Emotion

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Do Losses Loom Larger for Children Than Adults?

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Abstract

The large impact of loss of reward on behavior has been well documented in adult populations. However, whether responsiveness to loss relative to gain is similarly elevated in child versus adult populations remains unclear. It is also unclear whether relations between incentive behaviors and self-reported reward/punishment sensitivity are similar within different developmental stages. To investigate these questions, 7-10-year-old children (N=70) and young adults (N=70) completed the Behavioral Inhibition System/Behavioral Activation System (BIS/BAS) Scale, along with two probabilistic incentive tasks assessing gain approach and loss avoidance behavior. BIS/BAS subscales were calculated per Pagliaccio, Luking et al. 2015, which established an age invariant model of the BIS/BAS. Bias towards responses more frequently followed by gain feedback and away from responses more frequently followed by loss feedback, approach and avoidance behavior respectively, were quantified via signal detection statistics. Gain approach behavior did not differ across age groups, however children exhibited significantly elevated loss avoidance relative to adults. Children also showed greater reductions in accuracy and slower reaction times specifically following loss feedback relative to adults. Interestingly, despite age group differences in loss avoidance behavior, relations between self-report measures and approach/avoidance behaviors were similar across age groups. Participants reporting elevated motivation (BAS Drive) showed both elevated gain approach and elevated loss avoidance, with both types of behavior predicting unique variance in BAS Drive. Results highlight the often-neglected developmental and motivational roles of responsiveness to loss of reward.

Introduction

Losses and rewards are among the most potent sources of information guiding how we interpret and interact with our environment. Importantly, the pull of rewards and push of punishments differ across individuals and between developmental stages. Yet, few studies have investigated how *both* gain and loss sensitivity relate to approach/avoidance behaviors and how this relation may differ with developmental stage. Understanding how affective sensitivity to incentives relate within and across developmental stages has broad implications for public policy, parenting, education, and mental health, as evidence already links incentive sensitivity to a variety of domains including learning, risk for psychopathology, and risk taking within older age groups (Somerville & Casey, 2010; Somerville, Jones, & Casey, 2010; Spear, 2011).

The developmental literature has focused primarily on behavioral/neural responses to reward feedback. This literature largely reports similar striatal responses to rewards in children and adults, with responses to reward feedback peaking in adolescence (Galvan et al., 2006; Luking, Luby, & Barch, 2014; Richards, Plate, & Ernst, 2013). However, the few studies investigating negative feedback suggest that responsiveness to loss/punishment shows a different developmental trajectory. Specifically, adults show reduced neural response to loss/punishment feedback relative to both children (insula) and to adolescents (striatum and lateral orbitofrontal cortex) (Galvan & McGlennen, 2013; Luking et al., 2014; van Leijenhorst, Crone, & Bunge, 2006). Further, children show faster learning rates from negative than positive feedback (a pattern which reverses in adulthood) (van den Bos, Cohen, Kahnt, & Crone, 2012) and loss feedback may better facilitate response inhibition than reward in childhood (Barringer & Gholson, 1979; Costantini & Hoving, 1973; Geier & Luna, 2012; Getsie, Langer, & Glass, 1985). While together these results suggest that childhood may be a time of heightened response to loss feedback (relative to both adulthood and reward feedback), no studies have compared behavioral responsiveness to both gain and loss of reward in childhood and adulthood using separate tasks designed to isolate gain approach and loss avoidance behaviors. Given the extant behavioral and neuroimaging literature reviewed above, we expected that children and adults would display similar levels of gain approach behavior, while children would display enhanced loss avoidance behavior.

There are also important individual differences in incentive responsiveness that relate to mental health and functional outcomes. For example, individuals with elevated reward sensitivity are less likely to develop depression (Bress, Foti, Kotov, Klein, & Hajcak, 2013) and show better recovery if they do develop depression (McFarland, Shankman, Tenke, Bruder, & Klein, 2006). However, elevated reward responsiveness has also been linked to elevated substance use (Loxton & Dawe, 2001), risk taking (Galvan, Hare, Voss, Glover, & Casey, 2007), manic symptoms (Meyer, Johnson, & Winters, 2001), and reduced cooperation (Skatova & Ferguson, 2011). Elevated responsiveness to punishment/loss has also been linked to both negative outcomes, such as anxiety and other mood disorders (Eshel & Roiser, 2010; Johnson, Turner, & Iwata, 2003; Muris, Meesters, de Kanter, & Timmerman, 2005), and positive outcomes such as reduced risk taking and elevated group contributions during economic games (Galvan et al., 2007; Skatova & Ferguson, 2011). Investigating how individual differences in incentive sensitivity relate to behavior across developmental stages may be useful for informing trajectories of risk given the importance of incentive sensitivity in risk for/protection from psychopathology, and emerging evidence of developmental differences in the relative importance of these motivations and responses.

Carver and White's1994 Behavioral Inhibition System and Behavioral Activation System (BIS/BAS) Scale has been useful for assessing individual differences in reward and punishment sensitivity. BIS/BAS subscales indexing punishment sensitivity (BIS), reward responsiveness (BAS Reward), drive to obtain reward (BAS Drive), and fun/sensation-seeking (BAS fun seeking) have been linked to a variety of psychiatric symptoms in children, adolescents, and adults (Colder & O'Connor, 2004; Johnson et al., 2003; Loxton & Dawe, 2001). However, only recently has measurement invariance of the BIS/BAS from childhood through adulthood been tested and established (i.e. the same construct is being measured across ages) by removing specific items/subscales from Carver and White's original measure that show weak or inconsistent factor loadings/structure across developmental stages (Pagliaccio et al., 2015). Thus, modified BIS/BAS subscales can be calculated from the standard BIS/BAS and are appropriate for studies across development.

To investigate relations between self-reported BIS/BAS and approach/avoidance behaviors across children and adults, participants completed the BIS/BAS and developmentally appropriate versions of a probabilistic reward task utilized extensively in adult populations by Diego Pizzagalli and others. Children and adults with elevated anhedonic depressive symptoms (Luking, Pagliaccio, Luby, & Barch, 2015; Pizzagalli, Jahn, & O'Shea, 2005) show reduced effects of reward on choice behavior during this task. A modified version of this task, used previously in child populations, where punishment (loss of reward) feedback is received in conjunction with the standard reward paradigm, allows for separate investigation of loss avoidance and gain approach behaviors (Luking, Neiman, Luby, & Barch, 2015; Luking, Pagliaccio, et al., 2015). Interestingly, in these studies children reporting elevated anhedonic depressive symptoms/reduced hedonic capacity show reduced levels of loss avoidance behavior. These results are conceptually similar to adult studies where anhedonia has been linked to reduced neural and behavioral responsiveness to loss/negative stimuli (Dowd & Barch, 2010; Steele, Kumar, & Ebmeier, 2007; Stoy et al., 2012). Given the extant individual difference studies, we expected that elevated self-reported behavioral activation (BAS) would relate to both elevated gain approach behavior and elevated loss avoidance behavior similarly across development. Finally, we predicted that BIS would relate to loss avoidance rather than gain approach behavior, given this subscale's focus on punishment sensitivity.

Method

Participants

Child (N=70) and young adult (N=70) pairs, matched on sex and ethnicity, were drawn from four separate studies investigating gain and loss processing (Luking, Neiman, Luby, & Barch, 2015; Luking, Pagliaccio, Luby, & Barch, 2015) adult data are unpublished), no matched pairs were excluded. Sample sizes for each of the four studies were determined a priori based on estimates of power and practicality concerns and in no case were sample sizes/stopping rules based on observed effects. Participants were predominately female (N=41 in each age group) and Caucasian (N=44 in each age group) and were recruited from the St. Louis metropolitan area. Children were 7-10 years old (M=8.5; SD=1.1) and pre-/early-pubertal based on parent report (Petersen, Crockett, Richards, & Boxer, 1988). Young adults were 18-29 years old (M=20.1; SD=2.1). Young adults and parents provided written consent and children provided written assent in accordance with the Washington University in St. Louis Institutional Review Board.

Diagnostic interviews were conducted as a part of one child study (Luking, Pagliaccio, et al., 2015) investigating relations between approach/avoidance behavior and childhood risk for depression/depressive symptoms. Children from this study included in the current analyses (n=47) did not meet diagnostic criteria for any disorder (past or present) assessed via combined parent and child reports on the Kiddie-Structured Assessment for Affective Disorders-Present and Lifetime Version (Kaufman et al., 1997). The remaining children, from a study investigating relations between approach/avoidance behavior and individual differences in depressive symptoms/hedonic capacity (Luking, Neiman, et al., 2015), and all adults reported whether the child/adult participant (parents reported on their children) had ever been diagnosed with a psychiatric disorder. All children, and the majority of adults (~90%) reported no history of diagnosed psychopathology or use of psychotropic medication.

Procedure

Probabilistic Incentive Learning Tasks (PILT). Participants completed two modified versions of the probabilistic reward task based on (Heerey, Bell-Warren, & Gold, 2008; Pizzagalli et al., 2005), here termed PILT-Positive (PILT-P) and PILT-Negative (PILT-N), to assess gain and loss responsiveness respectively (Figure 1). Tasks were administered using E-prime (Schneider, Eschman, & Zuccolotto, 2012). Prior to beginning each task participants were given instructions and completed 20 practice trials as in (Heerey, Bell-Warren, & Gold, 2008).

On each trial, participants performed a perceptual discrimination and indicated whether a long or short stimulus was briefly presented. For the PILT-P, a portion of correct responses received gain feedback while, for the PILT-N, a portion of incorrect responses received loss feedback. Critically, for both tasks, one of the two responses (termed the RICH response) was scheduled to receive three times the amount of feedback as the alternative (LEAN) response. This asymmetry leads healthy, hedonic adults and children to preferentially select the RICH response across PILT-P task blocks (positive response bias) (Luking, Neiman, et al., 2015; Luking, Pagliaccio, et al., 2015; Pizzagalli, Iosifescu, Hallett, Ratner, & Fava, 2008; Pizzagalli et al., 2005) and to preferentially avoid the RICH response across PILT-N task blocks (negative response bias) (Luking, Neiman, et al., 2015; Luking, Pagliaccio, et al., 2015).

In both tasks feedback was presented in a pseudorandom order, such that no more than three trials in a row could receive feedback. This order was not standardized across participants given that feedback was contingent on the participant's response on a given trial. Instead a counter, which was reshuffled for each block, determined which trials of each type (short or long which, if correctly/incorrectly identified during the PILT-P/N respectively, could be followed by a RICH or LEAN response) were scheduled for feedback. If a correct/incorrect response (PILT-P/N respectively) was not made on a trial scheduled to receive feedback, feedback was delivered on the next available trial.Nose and mouth stimuli (Figure 1) were counterbalanced across tasks for a given participant to minimize learning effects across tasks. The stimulus set used were also counterbalanced across subjects for three studies (one adult and two child) and fixed across subjects for the remaining adult study. Task order was also fixed for the two larger studies (one adult, one child). As such, the majority of participants (85%) completed the PILT-P first and nose stimuli were used during the PILT-P for a majority of adults (84%). The proportion of participants that completed the PILT-P first did not differ across age groups (X^2(1, N = 140) = 0.50, p = 0.478); however, the proportion of participants where nose stimuli were used in the PILT-P did differ across age groups (X^2(1, N = 140) = 0.16.04, p < 0.001) . Mean discriminability and response bias (formulas below) for the PILT-P/N did not differ significantly based on PILT-P stimulus type or task order (effect of task order on PILT-N discriminability p = 0.145, effect of stimulus type on response bias p = 0.215 for the PILT-N, remaining p > 0.250). Relations between response bias, accuracy, and discriminability are reported in Supplemental Table 1. Which button response, right or left, was designated the 'RICH' response and whether that button response indicated that a short or long stimulus was presented was also counterbalanced across subjects in all child studies, and fixed in the larger adult study and thus differed significantly between age groups (all ps<0.001). Thus, variables indicating which button response was selected to receive more feedback and whether the 'RICH' button response indicated the participant thought a 'long' stimulus was presented for each task are included as covariates in all analyses.

To make the task more developmentally appropriate, children received candy (M&Ms or Skittles) as incentive feedback while adults received monetary incentives. Children earned one candy piece for gain feedback in the PILT-P and lost one candy piece from a 70-piece endowment for loss feedback in the PILT-N. Adults won 5 cents for gain feedback in the PILT-P and lost 5 cents from a $7.00 endowment for loss feedback in the PILT-N. Children completed three blocks of 40 trials (120 total), while adults completed three 60-trial blocks; however, for adults, only the first 120 trials were included in the present analyses to match the children. Not all trials received incentive feedback; specifically, 36 correct/incorrect 'RICH' responses and 12 correct/incorrect 'LEAN' responses were scheduled to receive gain/loss feedback for the PILT-P/PILT-N, respectively. To increase difficulty, and thus the number of incorrect responses in the PILT-N, a perceptual mask (row/column of pound signs; see Figure 1) was displayed following the nose/mouth stimulus and stimulus presentation time was decreased from 100 to 75 milliseconds for adults. Despite this manipulation, accuracy was relatively high, meaning that the full number of scheduled incorrect feedback instances did not occur for all participants. Thus, number of feedback instances for both the PILT-P and PILT-N were included as continuous predictors in all analyses.

Individual difference measures. Children and young adults completed the child and adult version of the Behavioral Inhibition/Behavioral Activation Scale (BIS/BAS) respectively (Carver & White, 1994; Muris et al., 2005). Mean scores were calculated for the revised, age-invariant subscales (BAS Drive, BAS Reward, and BIS) (Pagliaccio et al., 2015). See Supplemental Table 2 for items and wording for each subscale. It is important to note that while the factor structure, item loadings, thresholds, and unique/residual variances of the revised BIS/BAS showed age invariance, mean differences in all BIS/BAS subscales were still observed across development by Pagliaccio et al., (2015). Possible subscale scores ranged from one to four with a four indicating the greatest level for the given construct (see Supplemental Table 3 for subscale means and age group comparisons).

Data Processing

As in previous studies (Luking, Neiman, et al., 2015; Luking, Pagliaccio, et al., 2015; Pizzagalli et al., 2005), individual trials with reaction time (RT) either beyond 150-2500 msec or beyond +/- 3 standard deviations from the participant’s mean RT were excluded, after which discriminability and response bias were calculated for each of the three blocks of 40 trials. Greater discriminability (log d) indicates improved ability to distinguish long from short stimuli. Response bias (log b) assesses behavioral responsiveness to feedback. Positive values are typically observed during the PILT-P and indicate a greater propensity to select the more frequently rewarded (RICH) stimulus. Negative values are typically observed during the PILT-N and indicate a greater propensity to select the LEAN stimulus, i.e. to avoid the more frequently punished response.

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

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

Data Analysis

All analyses were conduced using SPSS 20.0.0. Analyses investigating response bias focused on change in bias across the initial (block 1) and final (block 3) task blocks (or the mean across these blocks), a standard approach for studies using the PILT (Luking, Neiman, et al., 2015; Luking, Pagliaccio, et al., 2015; Pizzagalli et al., 2005), *and did not include block 2*.

Relations among individual difference measures and differences by age group. Correlations between BIS, BAS Reward, and BAS Drive were conducted within each age group. Independent samples t-tests were conducted to test for differences in BIS/BAS levels across age groups.

Effects of age group and individual differences on response bias. A repeated measures ANOVA was conducted to investigate how response bias differed across tasks, blocks, age groups, BIS, BAS Reward, and BAS Drive. Task (PILT-P, PILT-N) and Block (first block = block 1, last block = block 3) served as the within-subject repeated measures. As our hypotheses focused on response bias change from the beginning to the end of the task (difference between blocks 1 and 3), only blocks 1 and 3 were included in the repeated measures ANOVA, and related post-hoc tests. However, results were qualitatively similar when block 2 was included in post hoc analyses. We were interested in both main effects of Task Type and Task Type by Block interactions. Age Group (children=0; adults=1), PILT-P Order (1=first, 2=second), PILT-P Stimulus Type (nose=0; mouth=1), Rich Button Response (1=left, 2=right – separate variables for each task), and Rich Button - Long (1= the rich button response indicated ‘long’ stimulus, 0= the rich button response indicated ‘short’ stimulus) – separate variables for each task) served as between-subjects factors. BIS, BAS Reward, BAS Drive, number of PILT-P and PILT-N feedback events were included as continuous predictors. Given our hypotheses regarding age and behavioral inhibition/activation, we focus on main effects and interactions of age group and the individual difference factors with Task Type and Task Type by Block.

Post-hoc regressions were preformed to determine sources/directions of significant effects in the repeated measures ANOVA. In post-hoc regression analyses, mean response bias (mean of blocks 1 and 3 as only blocks 1 and 3 were included in the ANOVA) for each task was used as a dependent measure to parse main effects and interactions with Task Type. Regression analyses with response bias change (block 3 – block 1) for each task were used to parse interactions of Task Type and Block. All factors/covariates from the repeated measures ANOVA were also included in post hoc regressions. To investigate whether the significant effect of a given BIS/BAS subscale on response bias differed with age, the interaction of that subscale and age group was included as a second step in the post hoc regressions. Finally, to investigate whether effects of BIS/BAS subscales on response bias were evident in each age group independently, an additional post-hoc repeated measures ANOVA, only including BIS/BAS measures as covariates, was conducted for each age group separately.

Effects of age group on speed and accuracy following feedback. Post-feedback slowing and decreases in accuracy are commonly observed. The degree of such slowing tends to be largest following incorrect feedback and in some studies is proportional to an individual's processing/sensitivity to that feedback (Notebaert et al., 2009). Thus, we conducted two additional repeated measures ANOVAs examining group differences in 1) reaction time and 2) accuracy to further test whether losses loom larger for children than adults. Task Type (PILT-P, PILT-N) and Feedback (feedback, no feedback) served as within-subject repeated measures. For the PILT-P, the factor 'Feedback' included speed/accuracy averaged across trials following *correct* responses that received either gain feedback or no feedback while for the PILT-N the factor 'Feedback' included speed/accuracy averaged across trials following an *incorrect* response. The factors/covariates from previous analyses, excluding BIS/BAS subscales, were included here. Post hoc regressions controlling for all factors in the ANOVA were conducted to examine any significant effects/interactions with Age Group. We focus on interactions of age group with Task Type (and Task Type by Feedback) as such interactions reflect age differences in response patterns that further differ based upon incentive type (gain/loss)/feedback, rather than a general improvement (main effect) in accuracy and reaction time with age.

A Bonferronni correction for multiple comparisons (0.05/3=0.017) was used to determine significance for effects/interactions from the 3 main ANOVAs investigating response bias, reaction time, and accuracy. Post hoc tests investigating significant main effects/interactions from the main ANOVAs or from analyses within separate age groups are discussed where $p<0.05$.

Results

Do Children and Adults Show Similar Levels of/Relations Between Behavioral Inhibition and Behavioral Activation?

Both children and adults showed strong positive relations between BAS Drive and BAS Reward (all $p \leq 0.001$). In adults BIS positively related to BAS Reward ($p<0.001$) and to BAS Drive at trend level ($p<0.10$), however these relations were not significant in children (all $p>0.40$). Adults reported higher scores on all subscales relative to children (BIS and BAS Reward $p < 0.001$; BAS Drive $p = 0.042$). See Supplemental Table 3 for intercorrelations and BIS/BAS descriptive statistics by group.

General Task Effects

The direction of change in response bias within a task differed between the PILT-P and PILT-N (Task Type x Block interaction, Table 1). Paired samples t-tests indicated that response bias did not significantly differ between blocks 1 and 3 during the PILT-P ($t(1,139)=-0.08$, $p=0.938$), but mean PILT-P bias was significantly greater than zero ($t(1,139)=9.63$ $p<0.001$) indicating that participants selected the RICH response paired with more frequent gain feedback at a greater rate than the alternative response. Conversely, during the PILT-N, response bias became significantly more negative from block 1 to block 3 during the PILT-N ($t(1,139)=2.98$, $p=0.003$) indicating that the propensity for participants to shift choice behavior away from the RICH response receiving more frequent loss feedback (i.e. negative response bias) increased across the PILT-N.

Do Losses Loom Larger For Children Than Adults?

Results from the repeated measures ANOVA investigating relations between response bias and Age Group are shown in Table 1 and Supplemental Table 4, post hoc regressions are shown in Table 2 and Supplemental Table 5.

Both mean response bias and response bias change (difference between the last and first block) for PILT-N differed by Age Group (interaction of Task Type and Age Group, and interaction of Task Type, Block, and Age Group in Table 1 and Figure 2A). Specifically, relative to adults, children showed both elevated mean levels of loss avoidance (more negative response bias) as well as a greater increase in loss avoidance (a greater change in negative response bias from the first to last block) within the PILT-N (Table 2, Supplemental Table 5). Age group remained a significant predictor of PILT-N bias change ($\beta = 0.39$, $t = 3.28$, $p = 0.001$) and mean bias ($\beta = 0.14$, $t = 2.42$, $p = 0.017$) after controlling for PILT-N discriminability. Discriminability was added as an additional predictor post hoc as it significantly differed based on age and was strongly related to the amount of feedback delivered and ratio of RICH to LEAN feedback instances, and thus potentially driving age differences in response bias (Supplemental Table 1). Conversely, no significant effects of age were observed for PILT-P mean bias or bias change (Table 2, Supplemental Table 5). Together these results suggest that children and adults show similar levels of gain approach behavior, but that children show enhanced loss avoidance relative to adults, i.e. losses loom larger for children than adults.

Results from the repeated measures ANOVA investigating relations between RT or accuracy post feedback and Age Group are shown in Table 3 and Supplemental Table 6.

Relative to adults, children were slower overall (main effect of age group) and age differences in RT further differed based on feedback (two-way interaction of Age Group with Feedback) (Figure 2B). Post-hoc regressions showed that children were significantly slower to respond than adults post-feedback versus post-no feedback (Age Group predicting RT post feedback – RT post no feedback; $\beta = -0.36$, $t = -3.32$, $p = 0.001$). The interaction of Age Group and Feedback also differed across Task Types (three-way interaction of Age Group, Feedback, and Task Type). Post-hoc regressions indicated that children showed exaggerated post-feedback slowing relative to adults following loss feedback (Age Group predicting RT post feedback – RT post no feedback during the PILT-N; $\beta = -0.33$, $t = -3.22$, $p = 0.002$) but not following gain feedback (Age Group predicting RT post feedback – RT post no feedback during the PILT-P; $\beta = -0.03$, $t = -0.33$, $p = 0.740$).

As intended by the post-stimulus perceptual mask, participants were generally less accurate during the PILT-N than the PILT-P (main effect of Task Table 3 and Supplemental Table 6, Figure 2C), allowing a necessary increase in incorrect responses that could receive loss feedback (see methods). Task Type also significantly interacted with Age Group such that the decrease in accuracy during the PILT-N versus PILT-P was greater in children than adults (Age Group predicting PILTP accuracy – PILTN accuracy: $\beta = -0.43$, $t = -4.92$, $p<0.001$).

In summary, relative to adults during the PILT-N, children showed 1) both more negative response bias and more negative change in response bias, 2) greater slowing post loss feedback than no feedback, 4) greater decreases in general accuracy (Figure 2A-C). No significant age differences were observed during the PILT-P for 1) mean response bias or change in response bias, 2) differences in RT following feedback versus no feedback, or 3) differences in accuracy.

Do Individual Differences in Behavioral Inhibition/Activation Predict Incentive-Related Behaviors Across Age?

As described above, the repeated measures ANOVA (Table 1, Supplemental Tables 4 and 7) and post-hoc regressions (Table 2, Supplemental Table 5) also tested whether individual differences in BIS, BAS Reward, and BAS Drive predicted behavioral responsiveness to incentive feedback. A significant three-way interaction of BAS Drive with Task Type and Block was observed (Table 1, Supplemental Table 4). Importantly this three-way interaction was also observed separately within each age group ($ps<0.05$; Supplemental Table 7).

In planned follow-up regression analyses, BAS Drive was a significant positive predictor of change in PILT-P response bias ($\beta = 0.30$, $t = 3.16$, $p = 0.002$), a significant negative predictor of mean PILT-N response bias ($\beta = -0.19$, $t = -2.53$, $p = 0.012$), and trend-level negative predictor of change in PILT-N response bias ($\beta = -0.20$, $t = -2.11$, $p = 0.037$) indicating that individuals with elevated BAS Drive show *both* greater increases in gain approach across the PILT-P *and* greater loss avoidance during the PILT-N (Table 2 and Supplemental Table 5; Figure 3). Importantly, the interaction of Age Group and BAS Drive did not significantly predict response bias for any task (Table 2). The main effects and interactions with BIS and BAS Reward were not significant (all $p > 0.10$; Tables 1-2, Supplemental Table 4).

Are Gain Approach and Loss Avoidance Behaviors Independent Predictors of BAS Drive?

Given that BAS Drive significantly predicted both PILT-P bias change and PILT-N mean bias, we conducted an additional post-hoc regression to investigate whether bias during each task predicted independent or common variance in BAS Drive. Specifically, age group, PILT-P bias change, and PILT-N mean bias were used to predict BAS Drive. Residualized bias scores (controlling for stimulus type, task order, feedback amount, rich button, and whether the rich button indicated a long stimulus) were used in the regression. Interestingly, PILT-N mean bias ($\beta = -0.19$, $t = -2.19$, $p = 0.030$) and PILT-P bias change ($\beta = 0.18$, $t = 2.24$, $p = 0.027$) were significant *unique* predictors of BAS Drive when also controlling for Age Group which also significantly positively predicted BAS Drive ($\beta = 0.26$, $t = 3.04$, $p = 0.003$). Results were similar when using PILT-N bias change as a predictor of BAS drive ($\beta = -0.18$, $t = -2.08$, $p = 0.039$)

instead of PILT-N mean bias.

Discussion

Despite a burgeoning literature regarding differences in reward-related behavior from adolescence to adulthood, little is known regarding how loss avoidance differs from childhood to adulthood. We report significantly elevated loss avoidance behavior in children relative to adults, but no significant difference in gain approach behavior between age groups. Across age groups, individuals reporting elevated levels of BAS Drive showed enhanced behavioral responsiveness to gain *and* loss feedback. Further, gain approach and loss avoidance predicted *unique* variance in BAS Drive.

In the past several decades, there has been a shift in parenting and education policy to focus on the benefits of positive feedback while punishment has been discouraged due to damaging effects on self-esteem and the parent-child relationship (Gershoff, 2002). However, loss (of reward) as a consequence for unwanted behaviors (or failing to complete wanted behaviors) can be powerful for shaping child behavior without the damaging effects of more active forms of punishment. The current findings suggest that children are quite sensitive to loss feedback and make larger changes in behavior based on this feedback than adults, a pattern mirrored by studies investigating learning rates from positive and negative feedback (Barringer & Gholson, 1979; van den Bos et al., 2012), although this developmental course is likely non-linear, as with response to reward (Cauffman et al., 2010; Galvan et al., 2006). Importantly, loss feedback appears to be effective in eliciting changes in specific behaviors, but not effective in improving speed and/or overall accuracy, as children showed reduced accuracy during the loss task *and* slower reaction times following loss feedback versus no feedback relative to adults. These findings could have important implications for informing educational incentives for school-aged children.

Across age groups, participants reporting elevated BAS Drive showed *both* greater gain approach behavior *and* greater loss avoidance behavior. This finding, along with the handful of studies linking elevated anhedonia (i.e. reduced experienced pleasure) and blunted responsiveness to both positive and negative feedback/stimuli (Chase et al., 2010; Dowd & Barch, 2010; Luking, Neiman, et al., 2015; Steele, Kumar, & Ebmeier, 2007), suggests that reduced drive/hedonic capacity may be better conceptualized as a general deficit in responding to incentive feedback rather than a hypo-responsiveness specific to reward. However, in the current study gain approach and loss avoidance predicted *unique* variance in BAS Drive. Suggesting that they reflect dissociable components of 'motivation' (here BAS Drive) rather than a common 'blunting' of responsiveness to valenced feedback. While we expected both gain approach and loss avoidance behaviors to relate to BAS Drive, we did not expect that these behavior would be independent predictors of self-reported motivation. A growing number of studies report blunted response to both positive and negative outcomes/stimuli with elevated anhedonia/low hedonic capacity, but no studies have investigated whether responsiveness to each type of stimuli explains unique variance in the construct of interest. As such, replication of this result is needed. However, if replicable this finding suggests that theories of motivation should be reconceptualized to explicitly include responsiveness to reward loss as well as gain.

This reconceptualization has important implications not only theoretically, but also clinically. Motivational/hedonic deficits are experienced across a wide variety of psychiatric disorders and are highlighted in the NIMH's RDoC initiative (Insel et al., 2010). Given that gain approach and loss avoidance both predict unique variance in BAS Drive, an interesting future direction will be to investigate whether altered gain approach and/or loss avoidance inform novel distinctions in domains of psychopathology associated with altered motivation/hedonic capacity. It is also interesting that loss avoidance in this task related significantly to motivation but not to punishment sensitivity (BIS). It is possible that BIS would more strongly relate to PILT-N behavior if punishments, such as aversive tastes or mild shocks, were delivered instead of loss of reward, given that BIS questions assess responsiveness to punishment/negative social outcomes. Future studies investigating *punishment* avoidance along with gain/loss approach/avoidance are needed to evaluate whether BAS Drive specifically predicts behavioral shifts towards appetitive outcomes (irrespective of the valence of feedback driving that behavior) or predicts responsiveness to all outcomes, including punishment.

Relations between self-reported BAS Drive and approach/avoidance behavior are of further interest given that similar patterns were observed in both age groups, suggesting that mechanisms underlying such relations are likely conserved across age. Longitudinal studies are needed to explicitly test this hypothesis. It is also interesting that age differences in BIS/BAS did not explain the observed age differences in behavior. Specifically, adults displayed *greater* BAS Drive relative to children and *elevated* BAS Drive was related to *enhanced* loss avoidance in both children and adults. However, adults displayed *reduced* loss avoidance relative to children, despite their *greater* BAS Drive than children. Thus, further work is needed to understand what factors mediate the observed age difference in loss avoidance behavior, as it does not appear to reflect age differences in self-reported BAS Drive. There is some evidence that developmental differences in striatal-prefrontal functional connectivity predicts differences in the relative influence of reward and negative feedback on learning from childhood to adulthood (van den Bos et al., 2012). However, future behavioral/neuroimaging studies investigating loss avoidance and gain approach are needed to explore the mechanisms explaining the current age difference, given that responses to negative feedback and loss of reward are not necessarily equivalent.

Limitations

In the current study, incentive feedback was tied to performance on a given trial, which allowed the number of feedback instances to differ, particularly with varying accuracy during the PILT-N. Children were generally less accurate than adults during the PILT-N and received more loss feedback, which could have influenced age effects. However, given that more loss feedback related to reduced loss avoidance within each group, and that age effects remained when controlling for feedback amounts/discriminability, it is unlikely that children's elevated loss avoidance is explained by larger loss feedback amounts/reduced discriminability. Future PILT studies where accuracy/discriminability is matched between age groups would further support this result. Another potential limitation is that children and adults received different types of incentives. Although we feel that this is a stronger approach than offering a fixed monetary reward, which is susceptible to age differences in incentive valuation, future studies using similar incentives are needed to replicate current findings. A final potential limitation is our use of self-reported BIS/BAS as self-report accuracy may differ across age. Importantly, measurement invariance from childhood through adulthood, i.e. whether the same construct is being measured across groups, has been tested and verified for the current BIS/BAS subscales (Pagliaccio et al., 2015). Further, similar relations between behavior and BIS/BAS self-report were observed in each age group. Thus, it is unlikely that issues with self-report in the child group substantially impacted the current results.

Conclusions

In sum, the current study highlights the often-neglected role of loss feedback from both a developmental and individual differences standpoint. Behavioral responsiveness to loss feedback is elevated in children and across developmental epochs in individuals reporting elevated BAS Drive. Thus, loss feedback may be a particularly useful motivator during childhood and may be an effective and potentially less damaging alternative to other punishments. Further, individuals reporting greater motivation (BAS Drive) showed elevated loss avoidance *and* elevated gain approach behavior across age groups. This finding suggests a reconceptualization of drive as comprised of behavioral/motivational sensitivity to both reward gain and loss feedback, rather than focusing only on positive feedback/outcomes. Future studies are needed to investigate the neural underpinnings of both developmental differences in loss avoidance as well as the unique relations between gain and loss responsiveness and drive. Additional investigation of this area is warranted to inform applications to parenting, education, and child development policy.

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Table 1: *Repeated Measures ANOVA Investigating Effects of Age, Task Type, Block, BIS, and BAS on Response Bias*

Interaction Type and Factor/Predictor	F-Statistic	Partial η^2	p
Main Effects			
Task Type	0.28	0.00	0.600
Age Group	**15.62****	**0.11**	**<0.001**
BIS	0.56	0.00	0.457
BAS Reward	3.06	0.02	0.083
BAS Drive	4.69[#]	0.04	0.032
Two-Way Interactions with Task Type			
Block	**6.52***	**0.05**	**0.012**
Age Group	**7.22***	**0.05**	**0.008**
BIS	0.17	0.00	0.680
BAS Reward	0.17	0.00	0.683
BAS Drive	3.50	0.03	0.064
Three-Way Interactions with Task Type and Block			
Age Group	**6.98***	**0.05**	**0.009**
BIS	2.24	0.02	0.137
BAS Reward	0.63	0.01	0.430
BAS Drive	**10.44***	**0.08**	**0.002**

Note: BAS = Behavioral Activation Scale, BIS = Behavioral Inhibition Scale, p = p-value. See Supplemental Table 3 for full ANOVA results. **$p \leq 0.001$ *$p<0.017$ [#]$p<0.05$

Table 2: *Post Hoc Regressions Predicting Mean Response Bias and Response Bias Change For the PILT-Positive (PILT-P) and PILT-Negative (PILT-N)*

Dependent Variable and Predictors	b (SE)	Lower CI Limit (b)	Upper CI Limit (b)	β	t	p
PILT-P Mean Response Bias						
Age Group	0.02 (0.05)	-0.07	0.11	0.04	0.38	0.704
BIS	0.01 (0.03)	-0.05	0.06	0.04	0.34	0.733
BAS Reward	0.04 (0.04)	-0.04	0.11	0.09	0.96	0.338
BAS Drive	<0.01 (0.03)	-0.05	0.06	0.00	0.01	0.991
Model 2: Age Group x BAS Drive	0.03 (0.05)	-0.07	0.13	0.21	0.56	0.576
PILT-P Response Bias Change						
Age Group	-0.03 (0.08)	-0.17	0.13	-0.03	-0.30	0.767
BIS	-0.07 (0.05)	-0.16	0.02	-0.17	-1.60	0.112
BAS Reward	-0.07 (0.06)	-0.19	0.05	-0.11	-1.13	0.263
BAS Drive	**0.14 (0.05)***	**0.05**	**0.23**	**0.30**	**3.16**	**0.002**
Model 2: Age Group x BAS Drive	0.12 (0.09)	-0.05	0.29	0.53	1.41	0.160
PILT-N Mean Response Bias						
Age Group	**0.75 (0.07)****	**0.14**	**0.39**	**0.36**	**4.05**	**<0.001**
BIS	0.02 (0.04)	-0.05	0.10	0.05	0.60	0.553
BAS Reward	0.06 (0.05)	-0.04	0.16	0.09	1.13	0.260
BAS Drive	**-0.10 (0.04)***	**-0.17**	**-0.02**	**-0.19**	**-2.53**	**0.013**
Model 2: Age Group x BAS Drive	0.13 (0.07)	-0.02	0.27	0.51	1.77	0.078
PILT-N Response Bias Change						
Age Group	**0.31 (0.08)****	**0.14**	**0.48**	**0.41**	**3.65**	**<0.001**
BIS	0.01 (0.05)	-0.09	0.11	0.02	0.22	0.827
BAS Reward	0.03 (0.07)	-0.10	0.16	0.05	0.48	0.632
BAS Drive	*-0.10 (0.05)*[#]	*-0.20*	*-0.01*	*-0.20*	*-2.11*	*0.037*
Model 2: Age Group x BAS Drive	0.13 (0.09)	-0.06	0.31	0.51	1.38	0.170

Note: PILT = Probabilistic Incentive Learning Task, Age Group coded as Adults=1 Children=0, BIS = Behavioral Inhibition Scale, BAS = Behavioral Activation Scale, b = unstandardized beta, 95% Confidence Interval (CI), β = standardized beta, t=t-statistic, p=p-value. See Supplemental Table 4 for the other covariates in model 1 (including Task Order, Stimulus Set, Feedback Amount, Rich Button Response, and whether the Rich Button Response indicated the long stimulus). The interaction of Age Group and BAS Drive was the only factor added in Model 2.

**$p \leq 0.001$ *$p<0.017$ [#]$p<0.05$

Table 3: *Repeated Measures ANOVAs Investigating Effects of Age, Task Type, and Previous Trial Feedback on Reaction Time and Accuracy*

Interaction Type and Factor/Predictor	Reaction Time ANOVA			Accuracy ANOVA		
	F-Statistic	Partial η^2	p	F-Statistic	Partial η^2	p
Main Effects						
Task Type	0.47	0.00	0.493	**20.64****	**0.14**	**<0.001**
Previous Trial Feedback	2.49	0.02	0.117	0.09	0.00	0.770
Age Group	**119.74****	**0.48**	**<0.001**	*5.37*#	*0.04*	*0.022*
Two-Way Interactions with Task Type						
Previous Trial Feedback	1.32	0.01	0.253	1.16	0.01	0.284
Age Group	0.00	0.00	0.964	**24.25****	**0.16**	**<0.001**
Two-Way Interactions with Previous Trial Feedback						
Age Group	**11.04****	**0.08**	**0.001**	1.40	0.01	0.240
Three-Way Interactions with Task Type and Previous Trial Feedback						
Age Group	**7.54***	**0.06**	**0.007**	2.83	0.02	0.095

Note: See Supplemental Table 5 for full ANOVA results. Other model covariates included Task Order, Stimulus Set, Feedback Amount, Rich Button Response, and whether the Rich Button Response indicated the long stimulus, p = p-value. **p≤0.001 *p<0.017 #p<0.05

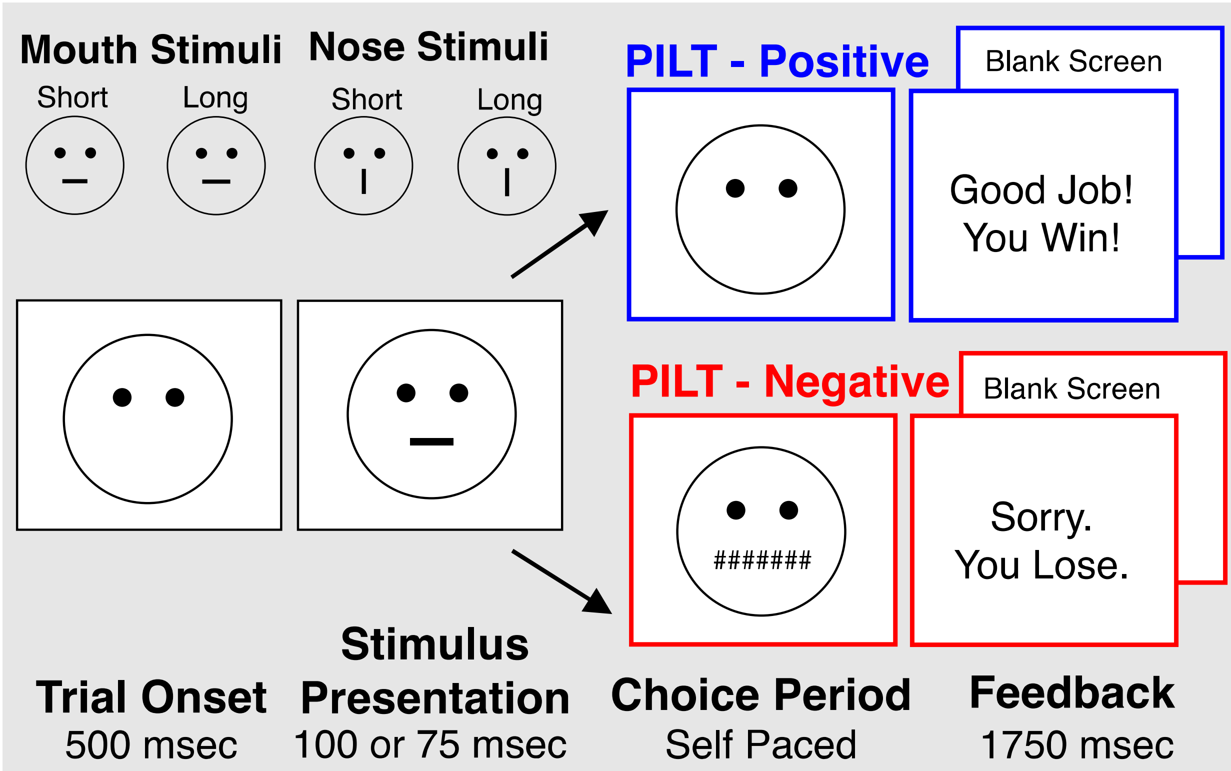

Fig. 1. Schematic diagram of the Progressive Incentive Learning Task (PILT). The PILT-Positive version where candy/money could be gained is depicted in blue. The PILT-Negative version where candy/money could be lost is depicted in red. Stimuli were presented for 75 msec for adults and 100 msec for children; other task parameters were the same for both age groups.

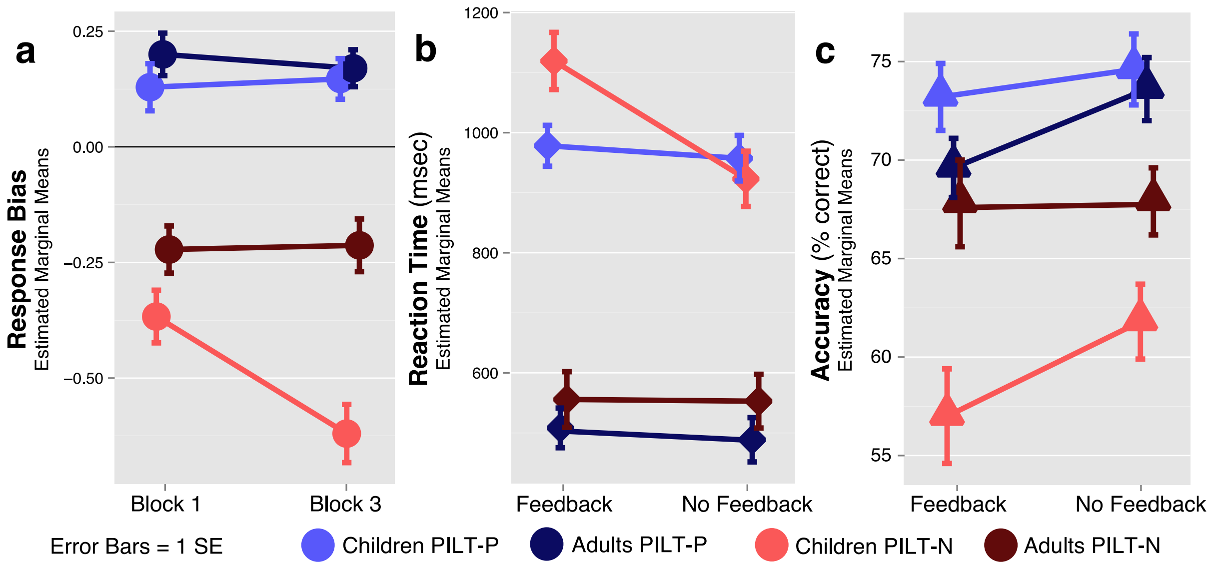

Fig. 2. Estimated marginal means from repeated measures ANOVAs investigating a) response bias, b) mean reaction time, and c) mean accuracy during the PILT-Positive (PILT-P) in blue and PILT-Negative (PILT-N) in red. Values are controlled for Task Order, Stimulus Set, Feedback Amount, Rich Button Response, and whether the Rich Button Response indicated the long stimulus in all panels; panel A values are also controlled for Behavioral Inhibition System Subscale, Behavioral Activation System - Reward Subscale, and Behavioral Activation System - Drive Subscale. Darker colors represent values for the adult group, brighter colors represent child group values.

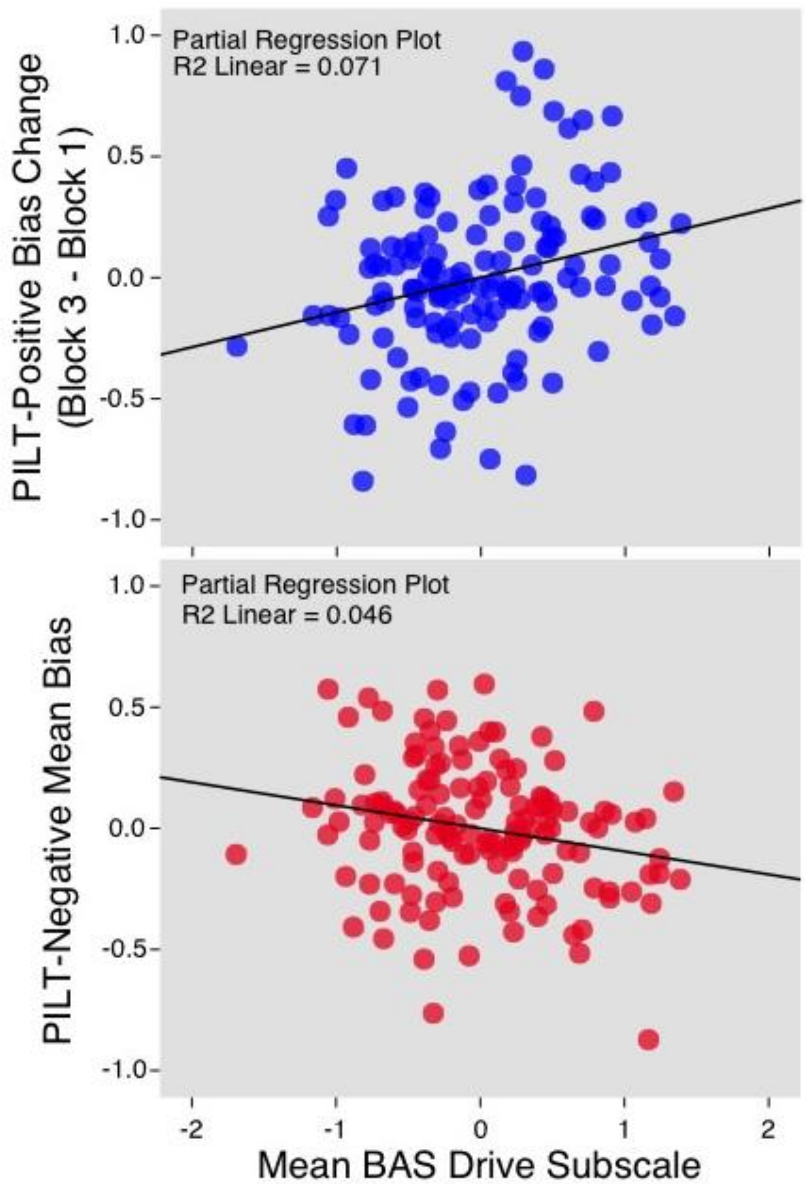

Fig. 3. Partial Regression Plot depicting relations between self-reported BAS Drive and response bias during the PILT-Positive (PILT-P – blue) and PILT-Negative (PILT-N – red). Covariates include BAS Reward, BIS, Age Group, Task Order, Stimulus Set, Feedback Amount, Rich Button Response, and whether the Rich Button Response indicated the long stimulus.