16	4	20	22	3.43	*<0.001*

Parametric Modulation with Age covariate of interest (controlling for Reactive Aggression)

Increasing proximity to reward: negative relationship with age

Insula	R	36	-26	26	22	3.94	*<0.001*

Parametric Modulation with Reactive Aggression covariate of interest

Increasing proximity to reward: positive relationship with reactive aggression

Superior occipital gyrus	R	24	-76	24	448	4.63	*<0.001*
	R	38	-66	26			*<0.001*
	R	24	-86	22			*<0.001*
Hippocampus	L	-26	-34	8	238	4.39	*<0.001*
	L	-16	-38	4		3.68	*<0.001*
	L	-22	-26	6		3.66	*<0.001*
Inferior temporal gyrus	R	48	-64	-22	45	4.14	*<0.001*
Middle occipital gyrus	L	-36	-66	8	493	4.1	*<0.001*
	L	-26	-56	22		4.05	*<0.001*
	L	-34	-76	20		3.93	*<0.001*
Posterior cingulate gyrus	L	-8	-40	26	34	3.81	*<0.001*

Posterior cingulate gyrus	R	12	-42	26	54	3.75	*<0.001*
	R	18	-50	26		3.5	*<0.001*
Sensorimotor cortex	L	-36	-16	36	32	3.69	*<0.001*
Mid cingulate gyrus	L	-2	-18	26	22	3.59	*<0.001*
Mid cingulate gyrus	R	6	0	34	33	3.48	*<0.001*
	R	6	8	30		3.48	*<0.001*
Thalamus	L	-14	-18	22	28	3.48	*<0.001*
Caudate nucleus	L	-14	24	2	47	3.47	*<0.001*
Caudate nucleus	L	-10	20	8		3.33	*<0.001*
Lingual gyrus	R	8	-50	-6	20	3.44	*<0.001*
Cerebellum	R	4	-62	-4	35	3.43	*<0.001*
Parametric Modulation with Reactive Aggression covariate of interest (controlling for Age)							
Increasing proximity to reward: negative relationship with reactive aggression							
Insula	R	36	-26	26	17	3.70	*<0.001*
Parametric Modulation with quadratic Age covariate of interest							
Anterior orbital gyrus	R	20	46	-12	61	4.01	*<0.001*
Inferior frontal gyrus	L	-46	44	-8	55	3.58	*<0.001*

Whole brain results for the parametric modulation (1<2<3<4) contrasts. Results show brain regions surpassing a peak-level uncorrected threshold (*p≤.001, k>10*). L/R=laterality (left/right); peak voxel co-ordinates are reported in Montreal Neurological Institute (MNI) standard space; k=cluster size; z=z-value for peak voxel.

b) Whole brain results at an uncorrected threshold for the high versus low contrast, including covariates of age and reactive aggression.

Brain Region	**L/R**	**Peak Voxel**			**k**	**z**	**Peak** *p-value*
Whole Brain Results: High versus Low Contrast							
High>Low contrast							
High>Low (4>3=2=1)							
Calcarine fissure	R	14	-86	8	1395	5.39	*<0.001*
	R	18	-94	20		4.74	*<0.001*
	R	14	-70	-2		4.67	*<0.001*
Lingual gyrus	L	-12	-78	-4	853	5.21	*<0.001*
	L	-24	-76	-6		4.9	*<0.001*
	L	-20	-80	8		3.83	*<0.001*
Middle occipital gyrus	L	-30	-88	22	65	3.67	*<0.001*
Insula	L	-34	20	-12	20	3.52	*<0.001*
Insula	R	36	18	-10	35	3.46	*<0.001*
High>Low with Age covariate of interest							
High>Low: negative relationship with age							
Calcarine fissure	R	32	-64	4	11	3.74	*<0.001*
Caudate nucleus	R	16	0	22	37	3.69	*<0.001*
	R	20	6	18		3.41	*<0.001*
Thalamus⁺	L	-4	-34	12	16	3.66	*<0.001*
Fornix⁺		0	0	8	34	3.66	*<0.001*
Periaquaductal gray⁺	L	-8	-26	-14	16	3.42	*<0.001*
Amygdala	R	26	2	-16	11	3.37	*<0.001*

High>Low: positive relationship with reactive aggression

Middle temporal lobe⁺	L	-28	-40	8	11	3.40	*<0.001*

High>Low with quadratic Age covariate of interest

Superior temporal gyrus	R	66	-32	12	11	3.48	*<0.001*
Superior temporal gyrus	R	46	-30	14	17	3.40	*<0.001*
Cerebellum	R	10	-40	-36	17	3.33	*<0.001*

Whole brain results for the High>Low (4>3=2=1) contrasts. Results show brain regions surpassing a peak-level uncorrected threshold (*p≤.001, k>10*. L/R=laterality (left/right); peak voxel co-ordinates are reported in Montreal Neurological Institute (MNI) standard space; k=cluster size; z=z-value for peak voxel.

c) **Whole brain results at an uncorrected threshold for the blocked>win and win>blocked contrasts.**

Whole Brain Results: Blocked>Win Contrast								
Brain Region	**L/R**	**Peak Voxel**			**k**	**z**	**Peak *p-value***
Win>Blocked contrast							
Medial frontal gyrus, orbital	R	4	48	-10	5069	5.50	*<0.001*
	L	-14	36	-10		5.41	*<0.001*
	R	8	58	0		5.38	*<0.001*
Posterior cingulate cortex[+]	R	6	-52	4	4938	5.10	*<0.001*
	R	12	-50	22		4.72	*<0.001*
	R	8	-50	34		4.57	*<0.001*
Middle occipital gyrus	R	38	-80	10	857	4.30	*<0.001*
	R	46	-78	4		3.98	*<0.001*
	R	46	-54	20		3.89	*<0.001*
Cerebellum[+]	R	20	-34	-32	1086	4.18	*<0.001*
	R	16	-40	-28		4.09	*<0.001*
	L	-10	-24	-30		4.08	*<0.001*
Superior temporal gyrus	L	-48	-36	6	145	4.11	*<0.001*
	L	-42	-26	4		3.61	*<0.001*
Insula/Putamen[+]	R	28	-18	10	151	4.03	*<0.001*
	R	26	-4	12		3.43	*<0.001*
Superior frontal gyrus, dorsolateral	L	-20	28	42	116	4.01	*<0.001*
Superior frontal gyrus, dorsolateral	R	22	36	42	111	3.97	*<0.001*
Fusiform gyrus	R	34	-10	-32	24	3.75	*<0.001*
	R	42	-14	-30		3.18	*<0.001*
Putamen	L	-28	-12	8	69	3.72	*<0.001*
	L	-22	-12	-26	17	3.57	*<0.001*

	R	30	-60	-38	49	3.5	*<0.001*
	L	-54	-46	-12	19	3.46	*<0.001*

Whole brain results for the Blocked>Win and Win>Blocked contrasts. Results show brain regions surpassing a peak-level uncorrected threshold (*p≤.001, k>10*). L/R=laterality (left/right); peak voxel co-ordinates are reported in Montreal Neurological Institute (MNI) standard space; k=cluster size; z=z-value for peak voxel.

d) **Whole brain results at an uncorrected threshold for the blocked>baseline contrast from Appendix 5.**

Whole Brain Results: Blocked>Baseline Contrast							
Brain Region	**L/R**	**Peak Voxel**			**k**	**z**	**Peak *p-value***
Blocked>Baseline							
Mean activation							
Inferior frontal gyrus (oper)	L	-58	10	12	308	4.59	*<0.001*
	L	-50	14	22		3.68	*<0.001*
Mid cingulate cortex	R	6	16	44	255	4.55	*<0.001*
	L	-4	16	42		4.47	*<0.001*
	R	6	28	44		3.79	*<0.001*
Precentral gyrus	L	-44	2	36	64	4.1	*<0.001*
Middle temporal gyrus	R	48	-26	-6	95	4.09	*<0.001*
Angular gyrus	R	34	-46	38	34	3.92	*<0.001*
	R	46	-42	40		3.34	*<0.001*
Postcentral gyrus	R	54	-20	32	182	3.83	*<0.001*
	R	54	-32	42		3.75	*<0.001*
Supramarginal gyrus	L	-58	-42	34	59	3.78	*<0.001*
Anterior cingulate cortex	R	10	30	24	46	3.46	*<0.001*
	R	10	28	32		3.4	*<0.001*

Whole brain results for the Blocked>Baseline contrast. Results show brain regions surpassing a peak-level uncorrected threshold (*p≤.001, k>10*). L/R=laterality (left/right); peak voxel co-ordinates are reported in Montreal Neurological Institute (MNI) standard space; k=cluster size; z=z-value for peak voxel.

Appendix 7: Frustration, motivation and surprise

The behavioural data suggest a moderate correlation between self-report ratings of frustration, motivation and surprise, therefore to ensure that the fMRI results found were specific to the effects of frustration an additional second level model was analysed which explored how the neural response varied with stage blocked while controlling for the effect of overall mean motivation and overall mean surprise (collapsed across the four blocked conditions and based on self-report data). At the whole brain level, controlling for motivation revealed small changes in cluster size, z-value of the peak and peak voxels, but no differences in which regions showed significant activation at the FWE-corrected threshold. At the uncorrected threshold, there was one additional cluster of activation in the middle temporal gyrus (*peak voxel= -42 -62 12, k=10, z=3.37, peak p<.001*). Controlling for surprise also revealed small changes in cluster size, z-value of the peak and peak voxels but no differences in which regions showed significant activation at either FWE-corrected or uncorrected thresholds. Similarly, ROI analyses of the model controlling for motivation or surprise did not alter the results but revealed the same ROIs to show significant BOLD signal increase; ACC and MCC.