Supplementary Material


In prior studies, increased BIS sensitivity has been linked to a number of clinical problems during adolescence. For example, Loxton and Dawe (2001) found increased BIS sensitivity to predict higher self-reported dysfunctional eating behaviors (e.g., dieting, concerns with weight) in adolescent females. Among Russian adolescents, heightened BIS sensitivity predicted lower subjective well-being and academic aspirations (Knyazev, 2004). Increased BIS sensitivity has been linked to parental reports of internalizing problem behaviors (Colder & O’Connor, 2004). Similarly, in response to negative stimuli encountered in laboratory paradigms, BIS hypersensitivity predicted self-rated negative affective reactivity among adolescents (Leen-Feldner, Zvolensky, & Feldner, 2004) and undergraduates (Leen-Feldner, Zvolensky, Feldner, & Lejues, 2004). There is also preliminary evidence for heightened BIS sensitivity actually lowering both the risk for substance use (O’Connor et al., 2009; Loxton & Dawe, 2001) and excessive computer use (Giles & Price, 2008) in adolescence.

It should be noted that although both heightened BIS and BAS sensitivities in adolescence increase risk for clinical symptoms, they predict distinct sets of problem behaviors. Specifically, heightened BAS sensitivity is more consistently linked to problematic pursuit of rewards, such as substance use, excessive computer use, and socializing with deviant peers, whereas BIS sensitivity is linked to anxiety-related
behaviors, such as internalizing symptoms and a decreased involvement in risky activities. This pattern of results is consistent with the overall hypothesized functioning of the two systems (e.g., Depue & Collins, 1999; Fowles, 1987; Gray, 1994).

In our study, we conducted analyses with the BIS scale, as a measure of threat sensitivity, analogous to those conducted using the BAS scales, in order to determine specificity of our reward sensitivity findings during adolescence.

Results

Longitudinal Changes in BIS sensitivity and Age and Sex Effects

In a series of repeated measures ANCOVAs with a between-subject factor of sex, age as a continuous covariate, and BIS scale as a repeated measures variable with two time points, main effects of time would reflect change, regardless of age, from Time 1 to Time 2. Main effects of age would suggest age effects on the BIS scales irrespective of time. Age by time interactions would indicate differential patterns of change across time for different ages. As summarized in Table 2 of the article, there were significant main effects of sex and age on the BIS scale. The sex effect was due to higher scores in females relative to males and there was a significant partial correlation (controlling for sex) between age and BIS scores averaged across two time points, \( r = .23, p = .003 \).

In follow-up of main effect of age, ANOVA with age group and sex as between-subjects factors yielded a significant interaction of age group by sex, \( F (2, 151) = 5.49, p = .005, \eta_p^2 = .07 \), which is illustrated in Supplemental Figure 2. Female early adolescents exhibited lower scores than female late adolescents \( (p = .029) \) and young adults \( (p < .001) \), while no differences were observed between age groups for male participants. Moreover, examining sex differences in a separate repeated measures ANOVA for each
age group yielded a significantly higher BIS score for females versus males in late adolescence, $F (1, 59) = 6.79, p = .012, \eta_p^2 = .10$, and in young adulthood, $F (1, 51) = 23.44, p < .001, \eta_p^2 = .32$, but is not present in early adolescence ($p = .95$). In other words, the age effect appeared to be specific to females as they only experienced increases in BIS sensitivity from early adolescence to young adulthood.

**Associations between Longitudinal Changes in Regional Brain Volumes and Longitudinal Changes in BIS Sensitivity**

In order to assess whether individual differences in volumes of lateral and medial OFC, Nacc, and amygdala predict individual differences in longitudinal changes in BIS sensitivity, a series of hierarchical regression analyses was conducted. For each regression, the BIS scale from Time 2 was entered as the outcome variable. Four regressions were ran to predict longitudinal change in the BIS scales as a function of changes in regional brain volumes of the nucleus accumbens, medial OFC, lateral OFC, and amygdala. Each hierarchical regression was similarly structured. In Step 1, age, sex, and the BIS scale from Time 1 were entered as predictors as well as scanner upgrade status. In Step 2, relevant right and left hemisphere volumes at Time 1 were entered as predictors. In Step 3, relevant right and left hemisphere volumes at Time 2 were entered as predictors, to examine the effect of developmental change in each brain region’s volumes and the unique contribution of longitudinal change in each hemisphere. The findings from Step 2 were of primary interest given the study’s hypotheses.

Baseline lateral OFC volumes significantly predicted longitudinal increases in BIS scores from Time 1 to Time 2 (change $R^2 = .05, p = .003$), with a significant unique effect of the baseline left lateral OFC volume (partial $r = .25, p = .003$). However, there
were no effects of longitudinal change in lateral OFC on longitudinal change in BIS from Time 1 to Time 2. There were also no significant effects of amygdala, medial OFC, or Nacc volumes on the longitudinal change in BIS scores. In other words, only baseline volumes of lateral OFC, proposed to be involved in processing of punishers, predicted prospective changes in BIS sensitivity during adolescence.
References


Behavioral inhibition: Relation to negative emotion regulation and reactivity. 

*Personality and Individual Differences, 36,* 1235-1247. doi:10.1016/S0191-8869(02)00113-7


Supplemental Figure 1. Examples of ROI brain volumes yielded by FreeSurfer cortical parcellation and subcortical segmentation in a representative participant from the sample. A. shows sagittal view of medial OFC (in red) and Nacc (in yellow) volumes for the right hemisphere, whereas B. shows axial view of lateral OFC (in blue) and amygdala (in beige) in both hemispheres.
Supplemental Figure 2. Interaction effect of age-group and sex on the BIS scale across Time 1 and 2. Females but not males show increases in BIS sensitivity from early adolescence to young adulthood.