Supplement A

Assessment of impulsivity
Choices for the scales, tasks, and indices used were based on two main reasons: first, they represent valid (behavioral) measures of trait impulsivity or of impulsive responsivity and decision making and, second, for replication purpose, to increase the comparability with related findings from the same sample as these indices have been used in the context of impulsivity in a previous papers from our group.

Trait impulsivity
The NEO-PI-R has been shown to provide a valid measurement for broad dimensions of personality [1] that is based on the Five-Factor Model of Personality. The SURPS measures lower-order personality trait dimensions related to psychopathology as well as different levels of personality risk factors for psychopathology (e.g. hopelessness, anxiety, impulsivity). Finally, the TCI-R was used as a third indicator of trait impulsivity to assess lower-order personality traits specifically linked to disinhibitory psychopathology.

Decisional impulsivity I: KIRBY - temporal discounting of delayed rewards
The KIRBY provides a measure of delay discounting by assessing the preference of immediate lower over delayed higher monetary rewards. This questionnaire asks for the subject’s preference between different pairs of reward options, where the option with the larger amount comes at a longer delay, so subjects are required to judge the relative value of increasing amounts over longer delays. Kirby scores (K1-K3) were calculated based on instructions in Kirby [2] addressing the consistency in choices representing a threshold for k where the subject switches between choosing smaller immediate reward (SIR) and larger, delayed reward (LDR) taking into account (in-)consistency of answers.
**Decisional impulsivity II: CANTAB CGT - delay aversion**

The CGT was developed to assess decision-making and risk-taking behavior. It is part of the Cambridge Neuropsychological Test Automated Battery (CANTAB) providing sensitive and objective measures of cognitive functioning [3]. Information is presented to the subjects without any need to learn or retrieve information over consecutive trials afterwards. On each trial, the subject is presented with a row of ten boxes across the top of the screen. Some of these boxes are red, others are blue. At the bottom of the screen are rectangles containing the words ‘Red’ and ‘Blue’. The participants are instructed to guess whether a yellow token is hidden in a red or a blue box. In the gambling stages, participants start with a number of points displayed on the screen. They can select a proportion of these points, shown in either rising or falling order in a second box on the screen to gamble on their confidence. A stake box on the screen displays the current amount of the bet. The participants are instructed to accumulate as many points as possible. Thereby, the relation between the subjective value of a reward and the probability of its receipt is taken into account. For the current modified version, the time between stakes is reduced from 5s to 2s to make the task shorter and more interesting. Stakes are displayed in ascending order first. For the current work, the delay aversion subscale was used. Here, delay aversion is defined as the tendency to select always the first bets, in both ascending and descending conditions. The higher the score, the higher the tendency to impulsive behavior.
Supplement B

Assessment of brain activity – fMRI paradigms
The Stop Signal Task (SST; [4])

During the SST, participants are presented with arrows in the center of a computer screen that point either to the left or right (go signal). Subjects are instructed to indicate the direction of the arrow by pressing either the left or right button as quickly and accurately as possible. On 20% of the trials, the go signal is followed by the stop signal (arrow pointing upwards) and subjects are instructed to withhold their response. To manipulate stopping difficulty across trials, the onset of the stop signal after the go signal (stop signal delay) was varied (for algorithm, see [4]). Consequently, subjects successfully stopped on 50% of trials. The total task contained 400 go trials with a stimulus-duration of 1000 ms each, and, furthermore, 80 stop trials with a stimulus duration varying between 0-900 ms (initial delay of 250 ms). A practice session was implemented prior to scanning to familiarize subjects with the task. Thereby, 60 trials were performed during 2 minutes. In the scanner, participants were reminded of the instructions.
Table S1
Descriptive statistics for behavioral performance data from fMRI SST

|                         | N  | M     | SD  |
|-------------------------|----|-------|-----|
| Go RT BL                | 2088| 466.63| 80.00 |
| SSRT BL                 | 2090| 151.33| 82.66 |
| Omission error BL       | 2098| 4.39  | 10.46 |
| Commission error BL     | 2098| 47.90 | 6.31  |
| Go RT FU                | 1405*| 400.66| 71.76 |
| SSRT FU                 | 1403| 196.95| 84.50 |
| Omission error FU       | 1406| 2.64  | 8.63  |
| Commission error FU     | 1406| 47.48 | 5.99  |

Note. RT – reaction time. SSRT – Stop Signal reaction time. Omission errors – Wrong Go trials (probability). Commission errors – Wrong Stop trials (probability).

Table S2
Correlations between behavioral performance data from fMRI SST and neural brain activity

|                         | fMRI inhibition-error processing BL | Go RT BL | SSRT BL | Omission error BL | Commission error BL | fMRI inhibition-error processing FU | Go RT FU | SSRT FU | Omission error FU | Commission error FU |
|-------------------------|------------------------------------|----------|---------|-------------------|---------------------|------------------------------------|----------|---------|-------------------|---------------------|
| fMRI inhibition-error processing BL | 1                                  | 0.049*   | 0.084***| -0.153***         | 0.156***            | 0.058                              | 0.032    | -0.021  | -0.018            | -0.015              |
| Go RT BL                | 1                                  | -0.340***| 0.322***| -0.194***         | 0.038               | 0.407***                          | -0.124***| 0.086** | -0.188***         |                     |
| SSRT BL                 | 1                                  | -0.693***| -0.700***| 0.015             | -0.147***           | 0.174***                          | -0.060*  | 0.130***|                     |                     |
| Omission error BL       | 1                                  | -0.853***| -0.108** | 0.187***          | -0.078**            | 0.158***                          | -0.016***|                     |                     |
| Commission error BL     | 1                                  | 0.064°   | 0.028   | 0.072°            | 0.025***            | -0.250***                         | -0.001   |                     |                     |
| fMRI inhibition-error processing FU | 1                                  | -0.300***| 0.245***| 0.448***          | -0.448***           |                     |                     |                     |
| Go RT FU                | 1                                  | -0.300***| 0.245***| 0.448***          | -0.448***           |                     |                     |                     |
| SSRT FU                 | 1                                  | -0.594***| 0.815***| 0.654***          | -0.654***           |                     |                     |                     |
| Omission error FU       | 1                                  | 0.064°   | 0.028   | 0.072°            | 0.025***            | -0.250***                         | -0.001   |                     |                     |
| Commission error FU     | 1                                  | -0.300***| 0.245***| 0.448***          | -0.448***           |                     |                     |                     |

Note. ° p≤.10, * p≤.05, ** p≤.01, *** p≤.001. RT – reaction time. SSRT – Stop Signal reaction time. Omission errors – Wrong Go trials (probability). Commission errors – Wrong Stop trials (probability).
On each trial of the MID task, participants are presented with one of three cues: a triangle, a circle with a line through it, or a circle with three lines through it. Each cue is presented for 250 ms, either on the left or on the right of the screen. The type of cue, and the cue’s location predict the reward value (possibility of winning 0, 2, or 10 points when responding correctly), and the location (left or right side of the screen) of a subsequently presented target (a white square). The cue stimulus is followed by a fixation cross (variable: 4000–4500 ms), which in turn is followed by the presentation of the target stimulus for a varied duration (between 250–400 ms). Subjects were told that they could win the predicted reward if they correctly indicate the location of the target by pressing a button with the index finger. If participants responded too early or too late they did not receive any reward. Feedback on reward points was given following the presentation of the target. In order to increase motivation, participants received a single sweet for every five points that they won. Task difficulty was varied using an algorithm that ensured that participants were successful on 66% of trials, and that they did not win more than 200 points. There were 22 trials per condition (no win, small win, big win). Total task duration was 11 min. Participants were familiarized with the task during a practice session for 3 min prior to scanning. In the scanner, participants were reminded of the instructions.
Data preparation

In short, for both tasks, data were slice-time corrected. Then, all volumes were aligned to the first volume and non-linear warping was performed to normalize slices to the standard Montreal Neurological Institute (MNI) space. Afterwards, images were smoothed with a Gaussian kernel of 5 mm full width at half-maximum (FWHM). At the first level of analysis, for each subject, linear models were created by convolving the canonical hemodynamic response function with the onsets of each trial-type to form regressors of interest. For each subject, movement parameters were added to the design matrix as regressors of no interest.

Supplement C

Influence of control variables on constructs of interest

![Graph](image)

Fig. S3. Sex differences for fMRI reward anticipation and fMRI inhibition-error processing at baseline.
Fig. S4. IQ effects on trait and decisional forms of impulsivity at baseline. A Trait impulsivity. B Delay discounting. C Delay aversion.
Fig. S5. Significant sex differences for fMRI paradigms and for delay discounting as a form of decisional impulsivity at follow-up.
Fig. S6. Significant IQ and age effects on fMRI paradigms and delay discounting as one form of decisional impulsivity at follow-up. Note. Age in days.
Fig. S7. Distribution of z-standardized (predicted) values for trait and decisional forms of impulsivity and for fMRI brain responsivity.
**Supplement E**

**Associations between all constructs of interest**

*Fig. S8.* Baseline associations between all constructs of interest. *Note.* ° $p \leq .10$, * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$, uncorrected. fMRI reward anticipation represents mean ROI activity in VS. fMRI inhibition-error processing reflects weighted mean ROI activity (CFA) in pre-SMA and IFG. Delay discounting represents mean of distinct categorical scores from KIRBY (K1-K3).
**FU2 associations (young adulthood)**

|                         | fMRI reward anticipation FU2 | fMRI inhibition-error processing FU2 | Trait impulsivity FU2 | Delay discounting FU2 |
|-------------------------|------------------------------|-------------------------------------|-----------------------|-----------------------|
| fMRI reward anticipation FU2 | ![Histogram](image) | ![Histogram](image) | ![Histogram](image) | ![Histogram](image) |
| fMRI inhibition-error processing FU2 | ![Histogram](image) | ![Histogram](image) | ![Histogram](image) | ![Histogram](image) |
| Trait impulsivity FU2 | ![Histogram](image) | ![Histogram](image) | ![Histogram](image) | ![Histogram](image) |
| Delay discounting FU2 | ![Histogram](image) | ![Histogram](image) | ![Histogram](image) | ![Histogram](image) |

**Fig. S9.** Follow-up associations between all constructs of interest. *Note.* $^*$ $p \leq .10$, $^*$ $p \leq .05$, $^{**} p \leq .01$, $^{***} p \leq .001$, uncorrected. fMRI reward anticipation represents mean ROI activity in VS. fMRI inhibition-error processing reflects weighted mean ROI activity (CFA) in pre-SMA and IFG. Delay discounting represents mean of distinct categorical scores from KIRBY (K1-K3).
**Supplement F**

**Associations between constructs of interest – outlier excluded**

![Graph](image)

**Fig. S10.** Relationship between fMRI reward anticipation and fMRI inhibition-error processing activity in adolescence; extreme values excluded; $p=0.048$.

![Graph](image)

**Fig. S11.** Relationship between fMRI reward anticipation activity and trait impulsivity in adolescence; extreme values excluded; $p=0.551$. 
Fig. S12. Relationship between fMRI reward anticipation activity and delay discounting in adolescence; extreme values excluded; \( p=0.476 \).

Fig. S13. Relationship between fMRI reward anticipation activity and delay aversion in adolescence; extreme values excluded; \( p=0.576 \).
Fig. S14. Relationship between fMRI inhibition-error processing activity and trait impulsivity in adolescence; extreme values excluded; \( p=0.043 \).

Fig. S15. Relationship between fMRI inhibition-error processing activity and delay discounting in adolescence; extreme values excluded; \( p=0.810 \).
Fig. S16. Relationship between fMRI inhibition-error processing activity and delay aversion in adolescence; extreme values excluded; $p=0.163$.

Fig. S17. Relationship between fMRI reward anticipation and fMRI inhibition-error processing activity in young adulthood; extreme values excluded; $p=0.739$. 
Fig. S18. Relationship between fMRI reward anticipation activity and trait impulsivity in young adulthood; extreme values excluded; $p=0.073$.

Fig. S19. Relationship between fMRI reward anticipation activity and delay discounting in young adulthood; extreme values excluded; $p=0.686$. 
Fig. S20. Relationship between fMRI inhibition-error processing activity and trait impulsivity in young adulthood; extreme values excluded; $p=0.026$.

Fig. S21. Relationship between fMRI inhibition-error processing activity and delay discounting in young adulthood; extreme values excluded; $p=0.413$. 
Supplement G

Plots of residuals and plots of random effects for mixed-effects models addressing changes in brain responsivity-impulsivity relationships

Fig. S22. Plots of residuals for mixed-effects models: change in brain responsivity-impulsivity relationships from baseline to follow-up. *Note.* A - changes in association between trait impulsivity and reward anticipation; B - changes in association between trait impulsivity and inhibition-error processing; C - changes in association between delay discounting and reward anticipation; D - changes in association between delay discounting and inhibition-error processing.
Fig. S23. Plots of random effects for visit in mixed-effects models: change in brain responsivity-impulsivity relationships from baseline to follow-up. Note. A - changes in association between trait impulsivity and reward anticipation; B - changes in association between trait impulsivity and inhibition-error processing; C - changes in association between delay discounting and reward anticipation; D - changes in association between delay discounting and inhibition-error processing.
Appendix H

Post-hoc analyses

Post-hoc simple-slope analyses for models on changes from baseline/adolescence to follow-up/young adulthood:

Table S3
Results from simple-slope analyses for change in trait impulsivity (dependent variable) with fMRI reward anticipation as predictor

| Trait impulsivity | visit | fMRI reward anticipation | Estimate | SE  | t    | df  | p   |
|-------------------|-------|--------------------------|----------|-----|------|-----|-----|
|                   | 1     | sstest                   | 0.43     | 0.97| 0.44 | 281 | 0.66|
|                   | 1.5   | sstest                   | 0.49     | 0.97| 0.50 | 281 | 0.62|
|                   | 2     | sstest                   | 0.55     | 0.97| 0.57 | 281 | 0.57|
|                   | sstest* | -1                      | -0.19    | 0.08| -2.48| 281 | 0.01*|
|                   | sstest | 0                        | -0.07    | 0.05| -1.33| 281 | 0.19|
|                   | sstest | 1                        | 0.05     | 0.08| 0.65 | 281 | 0.52|

Note. ° p ≤ 0.10, * p ≤ 0.05, ** p ≤ 0.01, *** p ≤ 0.001. sstest - A 'sstest' value in a particular column indicates that the simple slope for this variable was being tested.

Table S4
Results from simple-slope analyses for change in delay discounting (dependent variable) with fMRI reward anticipation as predictor

| Delay discounting | visit | fMRI reward anticipation | Estimate | SE  | t    | df  | p   |
|-------------------|-------|--------------------------|----------|-----|------|-----|-----|
|                   | 1     | sstest                   | -0.44    | 0.90| -0.48| 272 | 0.63|
|                   | 1.5   | sstest                   | -0.38    | 0.90| -0.43| 272 | 0.67|
|                   | 2     | sstest                   | -0.33    | 0.90| -0.37| 272 | 0.71|
|                   | sstest* | -1                      | -0.17    | 0.07| -2.49| 272 | 0.01*|
|                   | sstest | 0                        | -0.07    | 0.05| -1.41| 272 | 0.16|
|                   | sstest | 1                        | 0.04     | 0.07| 0.52 | 272 | 0.60|

Note. ° p ≤ 0.10, * p ≤ 0.05, ** p ≤ 0.01, *** p ≤ 0.001. sstest - A 'sstest' value in a particular column indicates that the simple slope for this variable was being tested.
Fig. S24. Plots of simple slopes for trait impulsivity as dependent variable with fMRI reward anticipation activity as the only neuronal predictor.

Fig. S25. Plots of simple slopes for delay discounting as dependent variable with fMRI reward anticipation activity as the only neuronal predictor.
Significant correlations were obtained for the dimensions of impulsivity (trait impulsivity: $r_{\text{partial}}=.334$, $p<.001$; delay discounting: $r_{\text{partial}}=.148$, $p<.001$). Non-significant associations were found for fMRI data (reward anticipation: $r_{\text{partial}}=.030$, n.s.; inhibition-error processing: $r_{\text{partial}}=.078$, n.s.) indicating substantial developmental changes in neural processing from adolescence to young adulthood. Figure S24 below presents plots of changes for constructs of interest from adolescence to young adulthood on an individual level.

![Figure S26](image-url)

**Fig. S26.** Plots of changes for constructs of interest from baseline to follow-up. Note. A – trait impulsivity; B – delay discounting; C – fMRI reward anticipation activity; D – fMRI inhibition-error processing activity.
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