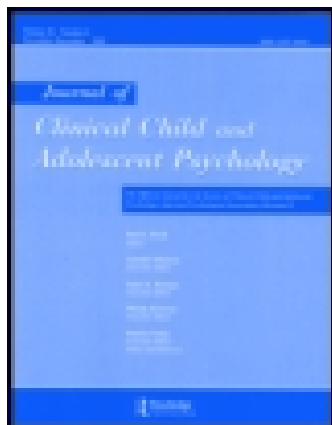


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Reduced Hedonic Capacity/Approach Motivation Relates to Blunted Responsivity to Gain and Loss Feedback in Children

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Adolescents and adults with major depressive disorder or elevated depressive symptoms show reduced reward responses and tend to show enhanced responses to negative stimuli. However, reward-related behaviors and adaptive responses to negative feedback undergo dramatic changes across puberty. Thus, key questions remain regarding how altered incentive processing relates to depressive and anhedonic symptoms in prepubertal child populations. Twenty-four nonclinical prepubertal children 7–10 years of age (15 male; 16 Caucasian) completed two signal detection tasks that assessed behavioral responsivity to candy gain and loss feedback, respectively. These tasks were based on Pizzagalli's probabilistic reward task where asymmetric feedback leads to greater bias toward the more frequently rewarded response in more hedonic or nondepressed adults. We further modified the task to create a version where incorrect responses could result in losses from an original allotment of candy. Children and parents/guardians also completed individual difference questionnaires to assess the child's depressive symptoms, general affect, and hedonic capacity/approach motivation. Regressions indicated a relation between hedonic capacity/approach motivation (child self-report) and response bias in both gain and loss tasks. No significant relations were observed between depressive (child self-report), internalizing (parent report), or externalizing symptoms (parent report) and bias in either the gain or loss task in this small sample. These results suggest that reduced hedonic capacity/approach motivation is associated with blunted responses to both gain and loss feedback in prepubertal children.

The relation between major depressive disorder (MDD) and blunted response to reward has been consistently documented both in adult and adolescent MDD literatures (for recent reviews, see Auerbach, Admon, &

Pizzagalli, 2014; Bogdan, Nikolova, & Pizzagalli, 2013; Eshel & Roiser, 2010; Forbes & Dahl, 2012; Treadway & Zald, 2011). Behavioral and neural responses to reward are similarly reduced in adults/adolescents without current clinically diagnosed depression but with elevated depressive symptoms or at elevated risk for developing depression (Bress, Smith, Foti, Klein, & Hajcak, 2012; Kujawa, Proudfit, & Klein, 2014; McCabe, Woffindale, Harmer, & Cowen, 2012; Pizzagalli, Jahn, &

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O'Shea, 2005). Conversely, *enhanced* responses to incentive loss and negative affective stimuli have been reported in adults and adolescents with clinically diagnosed depression, elevated depressive symptoms, or elevated risk for developing MDD (Elliott, Sahakian, Herrod, Robbins, & Paykel, 1997; Gotlib et al., 2010; Holmes & Pizzagalli, 2007; McCabe, Cowen, & Harmer, 2009; Monk et al., 2008; Santesso, Steele, et al., 2008). However, reward-related behaviors, adaptive response to negative feedback, and incidence of mood pathology undergo dramatic changes from childhood to adulthood (Crone, Zanolie, Van Leijenhorst, Westenberg, & Rombouts, 2008; Galvan, 2010; Geier & Luna, 2009; Kessler et al., 2005; Luking, Luby, & Barch, 2014; Richards, Plate, & Ernst, 2013; van den Bos, Cohen, Kahnt, & Crone, 2012; van Duijvenvoorde, Zanolie, Rombouts, Raijmakers, & Crone, 2008). Thus, key questions remain regarding how altered incentive processing relates specifically to self-reported hedonic capacity and other depressive symptoms within prepubertal child populations.

Anhedonia, the lack of experienced pleasure, is a key symptom of MDD (American Psychiatric Association, 2013). Findings of reduced responsivity to reward in adults with MDD and healthy adults with elevated anhedonic/depressive symptoms are consistently observed across many task types and components of incentive processing (Dowd & Barch, 2010; Pizzagalli et al., 2009; Santesso, Dillon, et al., 2008; Schaefer, Putnam, Benca, & Davidson, 2006; Sloan, Strauss, Quirk, & Sajatovic, 1997; Treadway, Bossaller, Shelton, & Zald, 2012; Treadway, Buckholtz, Schwartzman, Lambert, & Zald, 2009). The probabilistic reward task developed by Tripp and Alsop (1999) and used extensively by D. A. Pizzagalli, and others has proven to be a valuable tool for evaluating behavioral shifts driven by reward. In this task, one of two responses receives reward feedback more frequently; this asymmetry typically induces bias toward the more frequently rewarded response. However, individuals with elevated anhedonic depressive symptoms (Pizzagalli et al., 2005), current MDD (Pizzagalli, Iosifescu, Hallett, Ratner, & Fava, 2008), and remitted depression (Pechtel, Dutra, Goetz, & Pizzagalli, 2013) show less of this response bias, indicating reduced behavioral responsivity to reward. Reduced response to reward is similarly well documented across experimental modalities in the adolescent MDD literature (for recent reviews, see Auerbach et al., 2014; Forbes & Dahl, 2012). Adolescents with MDD or elevated depressive symptoms are less able to use reward contingencies to improve performance (via cognitive control; Hardin, Schroth, Pine, & Ernst, 2007; Jazbec, McClure, Hardin, Pine, & Ernst, 2005), are less sensitive to incentive magnitude (Forbes, Shaw, & Dahl, 2007), and show reduced neural responsivity to reward

feedback (Bress et al., 2012; Forbes et al., 2006; Forbes et al., 2010).

Within negative affective domains the effects of MDD/depressive symptoms are more mixed. The negative potentiation theory of emotion reactivity in MDD suggests that reactivity to negative stimuli is enhanced as negative mood states prime cognitive and attention biases toward congruent stimuli (Beck, 1976; Scher, Ingram, & Segal, 2005). There is experimental evidence supporting this hypothesis both within the basic neuroscience literature and in patient groups. For example, amygdala reactivity to negative stimuli is enhanced following induction of negative mood states (Berna et al., 2010; Wang, LaBar, & McCarthy, 2006), and MDD/high-risk groups, members of which experience greater negative mood relative to control/low-risk groups, tend to show *enhanced* behavioral/neural responsivity to negative pictures/feedback (Elliott et al., 1997; Foland-Ross et al., 2013; Gotlib et al., 2010; Hamilton & Gotlib, 2008; Holmes & Pizzagalli, 2007; Kellough, Beevers, Ellis, & Wells, 2008; Ladouceur et al., 2005; McCabe et al., 2012; Monk et al., 2008; Santesso et al., 2012; Santesso, Steele, et al., 2008; Tucker, Luu, Frishkoff, Quiring, & Poulsen, 2003). However, this effect is not universal, and other theories, such as Emotion Context Insensitivity (ECI), hypothesize a general *reduction* in reactivity to both positive and negative stimuli in MDD (Rottenberg, 2007; Rottenberg, Gross, & Gotlib, 2005). A recent meta-analysis of studies investigating emotional reactivity in MDD by Bylsma, Morris, and Rottenberg (2008) reports significantly *blunted* reactivity to both negative and positive stimuli in MDD across studies. Further support for ECI is provided by studies specifically investigating anhedonic symptoms within the incentive literature. These studies report *blunted* behavioral and neural responsivity to both positive and negative incentives in individuals with elevated anhedonia in patient and control groups (Chase et al., 2010; Dowd & Barch, 2010; J. D. Steele, Kumar, & Ebmeier, 2007; Stoy et al., 2012). As no studies, to our knowledge, have investigated how responsivity to loss of incentive relates to MDD or anhedonic symptoms specifically in children, it is unclear whether potentiated or blunted responses to loss/negative stimuli will be observed with elevated symptoms at these ages.

Although relations between MDD and responsivity to affective stimuli/incentive feedback are strikingly similar in the adolescent and adult literatures, normative responses to positive and negative incentives change dramatically from childhood through adulthood. These developmental changes may impact how depressive symptoms relate to gain and loss responsivity in prepubertal populations relative to adolescents and adults. From a typical developmental standpoint, adolescents

show markedly elevated sensitivity to reward relative to both children and adults, who tend to show similar responses to reward (Galvan et al., 2006; Luking et al., 2014; Paulsen, Carter, Platt, Huettel, & Brannon, 2012; Richards et al., 2013; van den Bos et al., 2012). Conversely, emerging evidence suggests that children are particularly reactive to loss/negative feedback relative to adults and adolescents (Luking et al., 2014; van den Bos et al., 2012; van Duijvenvoorde et al., 2008; van Leijenhorst, Crone, & Bunge, 2006). Thus, it seems especially important to investigate responding to both gains and losses in prepubertal populations, as loss may be a particularly powerful domain for detection of individual difference relations in this age group.

It is also important to note that although we have chosen to focus on MDD/depressive symptoms to motivate the current study, altered responsivity to incentives and anhedonia play prominent roles in psychopathology beyond MDD. For example, behavior on the probabilistic reward task also relates to attention deficit/hyperactivity disorder (ADHD) in children (Tripp & Alsop, 1999), bipolar disorder in adults (Pizzagalli, Goetz, Ostacher, Iosifescu, & Perlis, 2008), and comorbid MDD and substance abuse in adolescents (Boger et al., 2014). Altered responsivity to incentives is also observed in schizophrenia (Dowd & Barch, 2012; Heerey, Bell-Warren, & Gold, 2008), disordered eating (Loxton & Dawe, 2001), oppositional defiant disorder (Humphreys & Lee, 2011), and anxiety (Bress, Meyer, & Hajcak, 2013; Johnson, Turner, & Iwata, 2003). Further, patterns of gain/loss sensitivity within diagnostic (risk) groups often differ depending on comorbid disorders (e.g., Humphreys & Lee, 2011; Kujawa et al., 2014). Given these relations, and that relative incidence of types of pathologies change over development (i.e., age of onset for anxiety disorders is earlier than for MDD and incidence of anxiety disorders is greater than that of MDD, particularly in childhood; Kessler et al., 2005), we take care to control for both externalizing (indexing ADHD, oppositional defiant, and conduct disorder symptoms) and internalizing (indexing anxiety and depression) symptoms in our analyses although our hypotheses center on depressive symptoms.

While gain and loss behaviors relate to depressive symptoms even within non-clinical populations from adolescence onward, how such behaviors relate to depressive symptoms and hedonic capacity during childhood remains an important open question. Thus, the current study aims to investigate such relations while controlling for other types of symptoms related to gain/loss processing (i.e., internalizing and externalizing). To assess gain responsivity, children completed a modified version of the probabilistic reward task used extensively in the adult depression literature (Pizzagalli, Iosifescu, et al., 2008; Pizzagalli et al., 2005), where children earned

candy following some correct responses. To assess loss responsivity, a second modified version of the traditional task was completed in which children lost candy from an original allotment following some incorrect responses. Although we operationalize gain responsivity and loss responsivity as the tendency of such feedback to influence behavior and investigate each separately, it is important to note that neural systems responsive to gain and loss and involved in approach/avoidance behaviors are not entirely unique (Delgado, Nystrom, Fissell, Noll, & Fiez, 2000; Delgado, Stenger, & Fiez, 2004; Knutson, Westdorp, Kaiser, & Hommer, 2000). Thus, gain and loss responsivity are not necessarily orthogonal. However, as previous literature using the probabilistic reward task focuses on responsivity to gain, and different symptom types (e.g., internalizing vs. externalizing) relate differentially to reward/punishment sensitivity, we form separate hypotheses for gain and loss responsivity.

The adult probabilistic reward task literature clearly points to reduced responsivity to gain feedback in individuals with MDD or elevated anhedonic depressive symptoms (Huys, Pizzagalli, Bogdan, & Dayan, 2013; Pizzagalli, Iosifescu, et al., 2008, Pizzagalli et al., 2005). Thus, we hypothesize that reduced self-reported hedonic capacity or elevated depressive symptoms will relate to reduced behavioral responsivity to gain feedback in our child sample. Further, given evidence of blunted responsivity to negative stimuli with elevated anhedonic depressive symptoms or reduced hedonic capacity in adults, we expect lower self-reported hedonic capacity/approach motivation (HC/AM) to similarly relate to lower loss responsivity in our prepubertal sample. The adult MDD literature has been inconsistent in regards to how general depressive symptoms relate to loss responsivity. Further, different conceptual models of negative stimuli processing in MDD make different predictions, with ECI predicting blunted responsivity to negative stimuli/feedback and negative potentiation predicting enhanced responsivity to negative stimuli/feedback, with neither model having been examined in children. Therefore, it is unclear whether or how general depressive symptoms will relate to behavioral loss sensitivity.

METHOD

Participants

Twenty-eight children along with a parent/guardian participated in this study. Two children were unable to understand and follow instructions for the behavioral tasks, and two adults failed to complete reports on the child; thus, four children are excluded from analyses. The remaining 24 children were 7–10 years of age

($M=8.21$, $SD=0.98$) and were predominately male ($n=15$; 62.5%) and Caucasian ($n=16$; 66.7%). All children were prepubertal, established via parent/guardian Pubertal Staging Questionnaire reports (Carskadon & Acebo, 1993; Petersen, Crockett, Richards, & Boxer, 1988). A history of diagnosed mental illness, either for the child or immediate family members (adult report), and an inability to consume sugar or dislike of sweet candies served as exclusion criteria. Despite a lack of reported preexisting diagnoses (no clinical interviews were conducted), parent reports of internalizing/externalizing behaviors on the Child Behavior Checklist (CBCL) fell within the “borderline to clinical” range for five children (Achenbach, 1991). Thus, we characterize the sample as “nonclinical” rather than “healthy.”

Participants were recruited from the St. Louis, Missouri, metropolitan area via the research participant registry at Washington University in St. Louis. Adults completed a phone screen to determine the children’s eligibility prior to enrolling in the study. Parents/guardians provided written informed consent, and children provided written assent at the beginning of the in-person assessment. The Washington University in St. Louis Institutional Review Board approved all study procedures.

Procedure

On the study day, adults provided consent and completed questionnaires in an adjacent room. Before beginning behavioral tasks, children tasted two candy pieces of their choice (M&M’s or Skittles) and rated how much they liked the candy. Two children reported liking the candy “moderately,” four reported “quite a bit,” and 18 reported “extremely” (response options also included “not at all” and “a little”). Next, children completed two versions of a modified probabilistic incentive learning task (PILT) based on Heerey et al. (2008), Pizzagalli et al. (2005), and Tripp and Alsop (1999)—one where small candy pieces could be gained (PILT-Positive) (Figure 1A) and another where candy could be lost (PILT-Negative) (Figure 1B) from an original allotment (the order of PILT-P/PILT-N was counterbalanced across participants). Between the two PILTs, children completed several individual difference questionnaires with the assistance of the experimenter. Finally, children completed a posttest questionnaire where they rated affective responses to winning/losing candy.

Individual difference measures. Adults completed the CBCL (Achenbach, 1991), parent report version of the Child Depression Inventory (CDI-P; Kovacs, 1985), and a demographics form. Children completed self-report forms designed to assess depressive symptoms

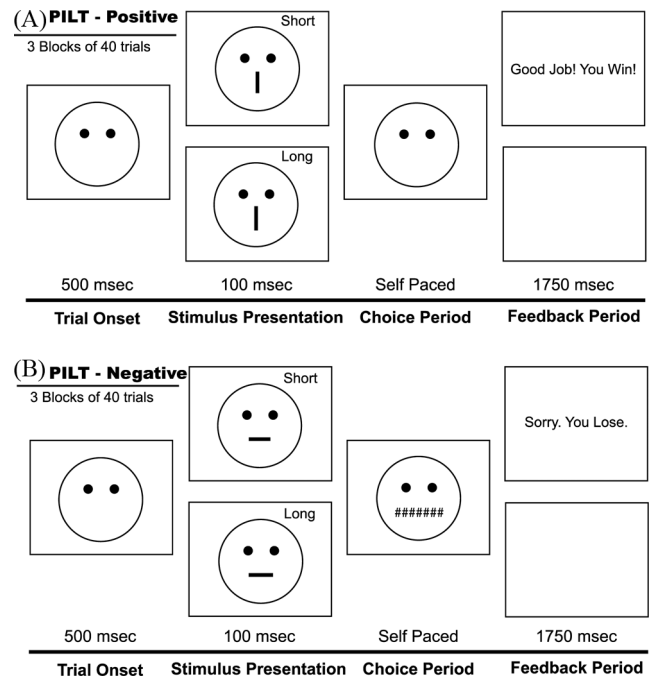


FIGURE 1 Probabilistic incentive learning task (PILT) schematics for (A) positive and (B) negative task versions.

(CDI-C; Kovacs, 1985; Short Mood and Feelings Questionnaire; Angold et al., 1995), general affect (child version of the Positive and Negative Affective Scale [PANAS-C]; Laurent et al., 1999), and hedonic capacity or reward/punishment sensitivity (modified version of the Child Pleasure Scale [CPS]; Kazdin, 1989; child version of the Behavioral Inhibition/Behavioral Activation Scales; Muris, Meesters, de Kanter, & Timmerman, 2005). See Table 1 for descriptive statistics.

The PANAS-C has positive and negative affective subscales. The Positive Affect scale comprises 15 positive words (e.g., *happy*, *interested*, *energetic*). Children rate the extent to which they experience that emotion; responses range from 1 (*very slightly or not at all*) to 5 (*extremely*), and responses are summed to create a total score. The Positive Affect scale shows good internal consistency (0.89) and construct validity in that it negatively relates to depressive symptom severity (Laurent et al., 1999).

The CPS consists of 30 items such as “You are eating your favorite ice cream,” “Your teacher tells you and your parents what a terrific student you are,” and “Your mother/father gives you a big hug”; the child rates how happy he or she would feel in that situation (1 = *not at all*, 2 = *happy*, 3 = *very happy*). CPS responses are summed to create a total score. The CPS shows adequate internal consistency ranging from 0.91 to 0.96 and criterion validity, that is, children with diagnosed MDD show significantly lower scores on the CPS than children not diagnosed with depression (Kazdin, 1989; R. G. Steele, Phipps, & Srivastava, 1999).

TABLE 1
Descriptive Statistics for Individual Difference Measures

Questionnaire	Scale	Range	<i>M</i>	<i>SD</i>	Cronbach's α	Coefficient of Variation (<i>Mdn Centered</i>)
Child Behavior Checklist	Internalizing <i>T</i> score	34–64	48.79	8.71	0.77	20.5%
	Externalizing <i>T</i> score	33–64	48.75	8.87	0.83	20.2%
Child Depression Inventory	Child Report Total <i>T</i> score	35–54	43.58	5.09	0.70	11.6%
Positive and Negative Affect Scales	Positive Affect subscale	48–72	60.83	7.56	0.778	12.5%
Behavioral Inhibition/Behavioral Activation Scales	Behavioral Activation Scale	30–51	38.92	6.28	0.87	17.2%
Child Pleasure Scale	Total score	30–59	45.67	8.07	0.87	17.6%
Hedonic Capacity/Approach Motivation Composite Score		–4–4	0.00	2.39		

The BAS component of the Behavioral Inhibition/Behavioral Activation Scales consists of 13 items such as “I get thrilled when good things happen to me,” “I get very excited when I would win a contest,” “When I see an opportunity to get something that I want, I go for it right away.” Responses range from 1 (*very true for me*) to 4 (*very false for me*); responses are reverse scored and summed to create a total score. Muris et al.’s (2005) BAS has shown adequate internal consistency (0.81) and criterion validity in children, relating to personality traits associated with elevated reward responding.

The CDI-C consists of 27 sets of items designed to assess different depressive symptoms. Responses on each item set are rated on a scale from 0 to 2 such that higher values indicate greater severity (e.g., 0 = *I have fun in many things*, 1 = *I have fun in some things*, 2 = *Nothing is fun at all*). Items are summed to produce a total score; age and gender normed *t*-scored total scores are used in the current study. Internal consistencies have been reported from .71 to .94; test–retest reliability is very good ranging from .66 to .90 and shows strong construct validity in a number of studies (Kovacs, 1985; Saylor, Finch, Spirito, & Bennett, 1984; Sitarenios & Kovacs, 1999).

The CBCL consists of 118 items describing behavioral problems such as “Feels he/she has to be perfect,” “Nervous, high-strung, or tense,” and “Sets fires.” The parent then rates on a 3-point scale, from 0 (*not at all true*) to 2 (*true or often*), the extent to which each item was true for the child in the past 6 months. Items are summed to create Internalizing (Anxious = Depressed, Withdrawn, and Somatic Complaints) and Externalizing (Aggressive and Destructive) Problems subscales; age and gender normed *t*-scored totals for each subscale are used in the current study. Internalizing and Externalizing Problems subscales show excellent internal consistency and test–retest reliability, both greater than .90 for each subscale, as well as strong construct validity (Achenbach 1991; Nakamura, Ebesutani, Bernstein, & Chorpita, 2009).

All measures were developed specifically for use in the respective population (either child or parent report) and have shown adequate internal consistency and validity. Specifically, within the current sample Cronbach’s alpha (Table 1) was above or near the .7 rule-of-thumb cutoff, which indicates adequate internal consistency.

Given the conceptual relation between hedonic capacity (CPS), approach motivation (BAS), and positive affect (PANAS-P), strong intercorrelation among measures (CPS and BAS), $r(28) = 0.45$, $p = .017$; CPS and PANAS-P, $r(27) = 0.48$, $p = .012$; BAS and PANAS-P, $r(27) = 0.54$, $p = .004$; and the lack of an a priori hypothesis regarding a specific questionnaire/scale versus another, *Z*-scored total scores from the CPS, BAS, and PANAS-P were summed to create a composite score, HC/AM, where greater values indicate greater HC/AM.

Probabilistic incentive learning tasks. We employed a modified version of the probabilistic reward task developed by Heerey et al. (2008), Pizzagalli et al. (2005), and Tripp and Alsop (1999) termed the PILT-Positive (PILT-P) to assess reward sensitivity (Figure 1A). To make the task more child friendly we utilized small candy pieces rather than money as the incentive and reduced the number of trials relative to previous studies. As in previous versions of this task, either a short or long nose/mouth is briefly presented within a cartoon face (stimuli are presented in a pseudorandom order—50% long trials, 50% short trials). Participants then indicate which stimulus was presented via button press. During the PILT-P, a portion of correct responses are followed by gain feedback indicating one candy piece was won. Remaining correct, and all incorrect, responses are followed by a blank screen. Of importance, this intermittent gain feedback is delivered asymmetrically such that one of the two responses (deemed the “RICH” response) is scheduled to receive gain feedback 3 times more often than the alternative “LEAN” response. Whether the RICH response corresponded to the right or left button and whether that button indicated the

short or long stimulus was counterbalanced across participants. Participants were not informed that one response would selectively receive more feedback; however, they were aware that not all correct responses would receive gain feedback.

To assess behavioral sensitivity to loss of reward, we further modified the PILT to deliver loss feedback; the loss version of the task is termed PILT-Negative (PILT-N). A perceptual mask (row/column of pound signs) replaced the nose/mouth stimulus to decrease task accuracy (PILT-P M accuracy = 70.5%, SD = 8.2%; PILT-N M accuracy = 55.3%, SD = 6.6%). This was necessary to ensure a sufficient number of trials in which to provide loss feedback. All other task parameters remained the same, except now feedback followed a portion of incorrect responses, again in an asymmetric fashion, and feedback indicated that one candy piece would be lost from an original allotment of 70 candy pieces.

Before beginning each of the PILT tasks, children performed 20 practice trials followed by three 40-trial task blocks. Within each task block, 12 (in)correct RICH responses and four (in)correct LEAN responses were selected to receive candy feedback (loss/gain respectively). Between each block the child and experimenter stood and stretched for approximately 30 s.

Data Processing

Individual trials were excluded from analysis either if reaction time (RT) did not fall within $\pm 3 SD$ of a participants' mean RT or if RT did not fall between 2,500 and 150 ms (Pizzagalli et al., 2005). On average, less than 5% of trials within a task were excluded for a given subject based on RT criteria. General task performance and responsiveness to incentive feedback were examined via discriminability ($\log d$) and response bias ($\log b$) statistics respectively. $\log b/d$ were calculated as in previous PILT studies, using all trials in a block (40 here) and adding 0.5 to the number of each of the four event types (Pizzagalli et al., 2005). Greater values for $\log d$ indicate better discrimination between the short and long stimuli. More positive response bias values indicate a greater propensity to select the RICH button response, whereas more negative values indicate a greater shift away from making the RICH button response.

Discriminability ($\log d$)

$$= \frac{1}{2} \log \left(\frac{\text{RICHcorrect} * \text{LEANcorrect}}{\text{RICHincorrect} * \text{LEANincorrect}} \right)$$

Response Bias ($\log b$)

$$= \frac{1}{2} \log \left(\frac{\text{RICHcorrect} * \text{LEANcorrect}}{\text{RICHincorrect} * \text{LEANincorrect}} \right)$$

RESULTS

Response Bias in the PILT-P and PILT-N

To determine whether response bias changed across the PILT-P/N, a repeated measures analysis of variance was conducted for each task with Block (1, 2, 3) as the repeated measure and response bias was the dependent variable. One-sample t tests were conducted to determine whether bias at the end of the task (Block 3) differed from zero for the PILT-P and PILT-N.

For the PILT-P, bias in B3 differed from zero, $t(23) = 3.01$, $p = .006$, such that participants as a whole tended to select the rich response more frequently than the lean response. Further, response bias increased across the task as a function of block, $F(2, 23) = 3.21$, $p = .049$ (Figure 2). For the PILT-N, bias in B3 significantly differed from zero, $t(23) = -3.72$, $p = .001$, such that participants as a whole selected the rich response, more frequently followed by loss feedback, *less* frequently than the lean response. Bias also became more negative across the task as a function of block, $F(2, 23) = 4.54$, $p = .016$ (Figure 2).

Relations Between Task Order/Stimuli and Discriminability

Univariate analyses of variance were conducted to determine whether mean discriminability during the PILT-P and PILT-N differed based on PILT-P order (first or second), PILT-P stimulus (mouth or nose), or the interaction of order and stimulus. Mean discriminability in the PILT-P and PILT-N did not vary as a function of either PILT-P order or stimulus type (all $p > .17$).

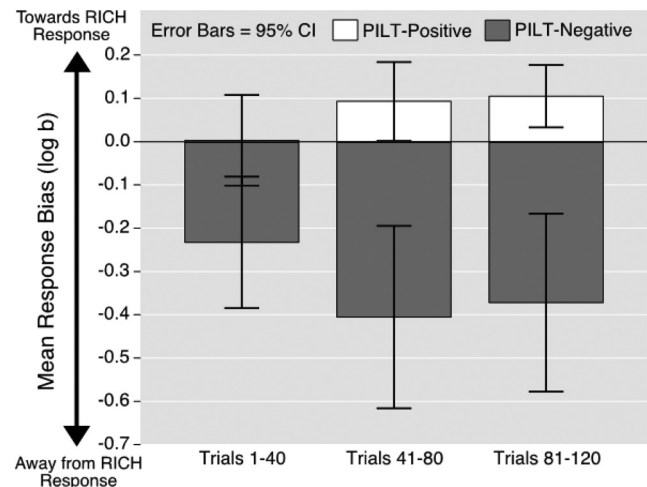


FIGURE 2 Response bias across the probabilistic incentive learning task (PILT)-Positive (white bars) and PILT-Negative (gray bars).

TABLE 2
Intercorrelations Among Predictors

Measure	1	2	3	4	5	6	7
1. CDI-C Total <i>t</i> Score							
2. CBCL Internalizing Subscale	0.05 (.82)						
3. CBCL Externalizing Subscale	0.08 (.73)	0.64 (<.01)					
4. Hedonic Capacity/Approach Motivation	0.14 (.51)	0.01 (.95)	0.06 (.77)				
5. PILT-P Response Bias in Block 3	0.07 (.76)	0.09 (.67)	-0.22 (.30)	0.42 (.04)			
6. PILT-P Change in Response Bias: Block 3-Block 1	0.50 (.01)	-0.02 (0.93)	0.06 (.78)	0.03 (.90)	0.08 (.70)		
7. PILT-N Response Bias in Block 3	0.22 (.31)	-0.11 (.60)	-0.39 (.06)	-0.42 (.04)	-0.24 (.26)	0.24 (.27)	
8. PILT-N Change in Response Bias: Block 3-Block 1	-0.07 (0.74)	-0.17 (.42)	-0.37 (.08)	-0.61 (<.01)	-0.19 (.38)	0.11 (.61)	0.68 (<.01)

Note: Pairwise correlations between dependent variables and predictors in regression analyses; *r* (*p* value). CDI-C = Child Depression Inventory-Child Version, total *t*-score reported; CBCL = Child Behavior Checklist, total *t* scores reported; PILT-P = PILT-Positive; PILT-N = PILT-Negative.

Relations Between Response Bias and Individual Difference Measures

Four regressions were conducted to assess relations between response bias and task order/stimulus type, depressive symptoms (CDI-C *t* score), internalizing symptoms (CBCL subscale *t* score), externalizing symptoms (CBCL subscale *t* score), and HC/AM. Internalizing and externalizing subscales were chosen because each indexes a number of symptoms (e.g., internalizing subscale assesses both anxious and depressive symptoms), balancing the need to control for symptoms that show relations with gain/loss responsivity with the need to maximize degrees of freedom.

Dependent measures included response bias in Block 3, and "bias change" or the difference in Block 3 and Block 1 response bias (B3 - B1), for both gain and loss

tasks. A Bonferroni correction ($0.05/4 = 0.0125$) was used to determine significance within regression analyses testing our hypotheses.

Tests for multicollinearity indicated that a very low level of multicollinearity was present (variance inflation factor [VIF] = 1.8 for Internalizing *T* score; VIF = 1.7 for Externalizing *T* score; VIF < 1.2 for all other variables). See Table 2 for bivariate correlations between all predictors and dependent variables.

PILT-P

Task order, stimulus type, CDI-C *t* score, Externalizing *t* score, and Internalizing *t* score were all nonsignificant predictors in both PILT-P regressions (Table 3). HC/AM significantly positively predicted PILT-P bias during Block 3

TABLE 3
Regressions Predicting Task Behavior

Dependent Variable	Predictors	PILT-Positive				PILT-Negative			
		R ²	Adj. R ²	Std. Beta	F/ <i>t</i> Statistic	R ²	Adj. R ²	Std. Beta	F/ <i>t</i> Statistic
Response Bias (Block 3)	Model Statistics	0.49	0.31		2.73 (<i>p</i> = .05)	0.47	0.28		2.47 (<i>p</i> = .07)
	Task Order			0.39	2.04			-0.04	-0.19
	PILT-P Stimulus			-0.16	-0.91			0.20	1.07
	CDI-C			0.10	0.55			0.27	1.49
	CBCL Internalizing			0.30	1.29			0.21	0.88
	CBCL Externalizing			-0.52	-2.289			-0.55	-2.35
	HC/AM			0.51*	2.81*			-0.42	-2.26
Response Bias Change (B3-B1)	Model Statistics	0.43	0.23		2.15 (<i>p</i> = .10)	0.49	0.30		2.67 (<i>p</i> = .05)
	Task Order			-0.38	-1.88			<0.01	0.01
	PILT-P Stimulus			-0.23	-1.23			-0.01	-0.07
	CDI-C			0.49	2.56			0.04	0.23
	CBCL Internalizing			0.05	0.18			0.08	0.32
	CBCL Externalizing			0.13	0.53			-0.38	-1.66
	HC/AM			-0.15	-0.76			-0.59*	-3.28*

Note: Regression Analyses with task properties, depressive/internalizing/externalizing symptoms, and hedonic capacity/approach motivation (HC/AM) predicting PILT-Positive (PILT-P) and PILT-Negative response bias (in Block 3 and difference in response bias between Block 3 and Block 1 [B3-B1]). CDI-C = Child Depression Inventory-Child Version; CBCL = Child Behavior Checklist; Std. = standardized.

**p* < .0125.

indicating that children with lower HC/AM show less bias toward the more frequently rewarded RICH response at the end of the PILT-P (Table 3; Figure 3). HC/AM was not a significant predictor of PILT-P bias change.

PILT-N

Again, task order, stimulus type, CDI-C *t* score, Externalizing *t* score, and Internalizing *t* score were all nonsignificant predictors in both PILT-N regressions (Table 3). HC/AM significantly negatively predicted PILT-N bias change, indicating that less hedonic children were less able to shift bias away from the more frequently punished RICH across the PILT-N (Table 3; Figure 3). HC/AM was not a significant predictor of PILT-N Block 3 bias.

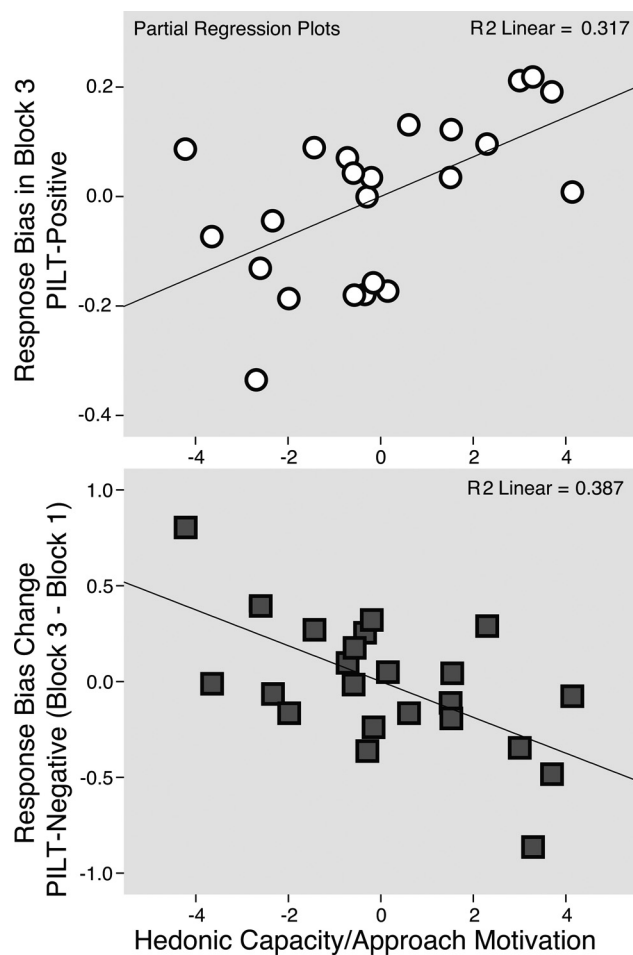


FIGURE 3 Partial regression plots of Hedonic Capacity/Approach Motivation (HC/AM) with response bias in Block 3 of probabilistic incentive learning task (PILT)-Positive (white circles) and change in response bias across PILT-Negative (gray squares) controlling for PILT-P order/stimulus and depressive symptoms, internalizing symptoms, and externalizing symptoms. *Note:* Results indicate greater responsivity to both gain and loss feedback in children with elevated HC/AM.

Qualitatively similar patterns of relations between behavior and predictors were observed for both the PILT-P and N when child's sex and parent reports of child anxiety and depressive symptoms from the CBCL were included as separate predictors (in place of combined "internalizing" symptoms).

HC/AM Post Hoc Analyses

Given the relation observed between response bias and HC/AM, additional post hoc correlations were run to determine whether HC/AM was related to amounts of feedback, ratio of rich to lean feedback, and mean discriminability during the two tasks. For both the PILT-P and PILT-N, HC/AM was not significantly related to (a) amount of feedback, PILT-P $r(22) = -.18, p = .386$; PILT-N $r(22) = -.06, p = .768$; (b) ratio of rich to lean feedback events, PILT-P $r(22) = .12, p = .573$; PILT-N $r(22) = .22, p = .305$; or (c) mean discriminability, PILT-P $r(22) = -.25, p = .235$; PILT-N $r(22) = -.13, p = .546$. Thus, relations between HC/AM and response bias were not likely driven by participants with high/low HC/AM experiencing differing amounts of feedback/ratio of that feedback or showing differing ability to distinguish long/short stimuli.

DISCUSSION

This goal of this study was to examine how behavioral responsivity to gain and loss feedback relates to hedonic capacity/approach motivation and dimensional subclinical depressive symptoms within a nonclinical prepubertal child sample. To do so we developed child-friendly gain and loss versions of a signal detection task that has been well studied in the adult literature. Like in adult studies, children in the current study learned to preferentially select the response paired more frequently with candy gain during the PILT-P (Pizzagalli, Iosifescu, et al., 2008; Pizzagalli et al., 2005). In the PILT-N, children successfully learned to shift behavior away from the response more frequently followed by candy loss. Of interest, the degree of these behavioral shifts related to hedonic capacity/approach motivation such that less hedonic children showed blunted response bias in both the PILT-P and PILT-N.

The current finding of reduced responsivity to gains in children with lower hedonic capacity/approach motivation is conceptually consistent with the adult literature where during this task, individuals with depression or elevated anhedonic depressive symptoms show reduced reward responsivity (Huys et al., 2013; Pizzagalli, Goetz, et al., 2008; Pizzagalli, Iosifescu, et al., 2008; Pizzagalli et al., 2005). This result has several important clinical

and developmental implications. First, the PILT-P seems to be a useful tool for assessing a child's ability to adaptively respond to incentive feedback, mirroring the utility of monetary versions of the same task in adults. Second, nonclinical prepubertal child populations are able to report on levels of hedonic capacity/approach motivation in a way that meaningfully relates to behavior. Third, given the similarity between these findings in prepubertal children and those in adults, it is likely that the mechanisms subserving relations between individual differences in reward responsivity and hedonic capacity/approach motivation are similar across development, although longitudinal studies investigating the trajectory of such behavior/individual difference relations across development are needed. Finally, although other studies using combined child/adolescent groups have reported relations between general depressive symptoms and reduced neural responsivity to rewards versus losses (Bress, Foti, Kotov, Klein, & Hajcak, 2013; Bress et al., 2012), this is the first study, to our knowledge, in a nonclinical prepubertal sample demonstrating a relation between reduced response to reward and lower hedonic capacity/approach motivation specifically.

In the PILT-N children with lower hedonic capacity/approach motivation showed reduced shifts in behavior away from the more frequently punished response, that is, reduced loss avoidance behavior. Overall this finding, in conjunction with results from the PILT-P, supports a pattern of blunted responsivity to valenced incentive feedback, positive or negative, in children with lower hedonic capacity. Although no adult studies using an individual differences approach have investigated responsivity to loss using similar signal detection tasks, adult neuroimaging studies also observe blunted responses to negative/positive stimuli with elevated levels of anhedonia (Chase et al., 2010; Dowd & Barch, 2010; J. D. Steele et al., 2007). This pattern is also reported in adolescents/children for whom elevated depressive symptoms or a maternal history of MDD (but not anxiety disorder) relate to reduced differentiation in neural responses to gain and loss feedback, a finding conceptually consistent with "blunted" response to valenced feedback (Bress et al., 2012; Kujawa et al., 2014). Although our results indicating that blunted loss responsivity are consistent with those of the adult anhedonia literature and child/adolescent depressive symptom/risk literature, studies comparing behavior in adult MDD groups to healthy controls during similar signal detection tasks with loss have either yielded null results or suggested enhanced responsivity in depressive groups (Henriques & Davidson, 2000; Henriques, Glowacki, & Davidson, 1994; Santesso, Steele, et al., 2008).

Likely explanations for the mixed findings in the adult literature and differences from the current study include the use of individual difference versus clinical/control group comparisons and heterogeneity within clinical

groups. MDD is a heterogeneous disorder, and patients can present with depressed mood or anhedonia, or both (American Psychiatric Association, 2013), and MDD often co-occurs with other disorders (such as substance use and anxiety disorders) that have also been linked to disrupted incentive processing as discussed in the introduction. Other studies investigating gain/loss sensitivity note qualitatively different patterns of responsivity across groups depending on these comorbidities (Humphreys & Lee, 2011; Johnson et al., 2003; Kujawa et al., 2014). Given MDD's heterogeneity and high rate of comorbidity, it is reasonable to hypothesize that the mixture of symptoms and comorbidities within a given clinical group differs across studies. As such, focusing on between-group comparisons rather than relations to specific symptom dimensions (e.g., anhedonia vs. depressed mood) likely contribute to the frequency of mixed findings in the MDD versus nondepressed literature.

Our analytical approach enabled testing for relations between behavior and specific domains (e.g., hedonic capacity/approach motivation) while assessing depression and other potentially relevant dimensions of behavior (e.g., internalizing and externalizing symptoms). This is a particularly useful approach if individual depressive and other symptoms (e.g., anhedonia, depressed mood, anxiety, ADHD, externalizing symptoms) show different directional effects on responsivity to loss of incentive such as elevated loss responses with greater depressed mood or anxiety and blunted loss responses with increasing anhedonia or externalizing symptoms. In our *nonclinical* child sample, this approach suggested a positive relation between hedonic capacity/approach motivation and loss responsivity, whereas significant effects of depressive, internalizing, and externalizing symptoms on response bias were not observed. However, it is possible that relations between PILT-P/N task behavior and depressive or externalizing symptoms, in addition to hedonic capacity/approach motivation, would be found in a larger sample or in a clinical sample where hedonic capacity would likely relate to depressive symptoms. Although depressive symptoms and hedonic capacity are typically thought to negatively correlate, in the current sample, and other child studies with larger sample sizes (Kingsbury, Coplan, Weeks, & Rose-Krasnor, 2013; Muris, Meesters, de Kanter, & Timmerman, 2005), self-reported reward sensitivity and depressive symptoms were unrelated. Future studies are needed to more fully test relations between child self-reported hedonic capacity and other depressive symptoms and whether each explains unique variance in behavioral responsivity to gain/loss.

Differences in development and incentive type between the current study and the adult literature may also contribute to somewhat discrepant results across age. Although we utilize primary incentives (candy), the adult literature has exclusively employed monetary

incentives that may be less affectively salient and thus tie more loosely to “hedonic” responses in the case of loss, especially if participants are already being paid a base rate for their time/effort. Further, it is likely that loss of an incentive such as candy/money differs qualitatively from interpersonal loss, such as loss of friendship and other types of social loss that likely induce enhanced negative responses in depressed/risk populations. Also, children seem to be particularly sensitive to feedback signaling loss of reward as evidenced by both behavioral and neuroimaging studies (Crone, Bunge, Latenstein, & van der Molen, 2005; Crone et al., 2008; Luking et al., 2014; van den Bos et al., 2012). As such, there may be more variation in loss-related behavior within child populations, aiding detection of relations between symptom levels and loss-related behavior.

Limitations and Future Directions

As the main limitation of this study is the small sample size, larger future studies are needed to replicate and then extend these findings into clinical and risk populations. The ethnic breakdown of our sample reflects that the greater St. Louis area and the sample did not include significantly different percentages of male and female individuals. Nonetheless, the generalizability of findings should be assessed in samples that are non-White and with greater female representation. It will also be important for future studies to establish both the stability of behavior/individual difference relations across development and the test/retest reliability of the PILT-P and PILT-N in this age group. Further, as loss feedback in the current study signals both an error and loss of something appetitive (candy), future studies capable of disentangling error and punishment/loss signals and relating the associated responses specifically with individual differences in hedonic capacity and other depressive symptoms are warranted. Our results highlight the relation between hedonic capacity and loss-avoidance behavior, in addition to gain-approach behavior. Future studies are needed to evaluate whether including hedonic capacity as a separate predictor (in addition to other depressive symptoms and internalizing/externalizing symptoms) can help rectify discrepant findings within the MDD literature regarding loss/negative affective domains.

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