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Anticipation of monetary gain but not loss in healthy older adults

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SUPPLEMENTARY RESULTS: STUDY 1

Self-report and neuropsychological measures. Younger adults reported having a more expansive future time perspective ($F_{1, 22}$ = 14.414, P = .001) than older adults. Younger adults also performed better than older adults on the Digit Symbol task ($F_{1, 22}$ = 28.197, P < .0005), Category Naming ($F_{1, 22}$ = 4.958, P < .05), and Trail Making Test ($F_{1, 22}$ = 5.590, P < .05). See **Supplementary Table 4** for all means and standard deviations.

MID task performance & valence and arousal. The two groups did not differ in cumulative earnings on the task (T_{22} = –0.058, P = .95) with younger adults earning an average of $44.67±$7.58 (mean±sd) and older adults earning an average of $44.83±$6.58.

An ANOVA conducted on cue-elicited affect yielded a main effect of magnitude ($F_{2, 21}$ = 77.124, P < .0005), which was qualified by a two-way interaction of valence and magnitude ($F_{2, 21}$ = 7.342, P < .005), indicating that high magnitude gain cues increased positive arousal (PA) and high magnitude loss cues increased negative arousal (NA) across all participants. Between-group comparisons of PA ratings for gain cues and NA ratings for loss cues revealed that younger adults reported higher levels of NA for Lose $5.00 cues than older adults (T_{22} = 5.899, P < .008). Affect ratings for the other five cues did not differ between groups at the threshold corrected for multiple comparisons (all P > .008).

For both age groups, within-subject t-tests (corrected for 8 comparisons, P < .006) indicated that arousal was greater for $5.00 than $0.00 for both gain (young: T_{11} = 7.60, P < .006; older: T_{11} = 6.09, P < .006) and loss cues (young: T_{11} = 7.60, P < .006; older: T_{11} = 6.38, P < .006). Both age groups indicated that valence was greater for gain $5.00 than gain $0.00 cues (young: T_{11} = 6.63, P < .006; older: T_{11} = 6.09, P < .006). For younger adult participants, a within-subject t-test indicated that valence was lower (i.e.,

more negative) for lose $5.00 than lose $0.00 cues (young: $T_{11} = –6.63$, $P < .006$). However, older adult participants did not endorse low valence associated with loss cues, and so within-subject t-tests of valence revealed no significant differences between lose $5.00 and lose $0.00 cues ($T_{11} = –0.90$, $P = .38$). See **Supplementary Figure 1** for a two-dimensional plot of raw valence and arousal ratings.

Statistical Maps

Gain ($0.50, $5.00) versus non-gain ($0.00) anticipation. Anticipation of gain activated foci in several striatal regions, including the caudate and putamen for both age groups (**Supp. Table 1**). Additional regions activated by both groups included the anterior insula, thalamus, anterior cingulate, and medial (mesial prefrontal cortex) and middle frontal gyri. While older adults showed a reduced spatial extent for clusters of activations in the striatum, they also showed more widespread activation than younger adults. Older adults showed additional clusters of activation in both frontal and parietal cortices, including more superior regions of middle and medial frontal gyri, inferior parietal lobule, and precuneus. See **Supplementary Figure 2** for activation maps.

Loss ($0.50, $5.00) versus non-loss ($0.00) anticipation. Anticipation of loss activated foci in the anterior insula, inferior frontal gyrus, medial caudate, and midbrain in younger adults at the global threshold and the ventral striatum at the small volume corrected threshold (**Supp. Table 1a**). Anticipation of loss activated foci in the middle frontal gyrus, anterior cingulate, and precentral gyrus in older adults at the global threshold, and bilateral clusters in the anterior insula emerged at the small volume corrected threshold (**Supp. Table 1b**). See **Supplementary Figure 3** for activation maps.

Gain ($0.50, $5.00) versus fail to gain ($0.50, $5.00) outcomes. No significant clusters emerged for either age group at the global threshold. At the small volume corrected threshold, both age groups showed activation in left mesial prefrontal cortex and ventral striatum (**Supp. Table 1**). Visual inspection of activation timecourses

extracted from VOIs reveals that this effect was driven by decreased MPFC and VS activation in response to gain miss outcomes (instead of increased activation in response to gain hits). See **Supplementary Figures 10a**, **b** for activation maps.

Avoid loss ($0.50, $5.00) versus loss ($0.50, $5.00) outcomes. No significant clusters emerged for either age group at the global threshold. At the small volume corrected threshold, both age groups showed activation in the ventral striatum for loss avoidance (**Supp. Table 1**). Visual inspection of activation timecourses extracted from the VOI revealed that this effect was driven by decreased VS activation in response to miss outcomes (instead of increased activation in response to hits / loss avoidance). Younger adults showed an additional region of activation in the insula and older adults showed an additional region of activation in the MPFC. See **Supplementary Figures 10c**, **d** for activation maps.

Group differences. Between-group t-tests revealed no significant age differences during gain anticipation. For loss anticipation, younger adults showed more activation in the anterior insula and medial caudate (**Fig. 2)**. For gain outcomes, younger adults showed more deactivation in the left insula. For loss avoidance outcomes, older adults showed more activation in the left medial frontal gyrus, right ventral striatum (caudate/putamen), and right hypothalamus, while younger adults showed more deactivation in the right insula. All regions only met the small volume corrected threshold, with the exception of the hypothalamus in loss avoidance, which met the global threshold (**Supp. Table 2**).

VOI Analyses

Anticipatory activation in the VS. A mixed-model ANOVA with valence (2), magnitude (3), and outcome (2) as within-subject factors and age (2) as the between-subject factor of anticipatory activation (TR 4) averaged within 6 mm diameter spheres placed in the right VS yielded a main effect of magnitude ($F_{2, 21} = 15.58$, $P < .0005$) qualified by a two-way interaction of valence and magnitude ($F_{2, 21} = 3.916$, $P < .05$),

indicating that activation during anticipation of gain was more highly modulated by magnitude than during anticipation of loss. Although the interaction with age was not significant, within-group ANOVAs (corrected for four comparisons, $P < .013$), revealed significant linear main effects of magnitude on ventral striatal activation for gain cues ($F_{2, 10} = 32.143$, $P < .0005$) and somewhat less for loss cues ($F_{2, 10} = 23.471$ $P < .005$) in younger adults. While older adults also showed a significant linear magnitude effect for gain cues ($F_{2, 10} = 12.576$, $P < .01$), they did not for loss cues ($F_{2, 10} = 1.881$, $P = .198$) (**Supp. Fig. 4**) (**Supp. Discussion**). Additionally, there were no significant effects of outcome, indicating that this relationship in the VS did not differ as a function of subsequent hits or misses (all $P > .05$). See **Supplementary Figure 5** for full activation timecourses.

Ventral striatal activation during gain anticipation correlated with self-reports of PA ($R = .42$, $P < .05$) and mean-deviated arousal ($R = .36$, $P < .05$), but not valence ($R = .24$, $P = .14$) or NA ($R = .21$, $P = .17$) (**Supp. Fig. 7a**). None of the self-report variables correlated with ventral striatal activation during loss anticipation (all $P > .05$) (**Supp. Fig. 7b**).

Anticipatory activation in the MCAUD. A mixed-model ANOVA with valence (2), magnitude (3), and outcome (2) as within-subject factors and age (2) as the between-subject factor of anticipatory activation (TR 4) averaged within 6 mm diameter spheres placed in the left MCAUD yielded a main effect of magnitude ($F_{2, 21} = 21.81$, $P < .0005$) qualified by a two-way interaction of valence and magnitude ($F_{2, 21} = 5.55$, $P < .05$). Additionally, there were no significant effects of outcome, indicating that this relationship in the MCAUD did not differ as a function of subsequent hits or misses (all $P > .05$).

Medial caudatal activation during gain anticipation did not correlate with any of the self-report variables (all $P > .05$) (**Supp. Fig. 7c**). However, unlike the ventral striatum, medial caudatal activation during loss anticipation correlated with self-reports

of NA ($R = .42$, $P < .05$) and valence ($R = -.44$, $P < .05$), but not PA ($R = -.03$, $P = .45$) or arousal ($R = .33$, $P = .06$) (all $P > .05$) (**Supp. Fig. 7d**).

Anticipatory activation in the AINS. A mixed-model ANOVA with valence (2), magnitude (3), and outcome (2) as within-subject factors and age (2) as the between-subject factor of anticipatory activation (TR 4) averaged within 6 mm diameter spheres placed in the right anterior insula yielded a main effect of magnitude ($F_{2, 21} = 23.15$, $P < .0005$) and a two-way interaction of valence and magnitude ($F_{2, 21} = 3.57$, $P < .05$). There were no significant main or interaction effects of outcome indicating that anticipatory activation did not differ as a function of subsequent hits or misses.

Anterior insular activation during gain anticipation correlated with self-reports of PA ($R = .41$, $P < .05$) and mean-deviated arousal ($R = .35$, $P < .05$), but not valence ($R = .22$, $P = .15$) or NA ($R = .20$, $P = .17$) (**Supp. Fig. 7e**). Like the medial caudate, insular activation during loss anticipation correlated with self-reports of NA ($R = .38$, $P < .05$) and valence ($R = -.40$, $P < .05$), but not PA ($R = -.03$, $P = .45$) or arousal ($R = .30$, $P = .08$) (**Supp. Fig. 7f**).

Outcome activation in the MPFC. A mixed-model ANOVA with valence (2), magnitude (3), and outcome (2) as within-subject factors and age (2) as the between-subject factor of outcome activation (TR 8) averaged within 6 mm diameter spheres placed in the left mesial prefrontal cortex yielded a main effect of outcome ($F_{1, 22} = 10.269$, $P < .005$). There were no main or interaction effects of age suggesting that the two groups did not differ in activation at outcome. Within-group paired samples t-tests were not significant at the threshold corrected for multiple comparisons ($P < .013$), but did reveal non-significant trends toward a difference between \$0.50/\$5.00 successful gain outcomes and \$0.50/\$5.00 miss gain outcomes for younger adults ($T_{11} = 2.825$, $P = .017$) and older adults ($T_{11} = 2.027$, $P = .068$). Activation was not significantly greater for \$0.50/\$5.00 loss avoidance outcomes than \$0.50/\$5.00 loss outcomes for either

younger (T_{11} = 0.236, P = .818) or older adults (T_{11} = 2.180, P = .052), as in prior research. For full activation timecourses see **Supplementary Figure 11.**

Outcome activation in the VS. A mixed-model ANOVA with valence (2), magnitude (3), and outcome (2) as within-subject factors and age (2) as the between-subject factor of outcome activation (TR 8) averaged within 6 mm diameter spheres placed in the right VS yielded significant main effects of magnitude ($F_{2, 21}$ = 7.732, P < .005) and outcome ($F_{1, 22}$ = 35.11, P < .0005) and a two-way magnitude by outcome interaction ($F_{2, 21}$ = 5.717, P < .05). There were no main or interaction effects of age suggesting that the two groups did not differ in activation at outcome. Within-group paired samples t-tests (corrected for 4 comparisons, P < .013) revealed greater activation for $0.50/$5.00 successful gain outcomes than $0.50/$5.00 miss gain outcomes for both younger (T_{11} = 3.128, P < .013) and older adults (T_{11} = 3.821, P < .013). Activation was also greater for $0.50/$5.00 loss avoidance outcomes than $0.50/$5.00 loss outcomes for both younger (T_{11} = 4.069, P < .013) and older adults (T_{11} = 3.265, P < .013). For full activation timecourses see **Supplementary Figure 12**.

Outcome activation in the MCAUD. A mixed-model ANOVA with valence (2), magnitude (3), and outcome (2) as within-subject factors and age (2) as the between-subject factor of outcome activation (TR 8) averaged within 6 mm diameter spheres placed in the left MCAUD yielded no significant main or interaction effects of outcome (all P > .05).

SUPPLEMENTARY RESULTS: STUDY 2

MIL task performance. The two groups did not differ in cumulative earnings on the task (T_{22} = .036, P = .97) with younger adults earning an average of $1.92±$6.04 (mean±sd) and older adults earning an average of $1.83±$5.44. All participants subsequently played an additional monetary task (as part of a larger independent study) and those with negative net earnings on the MIL task were able to bring their total task earnings for the session above zero.

An ANOVA conducted on hit rate yielded a main effect of condition ($F_{1, 22}$ = 4.948, P < .05) such that performance was higher for gain acquisition than loss avoidance trials replicating previous work using a similar task with younger adults [1]. The condition by age interaction was not significant ($F_{1, 22}$ = 0.261, P = .61) suggesting that younger and older adults did not differ in overall task performance (**Supp. Table 3**). Both age groups selected a higher percentage of high probability gain acquisition cues (younger: T_{11} = 6.00, P < .0005; older: T_{11} = 5.72, P < .0005) and loss avoidance cues (younger: T_{11} = 4.97, P < .0005; older: T_{11} = 6.50, P < .0005) and showed no bias in selecting between neutral cues (younger: T_{11} = 0.00, P = 1.00; older: T_{11} = –0.83, P = .42) (**Supp. Fig. 13**).

There was a significant main effect of trial quarter ($F_{3, 20}$ = 15.66, P < .0005) suggesting that both age groups improved in performance over the course of the task. The interaction of task condition, trial quarter, and age was not significant ($F_{3, 20}$ = 1.338, P = .29). Younger and older adults did not significantly differ in accuracy on any quarter of either the gain acquisition or loss avoidance trials (all P > .05) (**Supp. Fig 14**). Although not statistically significant, visual inspection of the data suggests that older adults may perform slightly better than the young in the first ten trials of gain acquisition, but slightly worse than the young in the second quarter of loss avoidance. It is possible that older adults may be slower than younger adults to learn on loss avoidance trials, but show no difference in overall performance. Younger adults show a somewhat

convex learning curve whereas the learning curve of older adults appears more concave. Larger samples may be necessary to comprehensively assess potential age differences in learning over time.

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SUPPLEMENTARY DISCUSSION: STUDY 1

Some patterns in the present data did not strictly conform to prior findings using the MID task. Specifically, younger adults (but not older adults) showed increased ventral striatal activation to both anticipated gains and losses (but only at a small volume corrected threshold). This may be due to modifications that made the MID task more amenable to older adults, including introduction of literal rather than abstract cues and three rather than four levels of incentive magnitude. However, even in the present study, the linear effect of loss anticipation on ventral striatal activation was not as robust as that of gain anticipation in younger adults. The similarity in striatal activation during anticipation of gains and losses in the younger adults observed is more consistent with activation patterns observed in medial caudate regions in previous studies [1–3].

Additionally, the results at outcomes did not strictly conform to prior findings using the MID task. Gain versus non-gain outcomes did not activate mesial prefrontal cortex at corrected significance levels, nonetheless, all analyses suggested such an effect at trend levels, suggesting that the present design may have lacked power to detect this effect [4].

Although this is the first event-related FMRI study of incentive anticipation in older adults, the pattern of results is compatible with findings from other research. Specifically, the reduced spatial extent and more diffuse patterns of activation in older adults are consistent with findings in other neuroimaging studies of aging [5, 6]. Theorists have debated whether more widespread activation reflects functionally adaptive reorganization with age, compensation in response to a decline in function, or both [7, 8]. Since performance was equated across groups, the present study cannot address the plausibility of these alternative interpretations. However, the increased activation in parietal cortex accompanying a reduced extent of activation in the striatum during gain anticipation is consistent with the prior findings indicating that increased parietal

activation in older adults correlates with performance on a category learning task which also recruits the caudate [9]. Future work will further investigate the role of these parietal activations in incentive processing, as well as choice.

An atypical feature of the present study is that the sample consisted of participants with an above-average level of education. Although all participants were recruited from the San Francisco Bay Area community (Stanford undergraduates excluded), nearly all younger and older adults had at least a bachelor's degree, with many in each age group also holding single or multiple graduate degrees. Despite this high level of education, older adults performed significantly worse on some measures of cognitive ability. These differences, however, were not related to self-reported affect, neural activation, or behavior on the task. Nevertheless, future studies will need to address the generalizability of these results to samples varying more in socio-economic status. Although our sample was fairly homogeneous across a range of demographic variables, all studies comparing younger and older adults should take caution in comparing a randomly selected community sample of older adults to a potentially more homogeneous sample of college undergraduates.

A prevalent concern in cross-sectional FMRI studies of older adults involves potential baseline differences in the shape of the hemodynamic response functions (HRFs) (e.g., due to cardiovascular confounds) [5]. A basic perceptual task was also implemented in the present study, but analyses revealed no age differences in the amplitude of HRFs between age groups. Thus, even if differing HRFs were of concern, this should primarily bias localization analyses (for which fit statistics depend on regressors convolved with a canonical HRF) and not statistical tests comparing modulation of raw signal peaks extracted from individuals' volumes of interest between conditions. Of additional potential concern, age-related differences in activation may result from increased gray matter atrophy and white matter demyelination in older adults. Specifically, recent reports show that both the insula and caudate undergo

substantial atrophy with age [10]. One could infer that structural degeneration in these regions should then uniformly degrade all patterns of activation in the older adults. However, while both regions were less activated during loss anticipation in older adults, they showed no significant differences in either region during gain anticipation. Additionally, care was taken to ensure that data from volumes of interest only included gray matter for each individual.

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SUPPLEMENTARY METHODS: STUDY 1

Participants. Five additional subjects were recruited but excluded prior to analysis due to an imaging artifact (73 y.o. male), excessive head motion (23 y.o. male), vision trouble (71 y.o. male), medication (75 y.o. male), and inability to follow instructions (79 y.o. female). Participants were recruited from the San Francisco Bay Area and then followed up by laboratory personnel for a complete phone interview to determine eligibility. The phone interview included questions relevant to their safety and their history of physical or mental disorders (specifically stroke and neurological damage, history of heart failure, or prescription medicine shown to interfere with the blood oxygen level dependent signal, e.g., either psychiatric or cardiac). If eligible, participants completed two sessions. In the first session, participants completed a questionnaire packet, a cognitive test battery, a thorough explanation of the scanning procedures, and a practice version of the MID task. In the second session, participants engaged in the MID task while undergoing FMRI. In addition to earnings on the task, participants were paid $20/hour for their participation.

Prior to being scanned, participants received a verbal description of the task, and completed a 15-minute practice version. Participants were also shown the money that they could earn by performing the task successfully in the scanner, and all reported believing that they would receive cash based on their performance at the end of the experiment. Once in the scanner, anatomical scans were acquired. Participants then engaged in two 16-minute blocks of the incentive task and one 6-minute block of a visual localizer task during functional scan acquisition. After the scan, in addition to affective ratings, participants estimated the ratio of gain cues to lose cues (no age differences were found in ratio estimates).

Questionnaire measures. A demographics questionnaire assessed the age, marital status, current and previous occupational status, level of income, number of

years of education, and ethnicity of the participants. Several individual difference measures were included to ensure that between-group differences in self-reported affect or BOLD activation were not due to baseline group differences in trait affect or personality. The trait version of the Positive and Negative Affect Schedule (PANAS-T) [1] was used to assess the extent to which participants experienced each of 22 emotional descriptors on a regular basis. A measure of physical health, the Wahler Physical Symptom Inventory (WPSI) [2], asked participants to indicate how often they are bothered by each of 42 physical symptoms. The Future Time Perspective (FTP) scale [3] is a 10-item self-report measure that assesses how much time people feel they have left in their lives. A 60-item short form of the Neuroticism-Extroversion/Introversion-Openness-to-Experience Personality Inventory (NEO-SF) [4] asked participants to indicate their level of endorsement of each of the statements related to commonly-assessed personality traits. The 5-item Subjective Well-being and Satisfaction with Life Scale (SWLS) [5] assessed general overall satisfaction with life.

Neuropsychological battery. The Mini-Mental Status Exam (MMSE) [6] was administered to all participants as a screen for dementia. Three subtests from the Wechsler Adult Intelligence Scale Third Edition (WAIS-III) [7] with well-validated ranges for older adults were administered to each participant. The WAIS-III Digit Span test requires that participants repeat numerical strings frontward and backward. It is considered a measure of working memory and correlates well with general intelligence. The WAIS-III Digit Symbol test requires participants to match symbols with letters as quickly and accurately as possible in a 120-second period. The WAIS-III Vocabulary test requires that participants provide definitions for words presented in both written and spoken form, and correlates well with verbal intelligence. Two subtests, Verbal and Category Fluency, of the Delis-Kaplan Executive Function System [8] were administered. The Verbal Fluency (FAS) subtest requires that participants name as many words as possible beginning with a given letter (first F, then A, then S) in a 60-second period. The

similar Category Fluency subtest requires that participants name as many words as possible that fall into the given category (animals) in a 60-second period. The Trail Making Test (TMT) from the Halstead-Reitan Neuropsychological Test Battery [9] has two parts (A & B) which are both timed until completion. The first part (Trails A) requires that participants sequentially connect 25 encircled numbers on a standard sheet of paper. The second part (Trails B) requires that participants connect a series of numbers and letters in an alternating pattern. Trails B is considered to be a good indicator of general frontal lobe cognitive function.

Visual localizer task. Collection of FMRI data in older adults raises many methodological issues, which necessitate careful sampling and measurement. Even assuming good health, the hemodynamic response of older individuals has been shown to be similar but more variable than that of younger adults in cortical regions [10–13]. Thus, a visual localizer task was included to examine potential age differences in individual hemodynamic response functions (HRFs). The task consisted simply of responding with a button press to flickering checkerboard stimuli that were presented for 2 s, separated by random interstimulus intervals ranging from 2–38 s. Timecourses of activation were extracted from voxels in primary visual cortex (V1) in individual participants. A multivariate GLM revealed no significant effect of age ($F_{1, 11} = 1.214$, $P = .371$). Additionally, it should be noted that none of the participants included in this study have abnormally shaped HRFs (**Supp. Fig. 15**) as has been found previously in FMRI studies of older adults.

VOI Definition. VOI spheres were manually adjusted for individual participants to account for potential anatomical variability between the age groups not corrected for by the Talairach warping procedure and in order to avoid partial voluming of functional signal. The definition procedure began with *a priori* coordinates selected from previous data sets [14–17] which could be shifted in two dimensions within a 10 mm x 10 mm constrained region along at least one fixed plane. An algorithm was created for each

VOI. For the VS, the start coordinates were 11, 12, 0 [15] with the coronal and axial planes fixed. If imposing a 6 mm diameter sphere resulted in sampling of the neighboring ventricle, the sphere was shifted within 10mm right/left. However, for the VS, the *a priori* coordinates were compatible with the anatomy of nearly participant (only two participants required shifting to the right). For the MCAUD, the start coordinates were –9, 13, 9 with the coronal plane fixed. If imposing a 6 mm diameter sphere resulted in sampling of the neighboring ventricle, the sphere was shifted within 10mm right/left or superior/inferior. For the MCAUD, over half of the participants required shifting to the left and only one participant requiring a 1mm shift inferior. For the AINS, the start coordinates were 39, 19, 7 [14, 17] with the sagittal plane fixed. If imposing a 6 mm sphere resulted in sampling of the neighboring CSF, the sphere could be shifted within 10 mm right/left or superior/inferior. All but 4 participants required at least a 1 mm shift in at least one plane. For the MPFC, the start coordinates were –1, 53, –6 [15] with the coronal plane fixed. If imposing a 6 mm sphere resulted in sampling of the neighboring CSF, the sphere could be shifted within 10 mm right/left or superior/inferior. All 24 participants needed at least a 1 mm shift in at least one plane (**Supp. Table 5**).

SUPPLEMENTARY METHODS: STUDY 2

Participants. Twelve younger (age 19–34, six female) and twelve older (age 65–81, six female) adults were recruited from the San Francisco Bay Area and completed one session. Seven younger and all twelve older adults from Study 1 participated in Study 2. An additional five younger adults were new but matched the younger adults from Study 1 on age, education, and socioeconomic status. All participants gave written informed consent, and the experiment was approved by the Institutional Review Board of the Stanford University Medical School. Each participant completed a demographic questionnaire, received a verbal description of the task, and completed a 30 trial practice version. Participants were also shown the money that they could earn by performing the task successfully. Participants then engaged in two 120 trial runs of an incentive learning task. In addition to earnings on the task, participants were paid $20/hour for their participation.

Monetary incentive learning (MIL) task. The design of the monetary incentive learning (MIL) task was inspired by a similar recently published incentive learning paradigm [18]. Across both runs, the entire task included 240 trials. During each trial, participants chose from a pair of abstract cues (decision), viewed their highlighted choice on screen, and received feedback about how much money they won or lost on the trial (outcome) (**Supp. Fig. 17**). The display duration of the first frame of the task was self-paced to accommodate differences in vision and decision reaction time among younger and older participants. Three pairs of cues were used in each run (gain, loss avoidance, neutral). Different pairs of cues were used during practice, run 1, and run 2 to avoid age-related impairments in reversal learning. Within gain and loss avoidance pairs one cue yielded a high probability optimal outcome (60% +$1.00, 40% +$0.00; 60% –$0.00, 40% –$1.00) and the other a low probability optimal outcome (30% +$1.00, 70% +$0.00; 30% –$0.00, 70% –$1.00). Both cues always had no impact on winnings (100% $0.00) in the neutral condition. Each cue within each pair appeared

equally often on the left and right side of the screen within runs. The pairing of cues with outcomes was counterbalanced across participants. The goal of the experiment was to learn which cue in each pair was higher in expected value (high probability gain acquisition, high probability loss avoidance). Each of three trial types was presented 40 times per run in an individually randomized order for each participant.

Hits were calculated as the percentage of correct responses per condition (i.e., the cue associated with a higher expected value) and averaged between runs. As the goal of this study was to test for a significant impairment in loss avoidance but not gain acquistion among older adults, hit rate was analyzed with mixed-model ANOVAs with incentive valence (gain acquisition, loss avoidance) and trial quarter (first 10 trials, second 10 trials, third 10 trials, last 10 trials) as the within-subject factors and age (younger, older) as the between-subject factor. Post-hoc analyses compared hits across all conditions (gain acquisition, loss avoidance, neutral) for each group with within-subject t-tests versus chance (50%) (corrected for six comparisons, $P < .008$). Additional post-hoc tests assessed learning differences between groups over time by comparing accuracy within all four quarters (ten trials per quarter) across both incentive conditions (gain acquisition, loss avoidance) with between-subject t-tests (corrected for eight comparisons, $P < .006$).

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Supplementary Table 1 Group maps for younger adults (a; N = 12) and older adults (b; N=12). Global threshold: $P < .0001$ uncorrected; SVC: $P < .005$ uncorrected. Volume units are micro-liters.

a Younger Adults

	Talairach coordinates (R, A, S)			Peak Z	Volume (μl)
Gain vs nongain anticipation					
L Medial Frontal Gyrus / BA10	–1	55	4	3.187	[SVC]
L Anterior Cingulate	–13	39	–2	4.413	152
R Anterior Insula	25	25	2	4.445	120
L Anterior Insula	–41	13	–2	5.278	288
R Inferior Frontal Gyrus	49	13	–4	4.299	152
L Caudate Head	–13	11	4	4.343	112
L Ventral Striatum / Putamen	–13	11	–3	3.629	[SVC]
R Caudate Head	7	11	12	4.173	72
R Lentiform Nucleus / Putamen	23	1	6	4.835	1136
L Lentiform Nucleus / Putamen	–17	–1	2	5.09	96
R Hypothalamus	9	–5	–10	4.868	64
R Ventral Lateral Nucleus / Thalamus	9	–11	4	4.732	240
R Medial Dorsal Nucleus / Thalamus	5	–11	14	4.172	112
L Middle Frontal Gyrus	–35	–11	38	4.965	88
L Middle Cingulate Gyrus	–9	–13	32	4.529	64
R Lateral Dorsal Nucleus / Thalamus	13	–19	16	4.405	152
L Caudate Body	–17	–21	18	4.982	1272
L Red Nucleus	–5	–23	–8	4.064	64
R Culmen	3	–41	4	4.162	152
L Culmen	–3	–61	–6	4.439	416
R Lingual Gyrus	23	–87	4	4.854	80
Loss vs nonloss anticipation					
R Anterior Insula	29	25	–4	4.402	184
L Middle Cingulate Gyrus	–1	19	40	4.632	120
R Lentiform Nucleus / Putamen	21	19	–8	4.026	64
L Anterior Insula	–35	17	8	4.262	64
L Anterior Insula	–37	15	–4	4.649	96
R Inferior Frontal Gyrus / Ant Insula	41	15	–4	4.526	72
R Ventral Striatum / Caudate	10	11	0	3.302	[SVC]
L Ventral Striatum / Caudate/Putamen	–13	11	–1	3.288	[SVC]
L Caudate Head	–13	7	4	5.063	1504
R Caudate Head	11	5	6	4.736	496
R Red Nucleus	7	–19	–4	4.419	144
Gain vs nongain outcome					
L Medial Frontal Gyrus / BA10	–7	–45	–4	4.003	[SVC]
R Anterior Insula	39	19	4	–3.439	[SVC]
L Ventral Striatum / Putamen	–16	12	0	3.647	[SVC]
Nonloss vs loss outcome					
L Anterior Insula	–39	25	7	–3.486	[SVC]
R Anterior Insula	39	18	0	–3.924	[SVC]
L Ventral Striatum / Putamen	–18	12	0	3.868	[SVC]

b Older Adults

	Talairach coordinates (R, A, S)			Peak Z	Volume
Gain vs nongain anticipation					
L Medial Frontal Gyrus / BA10	–5	51	6	4.968	240
R Middle Frontal Gyrus / BA10	29	51	0	4.426	136
R Medial Frontal Gyrus / BA10	5	47	2	4.369	120
R Middle Frontal Gyrus / BA10	37	45	4	4.553	128
R Anterior Cingulate Gyrus	23	43	4	4.469	136
R Middle Frontal Gyrus / BA8	19	31	36	4.26	64
L Anterior Insula	–29	27	10	4.676	104
R Anterior Insula	35	19	6	4.371	120
L Inferior Frontal Gyrus / Ant Insula	–47	11	14	4.676	144
L Caudate Head	–11	7	6	4.944	576
L Medial Frontal Gyrus / BA6	–13	7	52	4.396	80
R Ventral Striatum / Putamen	15	5	0	4.523	136
L Caudate	–13	1	16	5.167	288
L Middle Frontal Gyrus	–51	1	38	5.023	96
R Caudate Head	11	1	12	5.082	208
R Medial Frontal Gyrus / BA6	11	1	54	4.301	72
L Medial Frontal Gyrus	–37	–5	44	4.566	152
L Medial Frontal Gyrus	–7	–5	58	4.404	104
R Medial Frontal Gyrus	13	–7	58	4.777	344
R Ventral Lateral Nucleus / Thalamus	15	–11	10	4.758	424
L Precentral Gyrus	–25	–15	60	4.675	72
L Lateral Dorsal Nucleus / Thalamus	–11	–17	14	4.903	576
L Paracentral Lobule	–9	–17	46	4.51	128
L Postcentral Gyrus	–39	–19	46	4.535	280
R Cingulate Gyrus	3	–21	32	4.795	408
R Parahippocampal Gyrus	23	–21	–6	4.201	64
L Precentral Gyrus	–25	–27	64	4.81	72
R Cingulate Gyrus	19	–27	32	4.919	128
L Paracentral Lobule	–17	–29	46	4.387	112
L Inferior Parietal Lobule	–35	–37	44	5.119	192
R Precuneus	15	–37	44	4.478	424
R Inferior Parietal Lobule	35	–39	34	5.458	104
L Posterior Cingulate	–9	–43	16	4.943	176
L Posterior Cingulate	–9	–45	26	4.375	112
R Inferior Parietal Lobule	27	–45	42	5.302	368
L Inferior Parietal Lobule	–37	–49	50	4.916	288
L Precuneus	–9	–49	46	4.704	648
L Precuneus	–21	–55	50	4.923	384
R Middle Temporal Gyrus	55	–57	4	4.903	192
R Posterior Cingulate	23	–57	18	4.492	96
R Precuneus	15	–57	50	5.169	544
L Precuneus	–25	–59	26	5.077	160
L Precuneus	–9	–67	46	4.398	184
Loss vs nonloss anticipation					
R Anterior Insula	36	27	11	3.640	[SVC]
L Anterior Insula	–31	23	9	3.815	[SVC]
L Middle Frontal Gyrus / BA46	41	–37	16	4.395	88
R Anterior Cingulate	–13	–37	20	4.336	64
L Precentral Gyrus / BA6	43	7	46	4.485	96

Gain vs nongain outcome					
L Medial Frontal Gyrus / BA10	–4	52	–1	3.274	[SVC]
L Ventral Striatum / Caudate/Putamen	–9	12	–4	2.843	[SVC]
R Ventral Striatum / Caudate/Putamen	8	12	–4	3.167	[SVC]
Nonloss vs loss outcome					
L Medial Frontal Gyrus / BA10	–4	52	–10	4.142	[SVC]
L Ventral Striatum / Caudate	–14	12	1	4.247	[SVC]
R Ventral Striatum / Caudate/Putamen	11	10	–2	4.025	[SVC]

Supplementary Table 2 Comparison of older versus younger adults (Global threshold: $P < .0001$ uncorrected; SVC: $P < .005$ uncorrected). Volume units are micro-liters.

	Talairach coordinates (R, A, S)			Peak Z	Volume (μl)
Gain vs non-gain anticipation					
No significant clusters					
Loss vs non-loss anticipation					
L Medial Caudate	–7	13	9	–3.767	[SVC]
R Anterior Insula / IFG	31	27	–2	–3.883	[SVC]
Gain vs non-gain outcome					
L Anterior Insula	–26	26	6	3.405	[SVC]
Non-loss vs loss outcome					
L Medial Frontal Gyrus	–1	46	4	3.556	[SVC]
R Anterior Insula	41	19	0	3.396	[SVC]
R Caudate/Putamen	14	8	1	3.364	[SVC]
R Hypothalamus	7	–3	–2	4.450	88

Supplementary Table 3 Monetary incentive learning (MIL) task performance. Both younger and older adults chose a higher percentage of high probability gain and loss avoidance cues and showed no preference between neutral cues. Standard deviations listed in parentheses.

	Younger Adults (N = 12)	Older Adults (N = 12)
High Probability Gain	75.81% (14.46%)	78.55% (17.32%)
High Probability Loss Avoidance	68.65% (12.99%)	68.03% (9.61%)
Neutral	50.00% (23.04%)	45.10% (20.44%)

Supplementary Table 4 Demographics, questionnaire data, and cognitive test battery results. Standard deviations listed in parentheses.

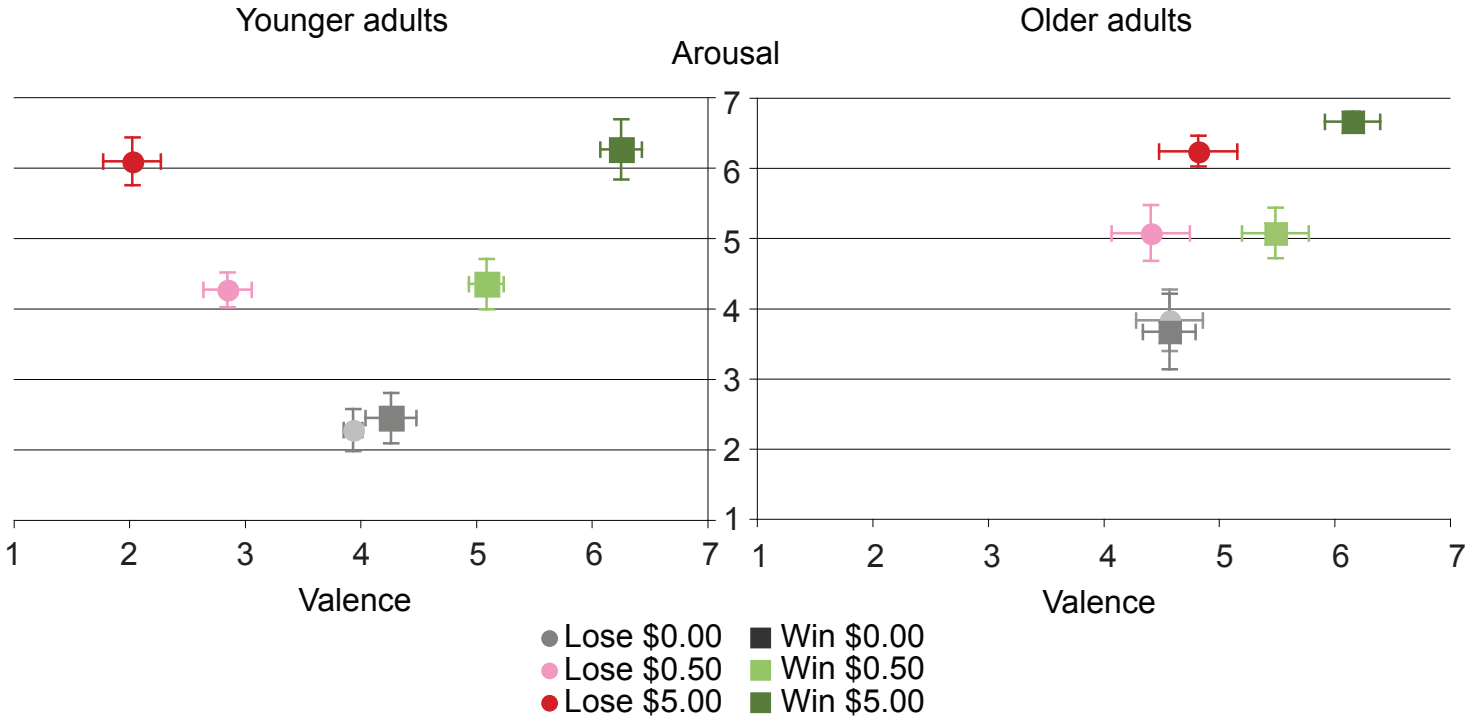
	Younger Adults (N = 12)	Older Adults (N = 12)
Gender (# Female)	6	6
Age (years)	23.75 (2.05) **	72.92 (5.50) **
Education (# of years)	17.00 (2.56)	16.92 (2.84)
Scaled Income	7.75 (4.12)	5.08 (2.81)
Positive Affect (PANAS-T)	38.83 (7.03)	39.50 (5.18)
Negative Affect (PANAS-T)	20.33 (5.21)	17.58 (4.03)
WAHLER	31.00 (16.03)	30.00 (19.69)
FTP	55.58 (8.21) **	39.25 (12.44) **
Neuroticism (NEO-SF)	19.83 (6.46)	15.67 (5.10)
Extraversion (NEO-SF)	30.75 (4.59)	27.58 (6.24)
Openness to Experience (NEO-SF)	32.21 (7.46)	31.83 (5.18)
Agreeableness (NEO-SF)	30.58 (5.18)	33.83 (4.17)
Conscientiousness (NEO-SF)	31.42 (9.77)	31.25 (5.26)
SWLS	21.58 (7.38)	21.17 (4.06)
MMSE	29.00 (1.90)	28.17 (2.48)
Digit Span (WAIS-R)	17.83 (3.33)	16.50 (4.06)
Digit Symbol (WAIS-R)	90.92 (12.94) **	65.92 (9.92) **
Vocabulary (WAIS-R)	49.92 (8.88)	53.33 (5.21)
Verbal Fluency (FAS)	50.08 (18.98)	41.67 (12.17)
Category Naming	23.58 (5.87) *	18.68 (4.91) *
Trails B – Trails A	30.92 (14.04) *	52.00 (27.52) *

* significant difference at $P < .05$ (two-tailed)

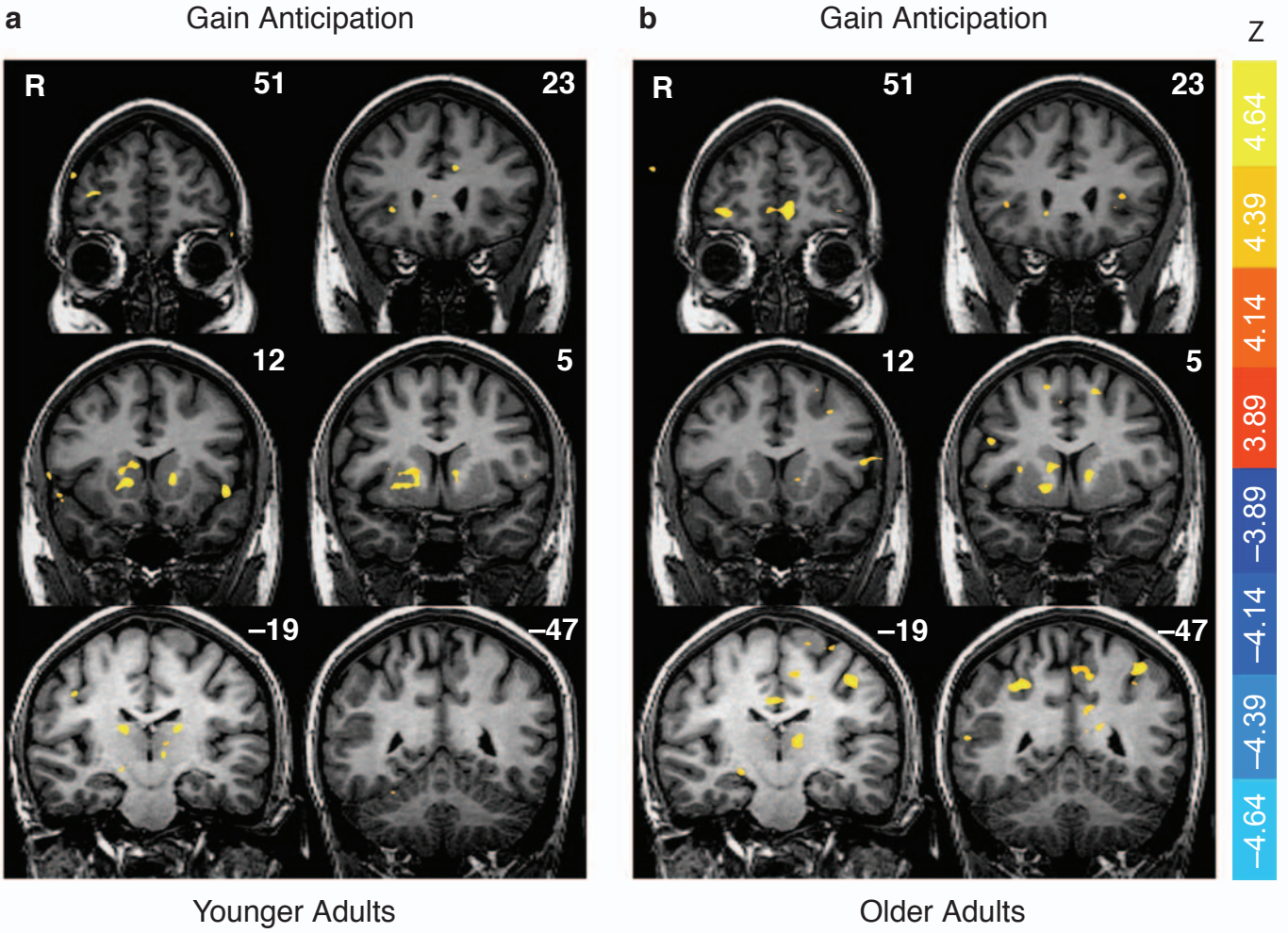
** significant difference at $P < .01$ (two-tailed)

Supplementary Table 5 Placement of 6 mm diameter VOI spheres. Blank cases are locations in which the *a priori* talairach coordinates (R, A, S) were compatible with the participant's anatomy (ventral striatum = 11, 12, 0; medial caudate = –9, 13, 9; anterior insula = 39, 19, 7; mesial PFC = –1, 53, –6).

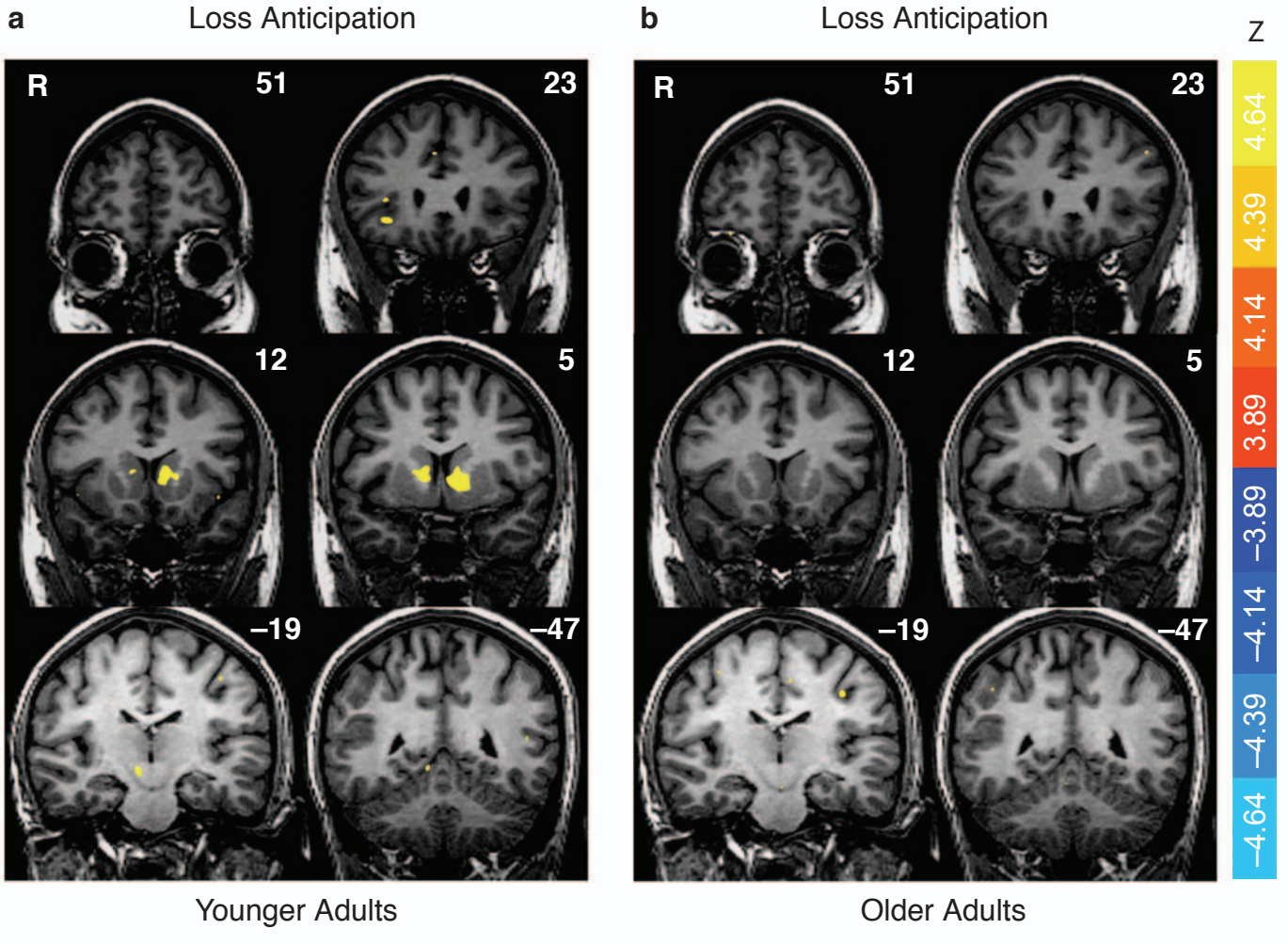
	R VS	L MCAUD	R AINS	L MPFC
Young adults			39, 20, 7	–7, 53, –6
			39, 21, 7	–4, 53, –6
		–11, 13, 9	39, 18, 7	–4, 53, –4
				–4, 53, –3
			39, 23, 7	–3, 53, –3
			39, 24, 7	–3, 53, –7
			39, 22, 7	–3, 53, –6
		–10, 13, 9	39, 21, 7	–1, 53, –1
			39, 24, 7	–2, 53, –2
		–11, 13, 9	39, 23, 7	–4, 53, –6
				–3, 53, –10
		–11, 13, 9	39, 21, 8	–4, 53, –7
Older adults		–12, 13, 9		–3, 53, –10
	12, 12, 0	–15, 13, 9	39, 19, 8	–5, 53, –5
		–15, 13, 9	39, 23, 7	–3, 53, –5
			39, 22, 7	–3, 53, –7
		–15, 13, 9	39, 28, 7	–6, 53, –2
		–10, 13, 9	39, 25, 10	–6, 53, 0
		–13, 13, 9	39, 22, 9	–5, 53, –4
		–14, 13, 9	39, 23, 6	–3, 53, –6
			39, 20, 7	–10, 53, –6
	13, 12, 0	–11, 13, 9	39, 23, 7	–5, 53, –1
		–14, 13, 9	39, 26, 6	–5, 53, –2
		–15, 13, 8	39, 19, 1	–8, 53, –4
Maximum	R–L = 2mm	R–L = 6mm	R–L = 0	R–L = 9mm
Deviations	A–P = 0mm	A–P = 0mm	A–P = 10mm	A–P = 0mm
	S–I = 0mm	S–I = 1mm	S–I = 9mm	S–I = 10mm



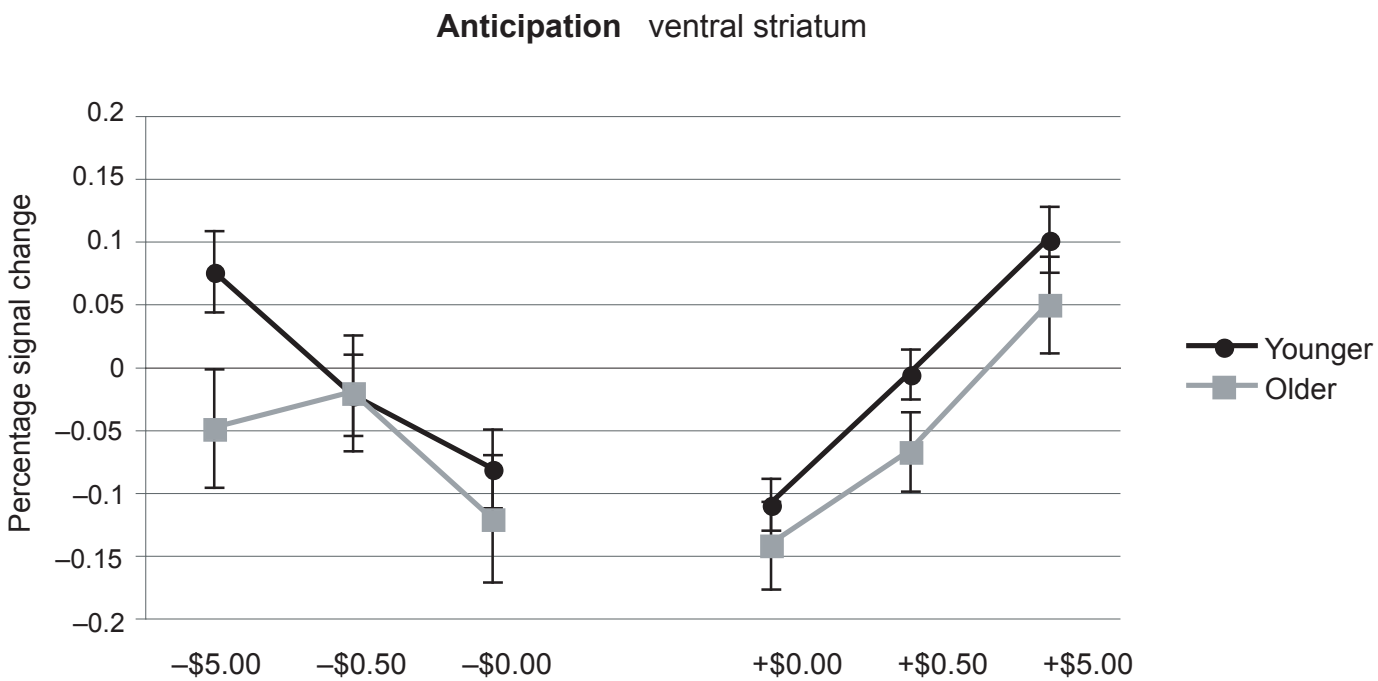
Supplementary Figure 1 Post-task cue ratings. Younger adults self-report increasing negative valence and arousal with loss cues and positive valence and arousal with gain cues in the anticipatory period. Older adults report increasing positive valence and arousal with gain cues, but only show increases in arousal and no change in valence as the magnitude of loss cues increases. Points are plotted according to group means (x,y = valence, arousal). X-error bars correspond to standard error of valence means, and Y-error bars to standard error of arousal means.



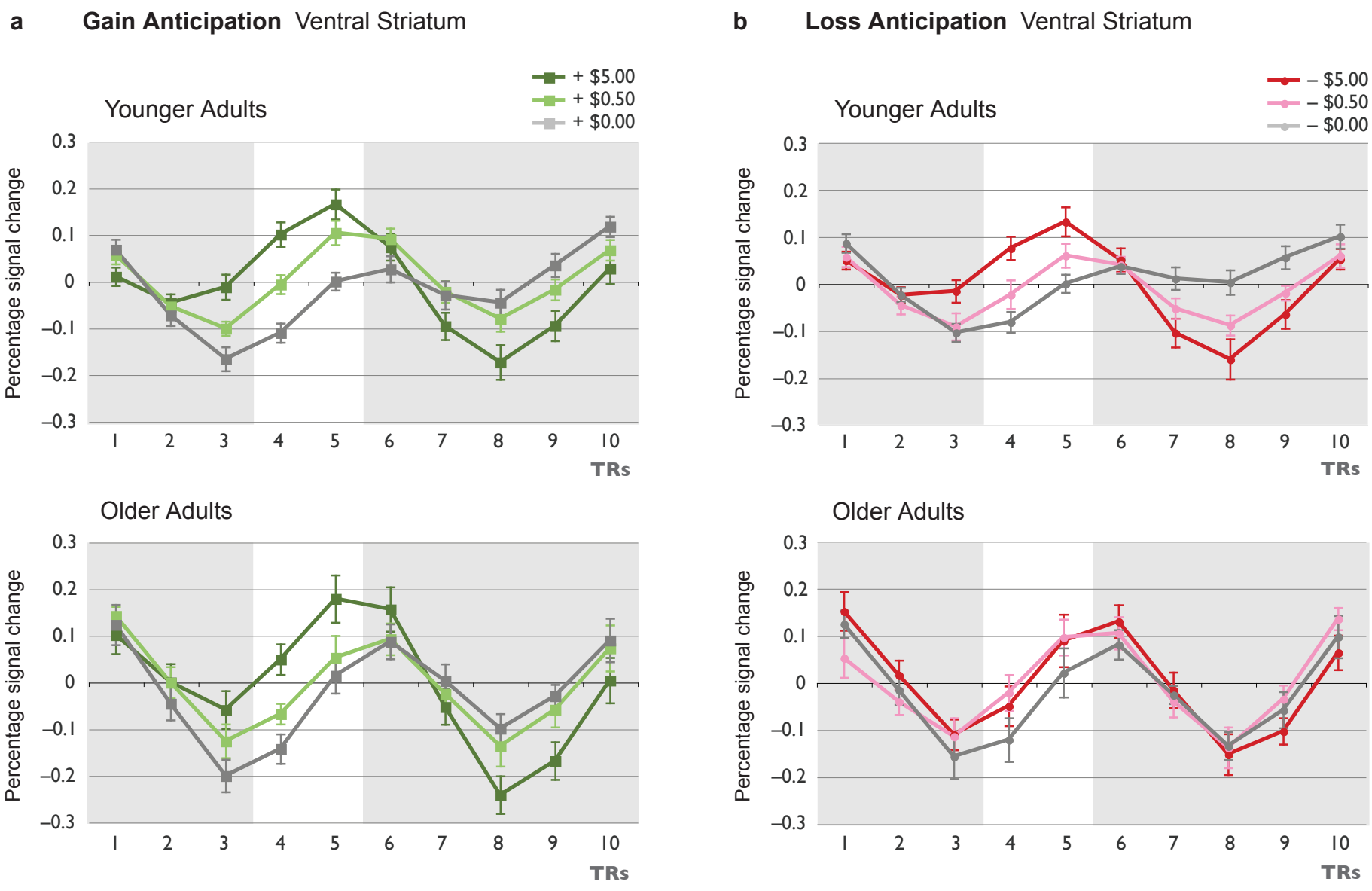
Supplementary Figure 2 Gain versus non-gain anticipation contrast maps for younger adults (a) and older adults (b) ($Z > 3.89$, $P < .0001$ uncorrected). A-value for each coronal image is listed in the upper right (A = 51 through MPFC volume of interest; A = 23 through anterior insula; A = 12, 5 through striatum; A = –19 through medial thalamus; A = –47 through inferior parietal lobule).



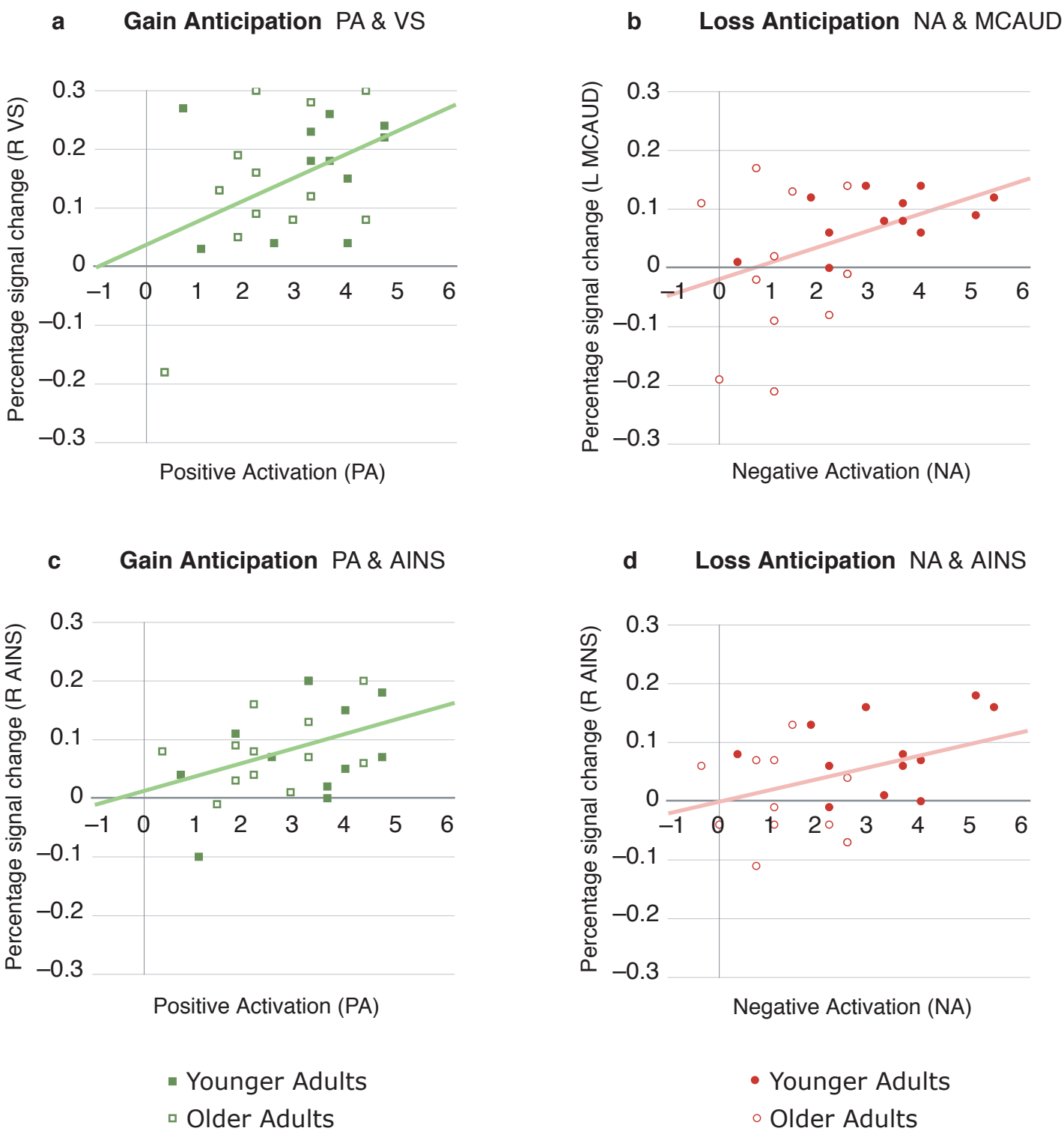
Supplementary Figure 3 Loss versus non-loss anticipation contrast maps for younger adults (a) and older adults (b) ($Z > 3.89$, $P < .0001$ uncorrected). A-value for each coronal image is listed in the upper right (A = 51 through MPFC volume of interest; A = 23 through anterior insula; A = 12, 5 through striatum; A = –19 through medial thalamus; A = –47 through inferior parietal lobule).



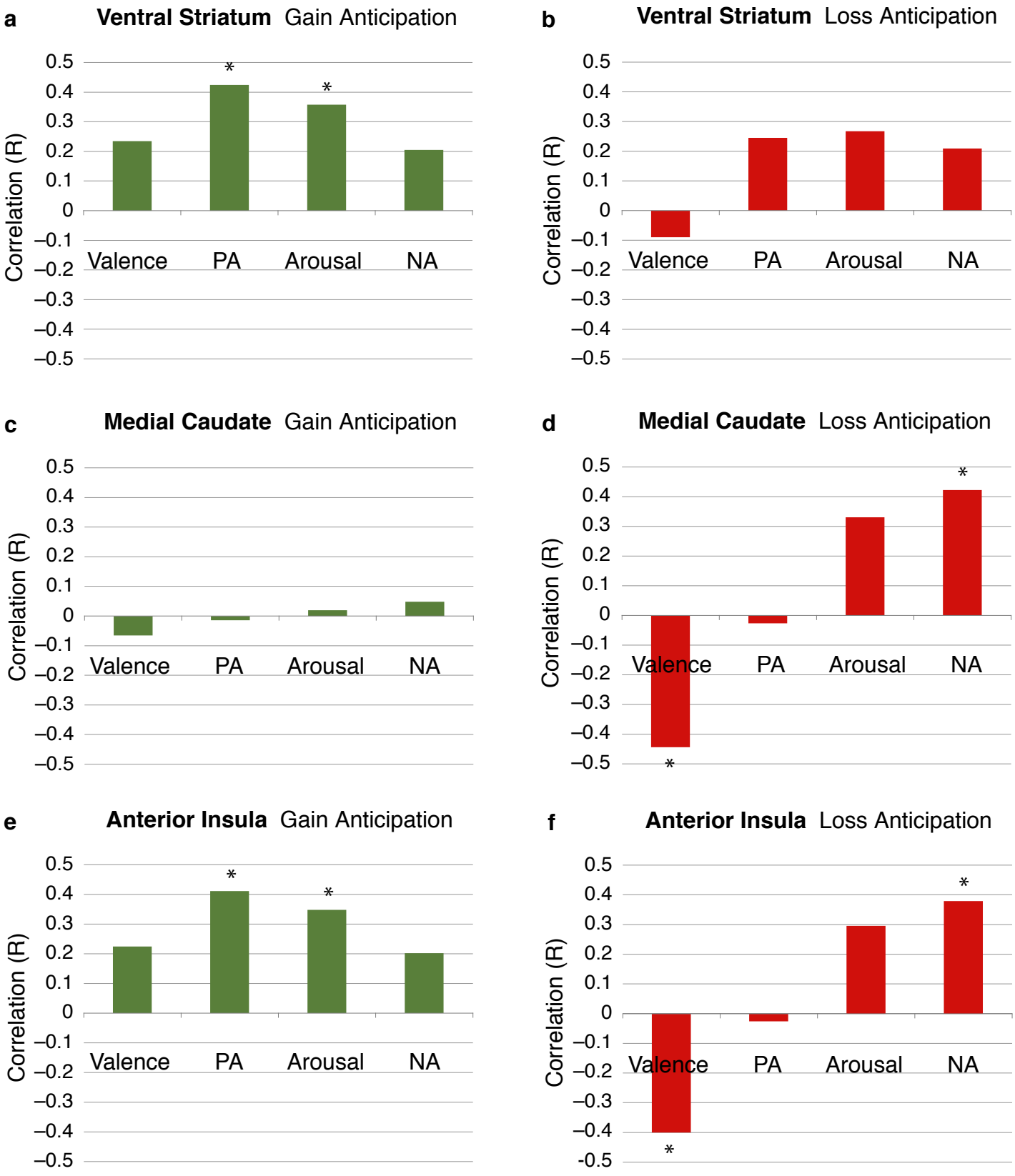
Supplementary Figure 4 BOLD activation extracted from the ventral striatum at anticipation. Younger adults show monotonically increasing activation for gain cues and somewhat less for loss cues in the anticipatory period. Older adults show monotonically increasing activation with gain cues, but non-significant increases in activation for loss cues. Error bars: s.e.m.



Supplementary Figure 5 Timecourses of activation during anticipation (6 s lag) of gain (a) and loss (b) in right ventral striatum indicated with a white background (younger adults, top; older adults, bottom). Y-axis is percentage signal change. Error bars: s.e.m.

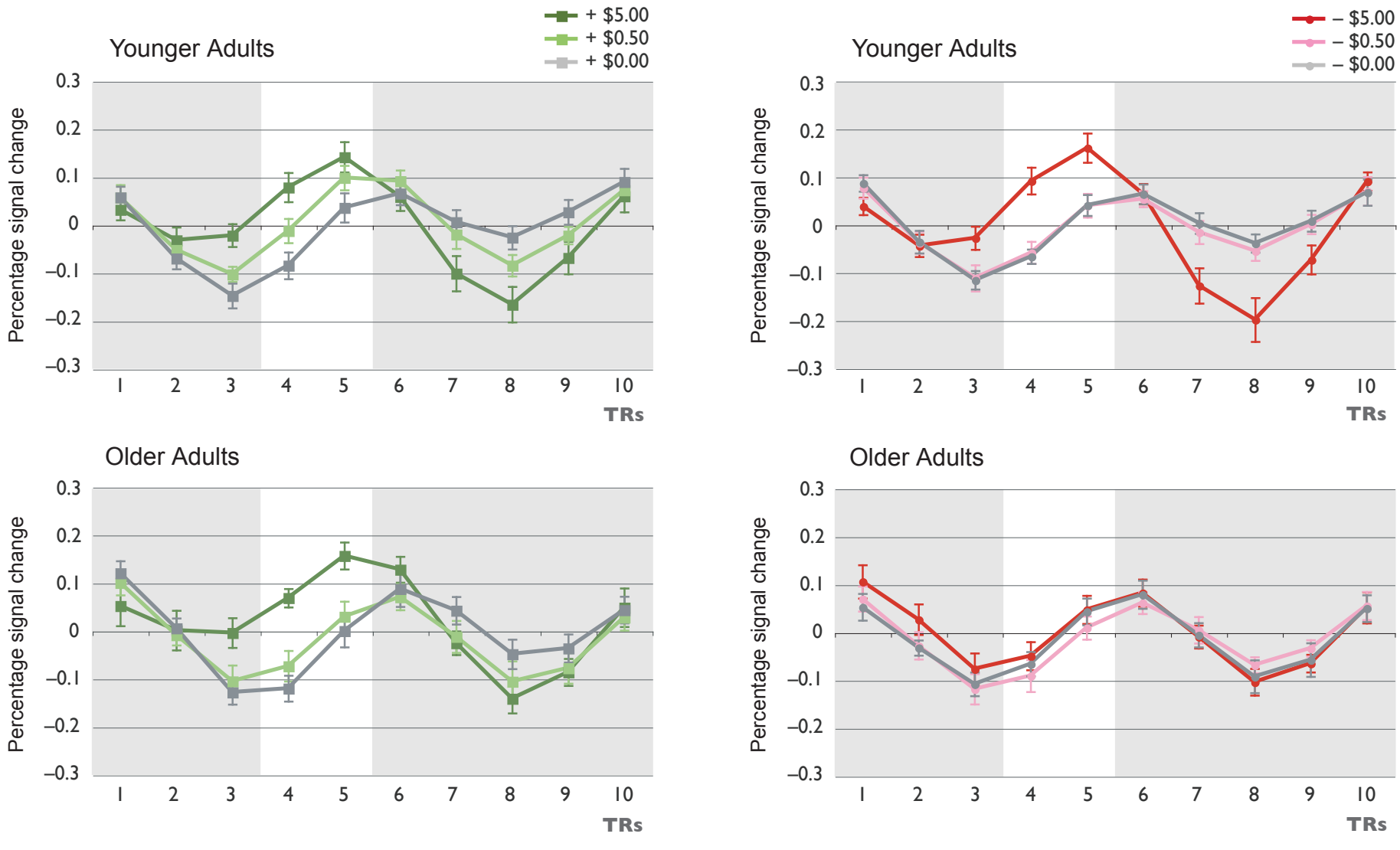


Supplementary Figure 6 Correlations between self-reported affect and brain activation. Cue elicited PA for gain cues correlated with activation in the right VS (a) during gain anticipation. Cue elicited NA for loss cues correlated with activation in the left MCAUD (b) during loss anticipation. Cue elicited PA for gain cues correlated with activation in the right AINS (c) during gain anticipation and cue elicited NA for loss cues correlated with activation in the right AINS (d) during loss anticipation.

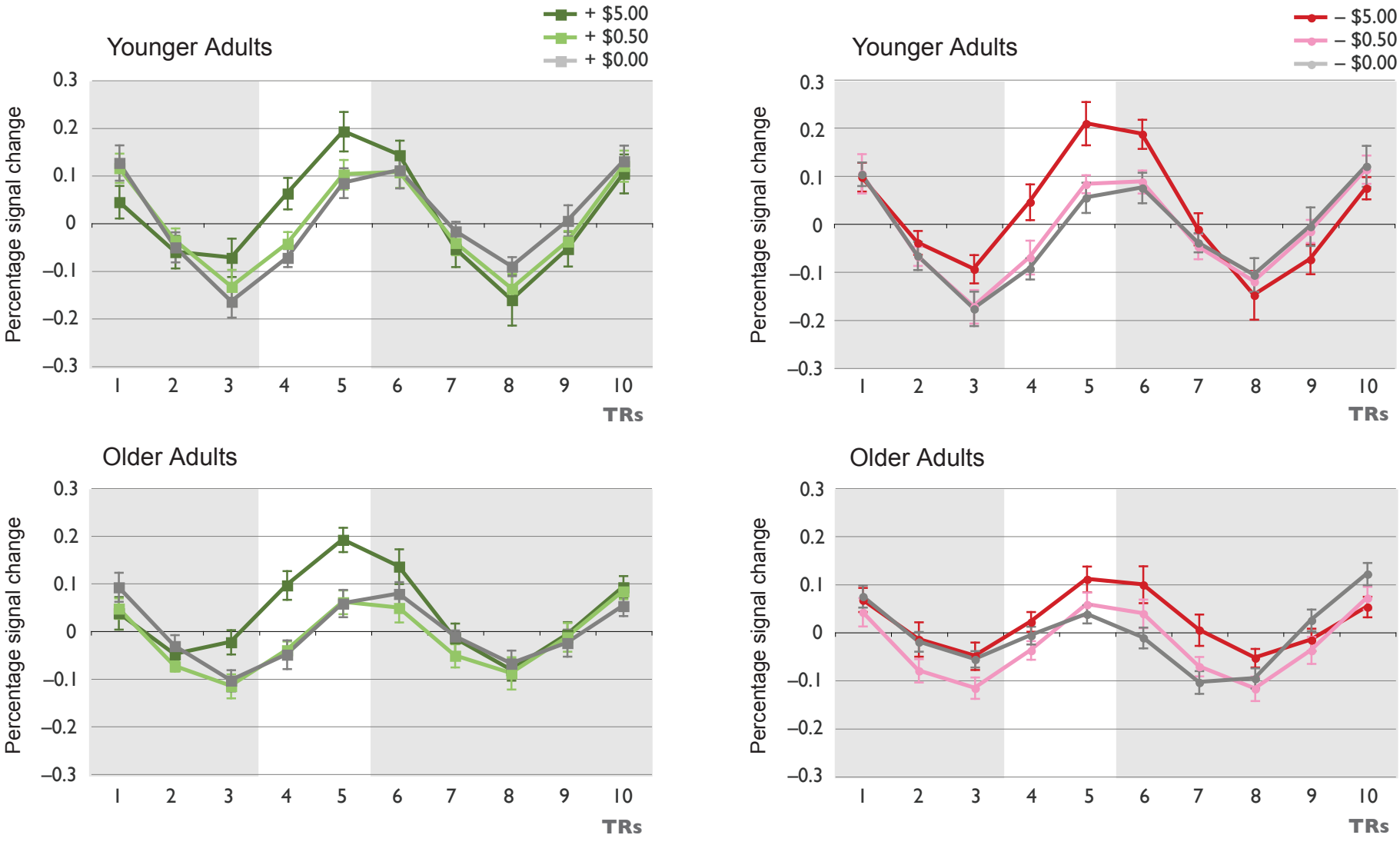


Supplementary Figure 7 Correlations between self-reported affect and brain activation. Activation in the right VS correlated with PA and arousal during gain anticipation (a), but did not correlate with self-reported affect during loss anticipation (b). Activation in the left MCAUD did not correlate with self-reports during gain anticipation (c), but correlated with valence and NA during loss anticipation (d). Activation in the right AINS correlated with PA and arousal during gain anticipation (e) and valence and NA during loss anticipation (f).

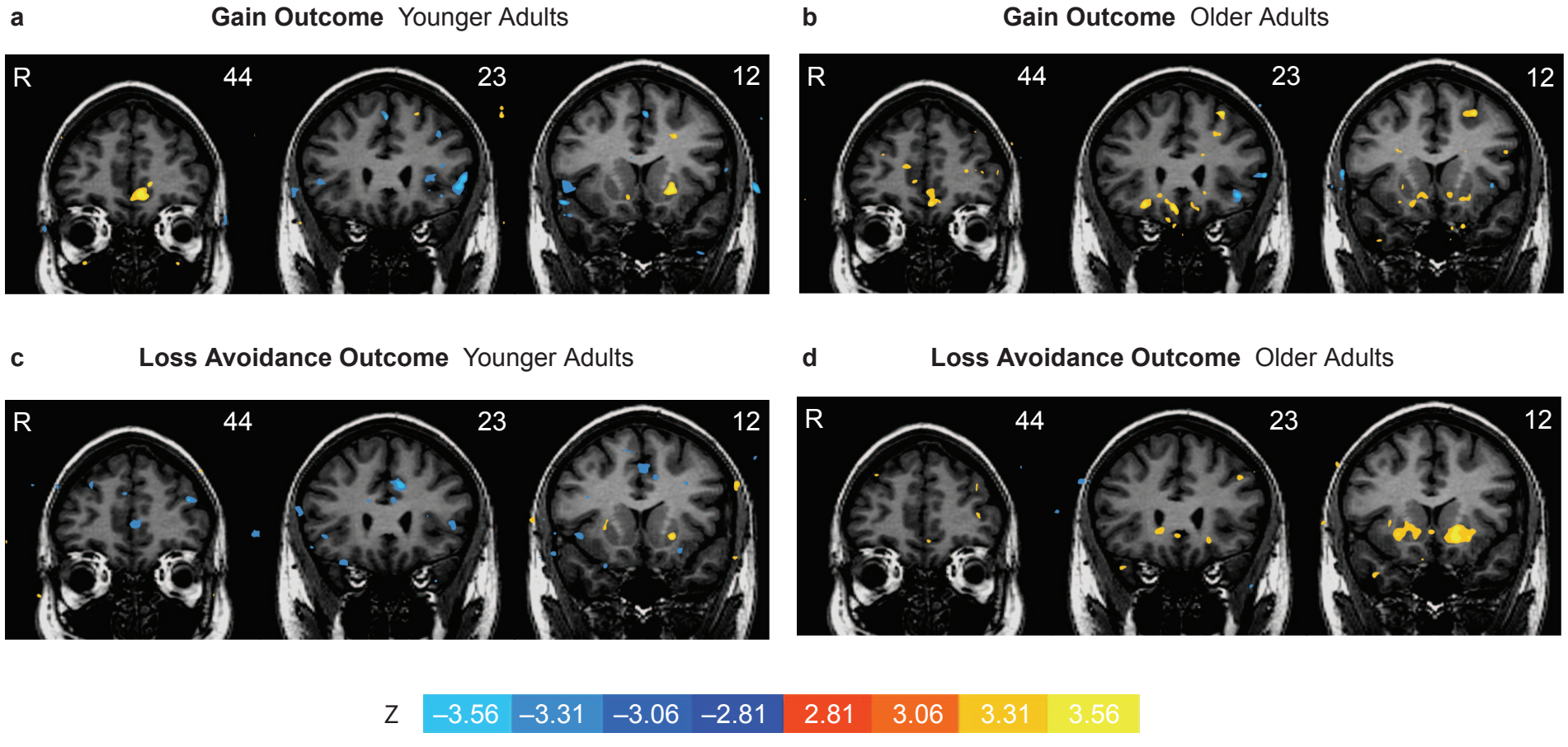
* $P < .05$



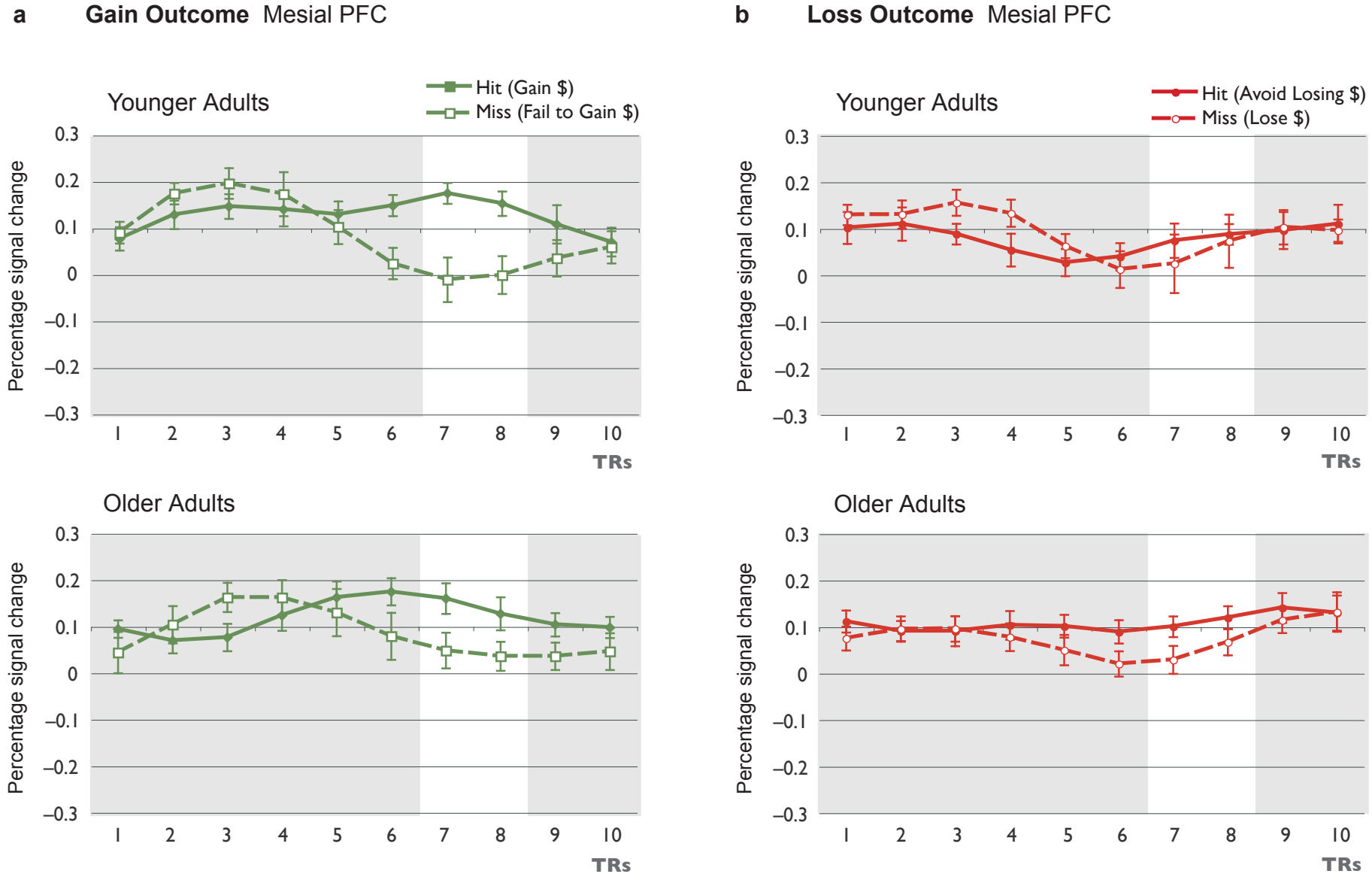
Supplementary Figure 8 Timecourses of activation during anticipation (6 s lag) of gain (a) and loss (b) in left medial caudate indicated with a white background (younger adults, top; older adults, bottom). Y-axis is percentage signal change. Error bars: s.e.m.



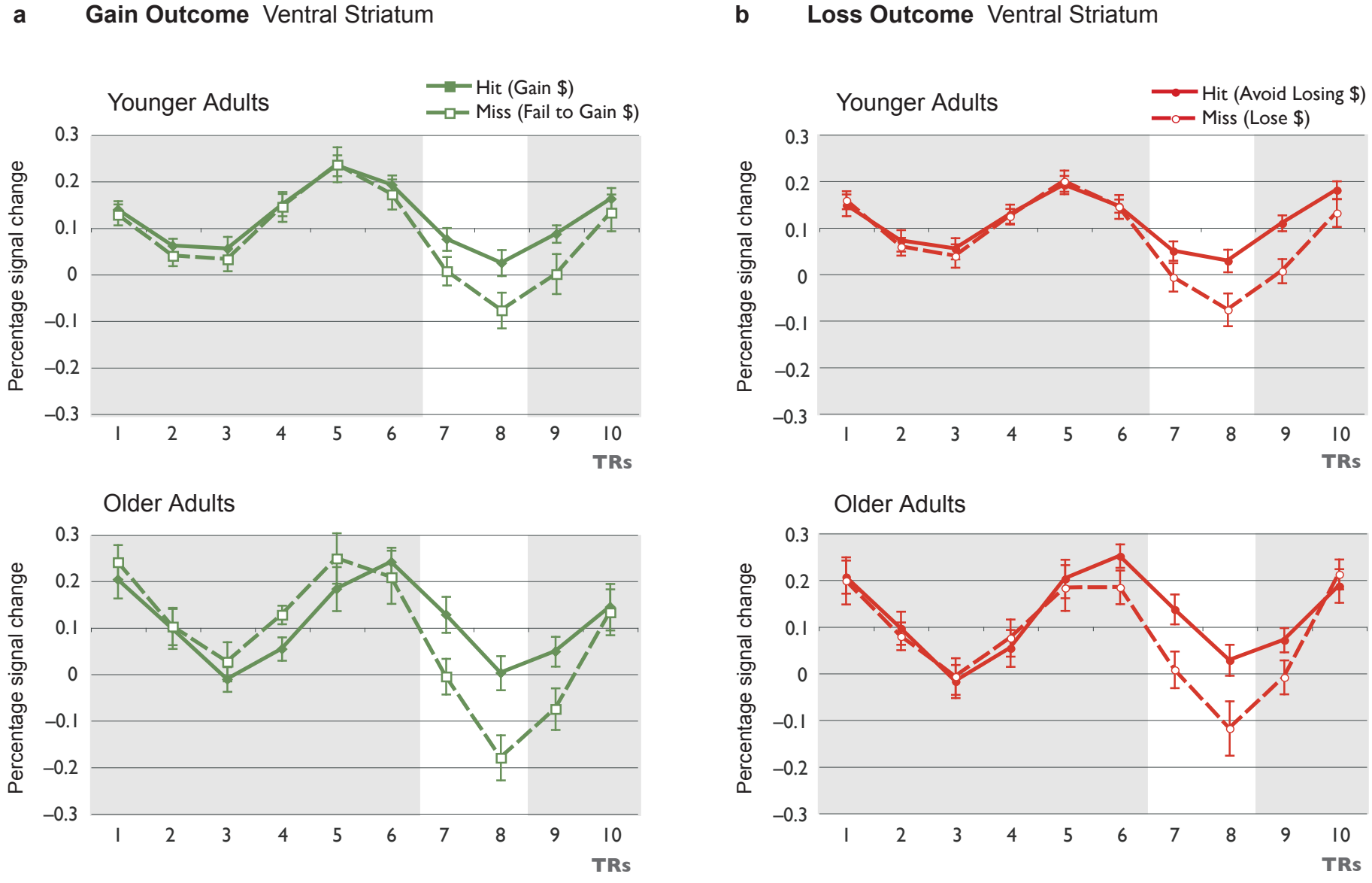
Supplementary Figure 9 Timecourses of activation during anticipation (6 s lag) of gain (a) and loss (b) in right anterior insula indicated with a white background (younger adults, top; older adults, bottom). Y-axis is percentage signal change. Error bars: s.e.m.



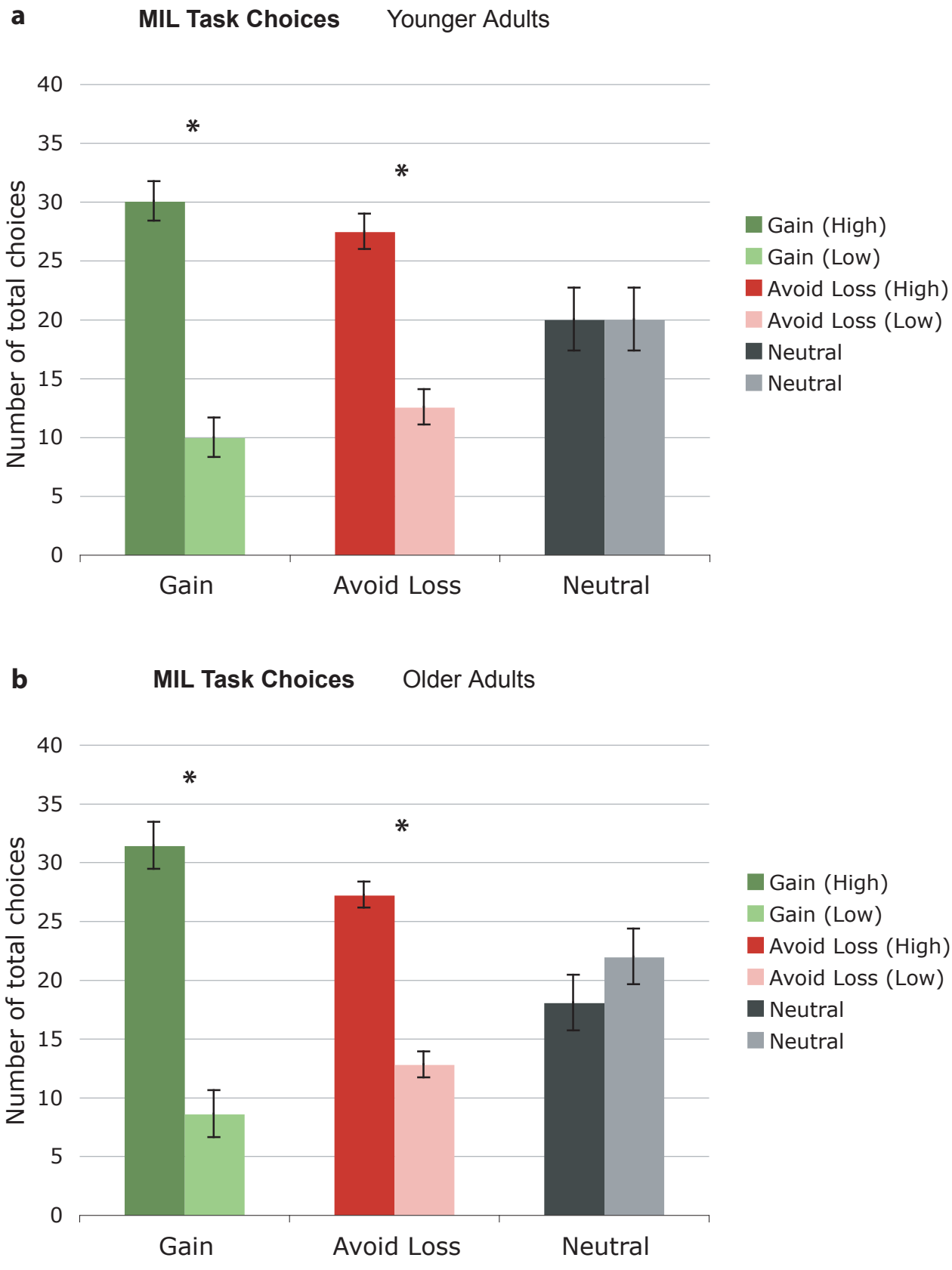
Supplementary Figure 10 Gain versus non-gain outcome (TR 7) contrast maps for younger adults (a) and older adults (b) (SVC: $Z > 2.81$; $P < .005$). Non-loss versus loss outcome (TR 7) contrast maps for younger adults (c) and older adults (d) (SVC: $Z > 2.81$; $P < .005$). A-value for each coronal image is listed in the upper right (A = 44 through mesial prefrontal cortex; A = 23 through anterior insula; A = 12 through striatum).



Supplementary Figure 11 Timecourses of activation during outcome (6 s lag) in left MPFC indicated with a white background (younger adults, top; older adults, bottom). Both groups showed reduced activation for missed gains, relative to gains (a). Neither age group showed modulation of activation by loss outcome in this region (b). Y-axis is percent signal change. Error bars: s.e.m.

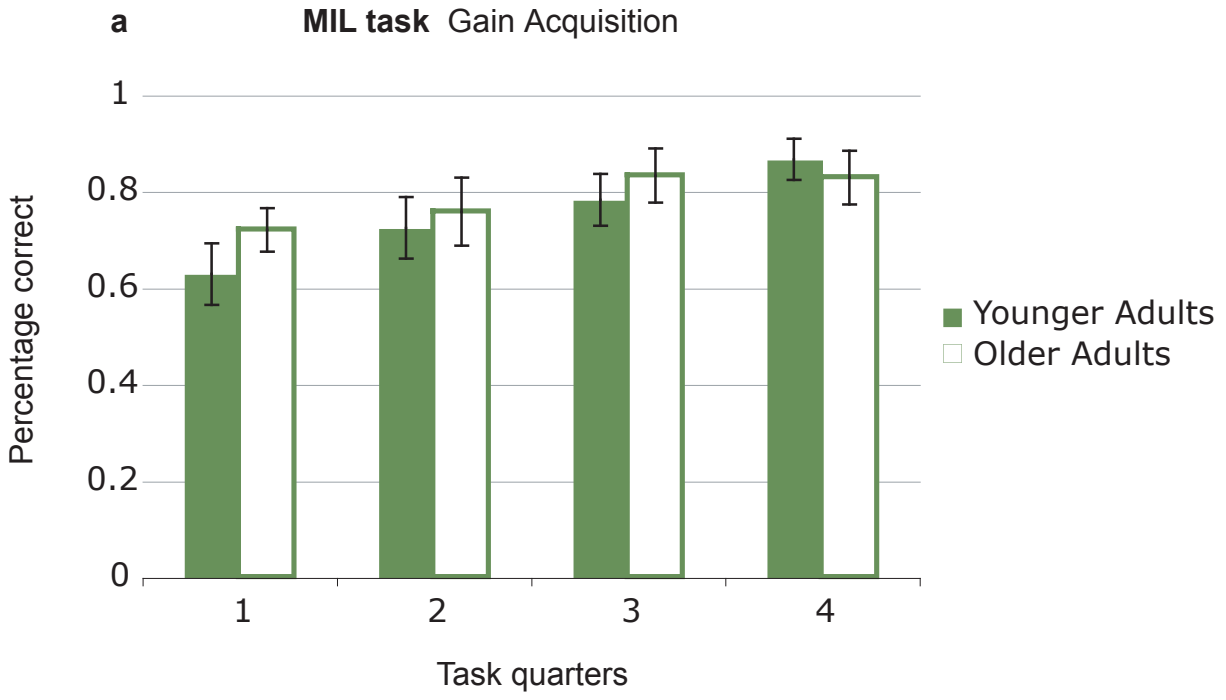


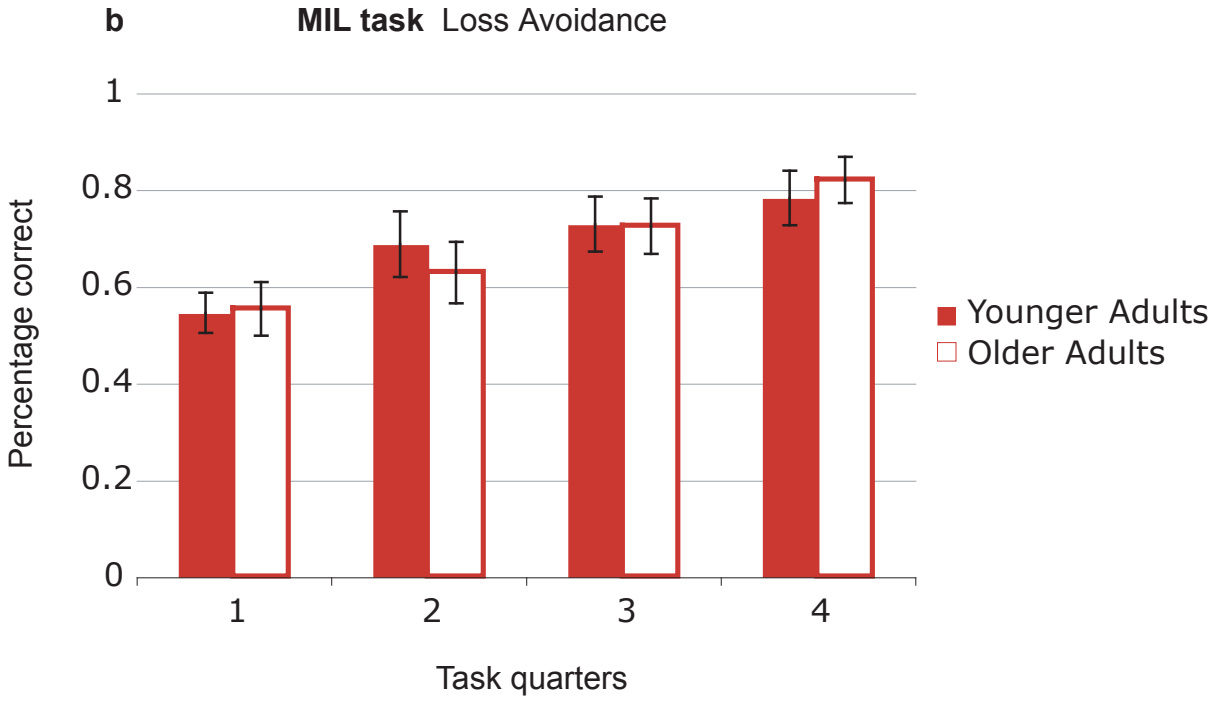
Supplementary Figure 12 Timecourses of activation during outcome (6 s lag) in right ventral striatum indicated with a white background (younger adults, top; older adults, bottom). Both groups showed reduced activation for missed gains, relative to gains (a) and loss outcomes, relative to loss avoidance (b). Y-axis is percent signal change. Error bars: s.e.m.



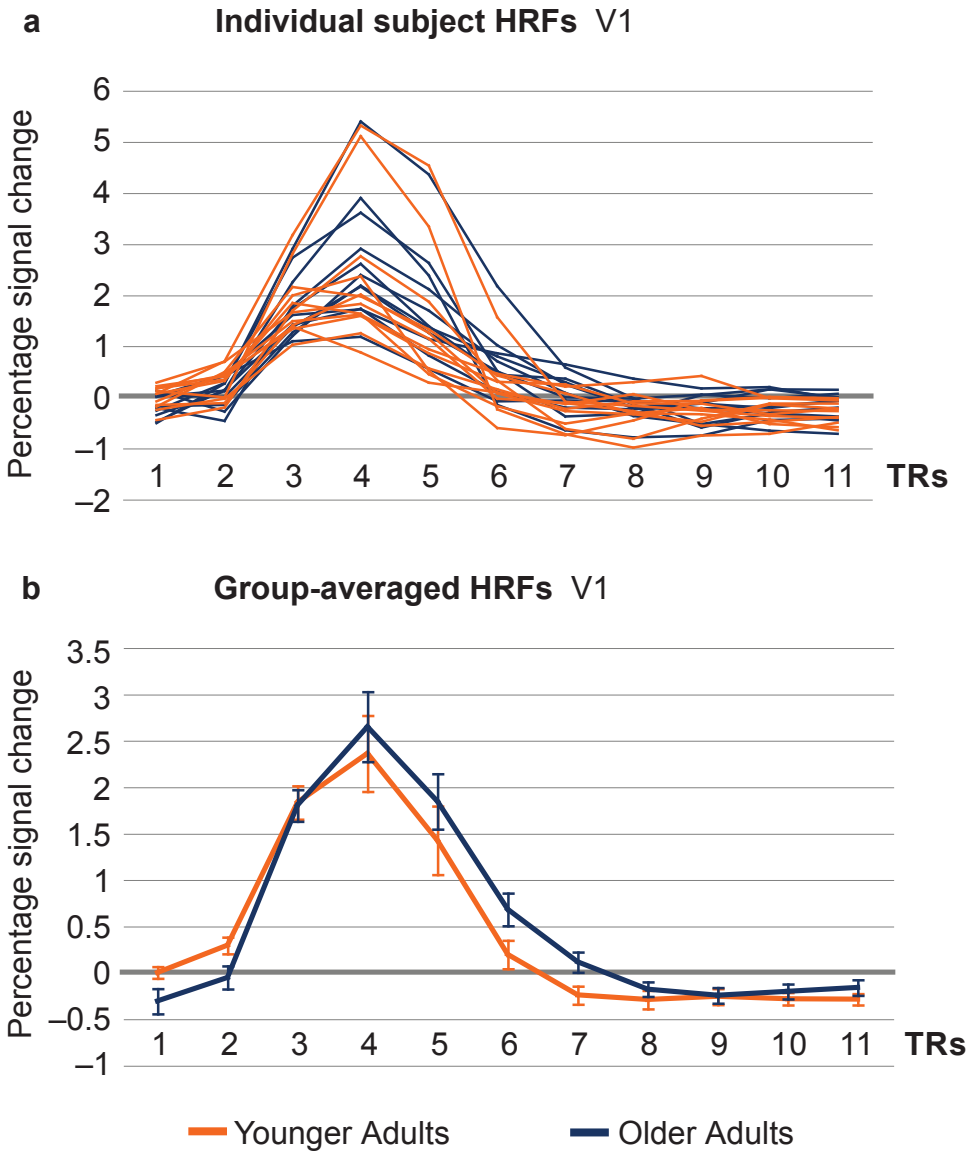
Supplementary Figure 13 MIL task performance. Both younger (a) and older (b) adults chose a greater number of high probability cues on gain acquisition and loss avoidance trials. Neither group showed a preference between neutral cues. Number of total choices on y-axis is averaged between experimental runs 1 and 2.

* $P < .008$

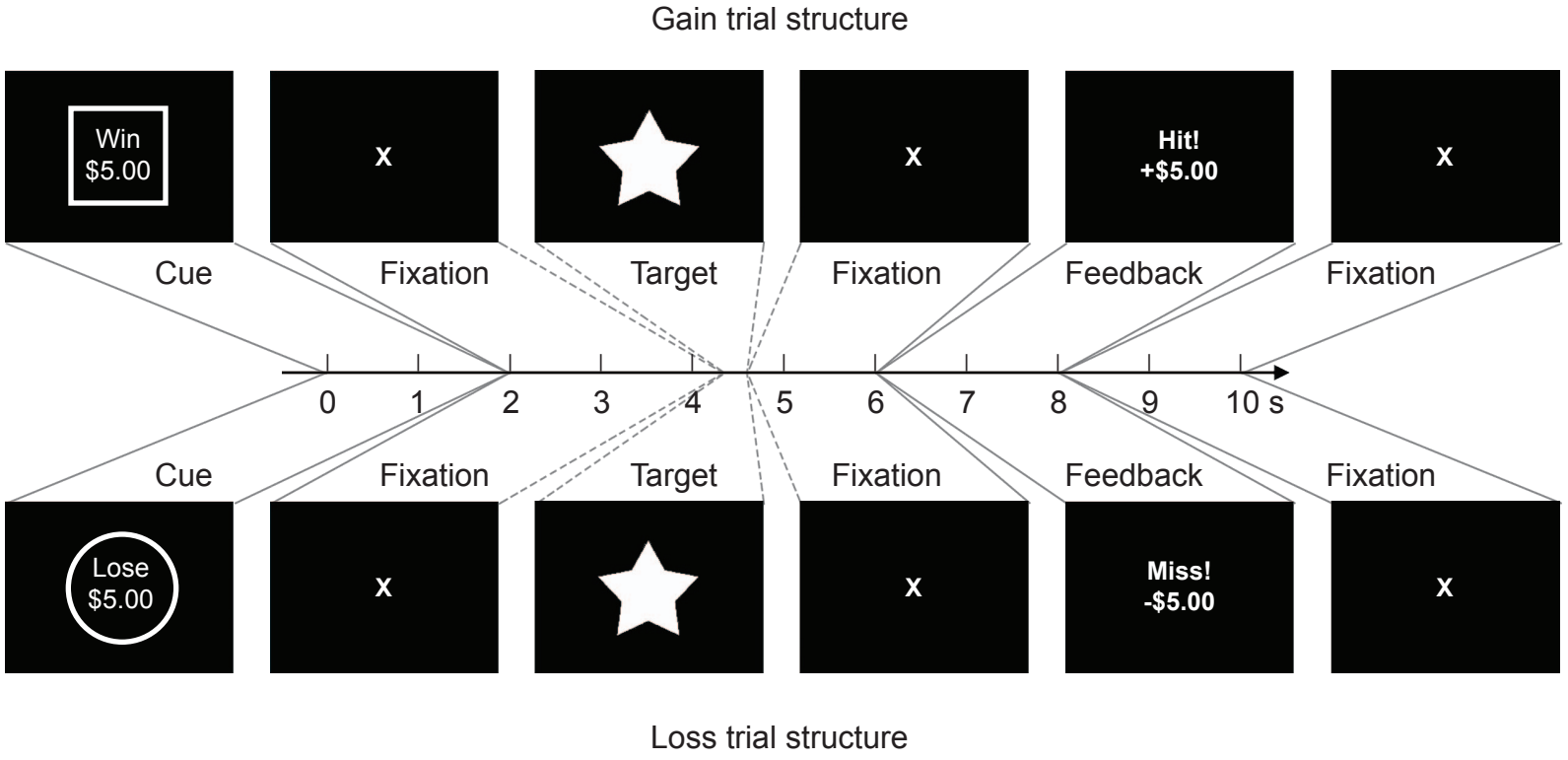




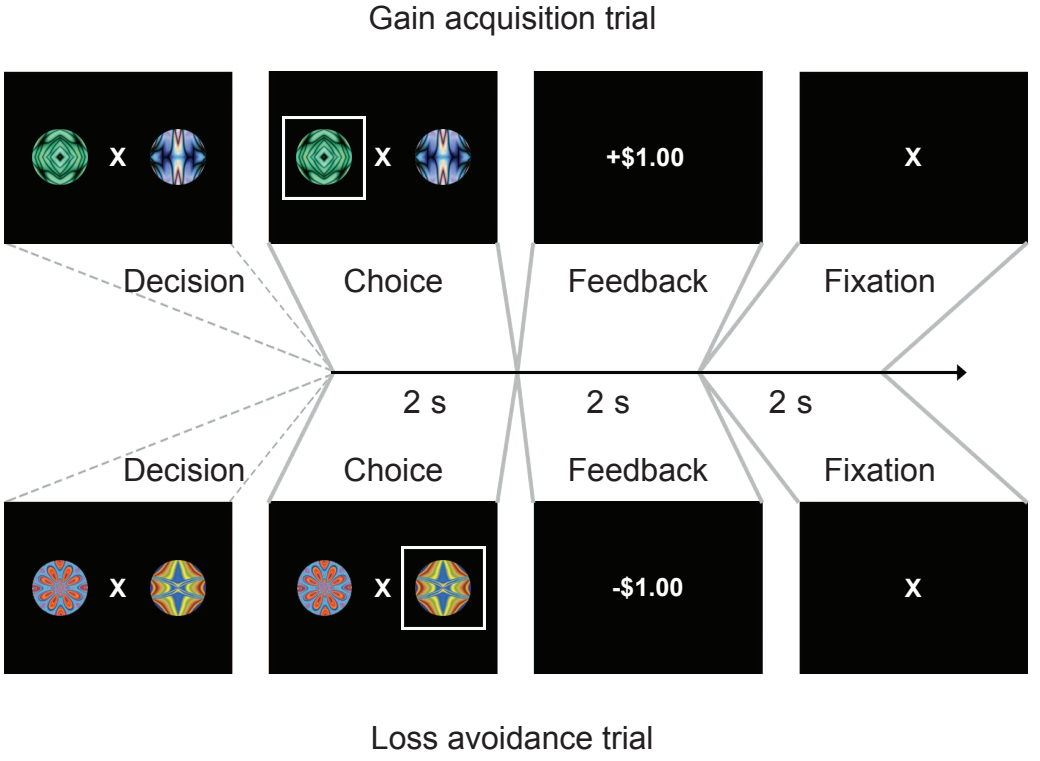
Supplementary Figure 14 MIL task performance over time. Younger and older adults did not significantly differ in performance in any quarter of either gain acquisition (a) or loss avoidance trials (b). Errors bars: s.e.m.



Supplementary Figure 15 Timecourses of activation from individual participants (young: orange, old: blue) extracted from voxels in primary visual cortex (V1) during a visual localizer task (a). Mean-averaged timecourses by group (b). Errors bars: s.e.m.



Supplementary Figure 16 MID task schematic. Participants saw a cue (Cue, 2000 ms), were instructed to focus on a fixation cross while waiting for a variable anticipatory delay period (Fixation, 2000–2500 ms), responded with a button press to a solid white star (Target, 100-400 ms), fixated on a cross (Fixation, 2000 ms minus Target duration), received feedback (Feedback, 2000 ms), and focused again on a fixation cross (Fixation, 2000 ms).



Supplementary Figure 17 MIL task schematic. Participants chose between a pair of cues (Decision, self-paced), viewed their highlighted choice (Choice, 2000 ms), received feedback (Feedback, 2000 ms), and focused on a fixation cross (Fixation, 2000 ms).