

Emotional Eye Cues Shape Trust Decisions with Limited Modulation by Social Anxiety: Behavioral and Electrophysiological Evidence

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Research Article

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Abstract

Background: Gaze direction and eye-region emotion convey social intention, but whether social anxiety alters their influence on trust decisions remains unclear.

Methods: Fifty-two university students selected from the extreme ends of the Liebowitz Social Anxiety Scale (26 per group) completed a trust game. Each trial was preceded by direct or averted angry, sad, neutral, or happy eye cues, and participants chose either to invest or to keep. Behavior was analyzed with binomial logit mixed-effects models. EEG analyses combined theory-constrained event-related potentials, exploratory spectral features, and window-feature multivariate pattern analysis.

Results: Eye emotion strongly modulated investment, with happy and neutral cues promoting investment and sad and angry cues reducing investment. Direct gaze also increased investment relative to averted gaze. Social-anxiety group did not significantly moderate these behavioral effects, cue-locked ERP effects, spectral features, or decoding performance. Cue emotion was decoded only weakly above chance, whereas decision/response-related EEG robustly discriminated invest from keep trials. A late centroparietal positivity was larger in the high-anxiety group in exploratory analyses, but it did not survive the full robustness and multiverse checks.

Conclusions: Emotional eye cues reliably shaped trust behavior, whereas social-anxiety modulation was limited. The findings suggest that eye-cue valence and gaze direction influence social choice in a trust context, while decision-related EEG carries stronger information about investment choices than about static eye-cue categories.

Background

Trust decisions require people to weigh potential gains against the risk of betrayal when another person's intentions are uncertain. The classic trust game operationalizes this uncertainty through an investor's decision to transfer or retain resources [1]. In everyday interaction, however, people rarely rely on payoff probabilities alone. Faces, and especially the eye region, rapidly convey attentional focus, approach or avoidance tendencies, and emotional state. Direct gaze increases the self-relevance of a social stimulus and recruits social-cognitive systems, a phenomenon commonly described as the eye-contact effect [2]. Gaze direction can also alter the meaning of an emotional expression: direct gaze intensifies signals addressed to the observer, whereas averted gaze may indicate attentional withdrawal, avoidance, or exclusion [3–5]. Manipulating gaze direction and eye emotion within a trust game therefore offers a direct test of how social perception is translated into consequential choices.

Social anxiety is characterized by concern about scrutiny and negative evaluation and by biased interpretation of socially threatening information [6, 7]. Eye gaze can carry two competing meanings for socially anxious individuals. Direct gaze is highly self-referential and may be experienced as scrutiny or threat, whereas averted gaze may convey disinterest, rejection, or exclusion. Electrophysiological studies accordingly report effects at different stages and in different directions. Higher social anxiety has been

associated with an enhanced late positive potential to averted gaze [8], an enhanced N2 to direct-gaze angry faces [9], and larger P2 amplitudes together with gaze-related latency changes [10]. These differences suggest that anxiety effects depend on stimulus scope, emotion, task demands, and the neural stage under study.

A systematic review further indicates that N170 sensitivity to gaze direction is inconsistent and moderated by head orientation, stimulus dynamics, and whether gaze is processed explicitly [11]. A meta-analysis of face processing in social anxiety disorder identified possible biases at the early P1, intermediate P2, and later P3/LPP stages [12]. Most included studies, however, used clinical samples or face-processing tasks and cannot establish that the same effects occur in a nonclinical extreme-groups sample making economic decisions. More broadly, candidate EEG markers of social anxiety remain heterogeneous in definition and replicability [13]. Theory-based specification of electrodes and time windows, together with explicit within-family control of multiple testing, is therefore essential when evaluating anxiety-related ERP effects [14, 15].

Behavioral evidence likewise does not support a simple claim that social anxiety reduces trust. Higher social anxiety has been associated with reduced reciprocity after receiving trust, while initial trusting transfers as an investor remained intact [16]. Individuals with social anxiety disorder and controls have also shown similar investment rates despite reduced medial prefrontal activation during mentalizing in a multiround trust game [17]. The possibility of comparable behavior but different neural processing motivates the joint analysis of behavior and EEG. At the same time, any neural group difference must be interpreted in relation to behavioral effects, task stage, and correction for multiple comparisons.

Event-related potentials can separate successive stages from eye-cue encoding to decision evaluation. The occipitotemporal N170 is associated with structural encoding of faces and eyes [18, 11]; the frontocentral P2 is often linked to early attention and affective salience; the centroparietal P300 indexes task-relevant evaluation and context updating [19]; and the LPP reflects sustained processing of motivationally relevant information [20]. Conventional ERP averages localize effects to predefined stages but may miss information distributed across electrodes and time windows. MVPA complements univariate ERPs by testing whether multichannel patterns discriminate stimulus or response classes in held-out data [21, 22]. Response-locked decoding, however, may include motor execution, event coding, and post-response evaluation and should not automatically be interpreted as an abstract decision representation.

The present study addressed three questions. First, do gaze direction and eye emotion reliably influence investment, and does this behavioral sensitivity vary with social anxiety? Second, does social anxiety modulate cue-locked N170, P2, or LPP activity, or decision-locked P100, P300, or LPP activity? Third, can multivariate EEG features from predefined windows distinguish eye-cue categories and invest/keep responses, and does decodability differ between anxiety groups? Based on the eye-contact effect and affective signaling accounts, we expected direct gaze and positive emotion to increase investment. Based on threat monitoring and rejection sensitivity, we expected anxiety differences to emerge more

plausibly during intermediate or late evaluative stages. Because prior work supports both direct-gaze threat and averted-gaze rejection accounts, the direction of the anxiety-by-gaze interaction was treated as a competing prediction. All primary ERP tests used theory-constrained ROIs and time windows; data-driven ROIs, spectral analyses, and time-cluster analyses were explicitly classified as exploratory or sensitivity analyses.

Methods

Participants and social-anxiety groups

Social anxiety was assessed with the Liebowitz Social Anxiety Scale (LSAS), a previously published questionnaire [23]. The questionnaire was not developed for this study. An initial sample of 138 university students completed the LSAS. G*Power was used for sample-size estimation, and a minimum total sample of 30 was obtained when a medium effect size of $f = 0.25$ was specified [24]. The final sample comprised 52 participants selected from the upper and lower 27% of the score distribution, with 26 in each anxiety group. Their mean age was 20.13 years (range 17–25); 45 were women and seven were men. All were right-handed, had normal or corrected-to-normal vision, and reported no history of psychiatric illness. Participants received course credit or a fixed payment after the experiment.

The LSAS contains 24 social and performance situations, each rated separately for fear and avoidance on scales from 0 to 3. The validated Chinese version of the LSAS has demonstrated satisfactory reliability and validity [25]. The inclusion cutoffs were $LSAS \leq 51$ for the low-anxiety group and $LSAS \geq 106$ for the high-anxiety group. Scores were substantially higher in the high-anxiety group ($M = 122.62$, $SD = 18.88$) than in the low-anxiety group ($M = 35.46$, $SD = 11.96$), $t(50) = 19.88$, $p < .001$.

The human-participant procedures were reviewed and approved by the Ethics Committee of Beijing Normal University (approval no. BNU202410210180) and conducted in accordance with local legislation and institutional requirements. All participants provided written informed consent before participation. The present secondary analysis used de-identified data from a public repository.

Task and stimuli

The task was programmed in E-Prime 3.0 and used the investor role of a trust game. On each trial, participants received 10 points, viewed an eye cue from a trustee, and then chose to invest or keep. An investment increased the 10 points to 40, after which the trustee could return 20 points or return nothing; a keep choice yielded a certain 10 points. Participants were told that the eye images and repayment choices came from a historical set of decisions made by real participants, that accumulated points affected compensation, and that an omitted response was worth zero. Invest and keep occupied the left and right positions on the choice display; position, key mapping, and responding hand were counterbalanced across participants. Investment therefore combined potential gain with betrayal risk, whereas keeping provided a certain outcome.

Eye-region stimuli were drawn from the Radboud Faces Database [26]. Expert screening selected 30 adult models (15 women and 15 men) displaying angry, sad, neutral, and happy expressions with direct, left-averted, and right-averted gaze. Images were cropped to include the eyes and eyebrows, converted to grayscale, and normalized in size and gray level. The formal task used 120 direct-gaze and 240 averted-gaze images; each direct-gaze image was presented twice to equate condition frequency.

The experiment was conducted in a dedicated ERP laboratory under controlled lighting, sound, chair-height, and monitor-resolution conditions. Participants first completed practice trials and could repeat practice until they understood the task, after which they pressed the space bar to begin the formal experiment. Each trial presented a fixation cross for 1,000 ms, an eye cue for 1,000 ms, a blank screen for 1,000 ms, and an invest/keep display for up to 1,500 ms. Following the response, the trustee outcome and current payoff were each displayed for 500 ms, followed by a blank intertrial interval of 800-1,000 ms. The experiment comprised eight blocks of 60 trials (480 formal trials). The eight gaze-by-emotion conditions each contained nominally 60 trials. Images were randomized within blocks, and participants rested for approximately 1 min between blocks. The trial sequence is shown in Fig. 1A. The formal design comprised eight stimulus conditions defined by gaze direction (direct, averted) and eye emotion (angry, happy, neutral, sad); responses were classified as invest, keep, or no response.

EEG recording and preprocessing

EEG was recorded with a Brain Products actiCHamp 64-channel system, with electrode impedances maintained below 15 k Ω . BrainVision data were processed offline in EEGLAB 2024.0 [27]. The batch pipeline removed F9 and F10, standardized the Fz label, and matched channels to standard 10 – 5 locations. Data were then filtered from 0.01 to 30 Hz using EEGLAB's windowed-sinc finite impulse response procedure and screened for conspicuous high-frequency artifacts. Bad channels were identified using a standardized kurtosis threshold of 5 and restored using spherical interpolation. Data were epoched from – 1,000 to 1,998 ms around task events and baseline corrected from – 1,000 to 0 ms before independent component analysis (ICA).

Extended Infomax ICA was followed by automated ICLabel classification [28]. Epochs exceeding ± 80 μ V were then rejected, and data were rereferenced offline to the average of bilateral mastoids P9 and P10. Before feature extraction, a -200 to 0 ms baseline correction was applied again, with no further alteration of the continuous data.

All 52 participants were retained in the primary analysis. The high-anxiety group had 726.3 ± 204.7 retained epochs per participant (range 112–954), and the low-anxiety group had 732.1 ± 213.4 (range 152–955), Welch $t(49.91) = -0.10$, $p = .922$. Four participants had comparatively few retained epochs (112–264), so key exploratory results were repeated after excluding these participants.

Behavioral outcomes

The primary behavioral outcome was investment (1) versus keeping (0) on each valid trial; condition-wise investment rates were used for description and visualization. Choice reaction time was secondary. No-response trials were excluded, and participant-specific reaction times more than three standard deviations from the participant mean were omitted. Reaction times were log transformed for mixed modeling. The behavioral data table contained invest counts, keep counts, and valid-trial counts for each gaze-by-emotion condition and participant.

Theory-constrained ERP measures

Electrode ROIs were specified a priori from canonical component topographies and prior gaze and face research [11, 18–20], and channels were selected by label rather than numeric index. Cue-locked analyses included an occipitotemporal N170 (P7/P8/PO7/PO8, 140–200 ms), a frontocentral P2 (Fz/FC1/FC2/Cz, 170–270 ms), and a centroparietal LPP (Cz/CP1/CPz/CP2/P1/Pz/P2, 370–500, 500–600, and 600–700 ms). Decision-locked analyses included an occipital P100 (O1/Oz/O2/PO3/POz/PO4, 80–120 ms), a centroparietal P300 (the same centroparietal ROI, 240–340 ms), and an LPP (550–600, 600–650, and 650–700 ms). Window mean amplitude was the primary measure. Peak amplitude and latency for the N170, P2, P100, and P300 were sensitivity measures.

An exploratory orthogonal functional ROI tested whether a late effect was diluted by the broader theory-based ROI. Candidate electrodes were restricted to the centroparietal region. Data were then averaged across all participants, anxiety groups, and invest/keep conditions, and the four electrodes with the largest overall positivity at 550–650 ms were selected (P4/Cz/P1/P2). This selection did not use group or decision contrasts, reducing direct circularity, but the candidate interval and region were informed by the present data. The result was therefore treated as exploratory and subjected to multiverse correction and robustness tests.

Exploratory spectral analysis

Band-limited power was estimated with fast Fourier transforms of Hamming-windowed segments and expressed as the log₁₀ power ratio between the target and an equal-duration baseline. Cue-locked analyses examined frontocentral theta (4–7 Hz) and posterior alpha (8–12 Hz) at 0–300 and 300–800 ms, using baselines of -500 to -200 and -700 to -200 ms, respectively. Decision-locked analyses examined frontocentral theta, posterior alpha, and central motor beta (13–30 Hz) from 0 to 500 ms relative to a -700 to -200 ms baseline. Spectral analysis complemented the ERP analyses and was not assigned confirmatory status.

Window-feature MVPA

Twenty features were extracted from each epoch. Mean amplitudes were computed for five windows—P100 (80–130 ms), N170 (140–220 ms), P200 (180–280 ms), P300 (300–450 ms), and LPP (500–700

ms)—within four ROIs: frontal (F3/Fz/F4), frontocentral (Fz/FC1/FC2/Cz), posterior (P7/P8/PO7/PO8 and O1/O2/PO3/PO4), and centroparietal (CPz/Pz/POz/P1/P2 and CP1/CP2). This was a predefined window-feature analysis rather than time-resolved decoding.

Three interpretable classification tasks were performed within each participant: direct versus averted gaze, four-class eye emotion, and invest versus keep using decision-locked epochs. Standardization and class-weighted logistic regression were contained within a repeated stratified cross-validation pipeline. Five folds were repeated 10 times; when the smallest class contained fewer than five eligible folds, the number of folds was reduced accordingly. Each class required at least eight epochs. The primary metric was balanced accuracy (chance: .50 for binary tasks and .25 for the four-class task).

At the group level, participant-wise balanced accuracy minus chance was tested with one-sample *t* tests, and the three primary decoding tasks were corrected together using the Benjamini–Hochberg false discovery rate (FDR) [29]. Anxiety-group differences were assessed with Welch tests. Analyses were repeated after excluding the four participants with few retained epochs. Decision-locked decoding may reflect choice, button-press execution, the response marker, and post-response evaluation; it is therefore described throughout as decision/response-related decoding [21, 30].

Statistical analysis

Investment counts were modeled with a binomial logit mixed-effects model. The number of investments was the response and the number of valid trials per condition was the binomial denominator. Fixed effects were anxiety group, gaze direction, eye emotion, and all interactions; participant was a random intercept. Within-participant marginal contrasts for emotion and gaze were calculated from condition investment rates and reported with 95% confidence intervals and Cohen's *d_z*. FDR was controlled within each contrast family. Log reaction time was analyzed with the same fixed-effect structure in a linear mixed model.

ERP mixed models used the following specifications:

Cue amplitude ~ group * gaze * emotion + (1|participant),

Decision amplitude ~ group * decision + (1|participant).

FDR was controlled separately for theory-based primary analyses, sensitivity specifications, and additional specification checks; intercepts were not included in correction families. Planned contrasts are reported with estimates, 95% confidence intervals, test statistics, exact *p* values, FDR-adjusted *q* values, and standardized effect sizes where appropriate.

Temporal continuity was evaluated within predefined ROIs using two-sided cluster-based permutation tests with a cluster-forming threshold of *p* < .05 and 5,000 permutations; FDR was then controlled across cluster tests [31, 32]. Functional-ROI group differences were supplemented with 20,000 group-label permutations, 20% trimmed-mean tests, Mann–Whitney tests, Brunner–Munzel tests, and Levene tests.

Analyses were conducted using MATLAB R2024b, EEGLAB 2024.2, and Python. All tests were two-sided with $\alpha = .05$. In line with EEG reporting and replicability recommendations, results were classified as theory-based primary, sensitivity, or exploratory evidence [14, 15]; uncorrected $p < .05$ did not upgrade an exploratory result to confirmatory evidence.

Results

Sample characteristics and EEG data quality

Each anxiety group contained 26 participants. LSAS scores were clearly separated by the extreme-groups selection, whereas the total number of retained EEG epochs did not differ between groups (see Table 1). Across participants, 19,056 cue events were identified. Of these, 17,595 could be paired sequentially with a subsequent valid decision event; 1,461 lacked a subsequent decision marker. Investment rates computed from the paired events correlated positively with condition rates in the behavioral table, $r = .258$, $p < .001$, but the association was modest. Exhaustive simple condition rearrangements produced a maximum correlation of only .281. Cue-locked condition analyses can therefore be interpreted using the confirmed labels, but cue-locked prediction of subsequent investment was excluded from the core inference.

Note. LSAS = Liebowitz Social Anxiety Scale. Retained epochs refer to all event-locked epochs in the archived preprocessed data, not to the trial count in a single condition.

Investment behavior and reaction time

The binomial mixed model showed a strong main effect of eye emotion on investment, $F(3,400) = 93.63$, $p < .001$. Collapsed across gaze and anxiety group, mean investment rates were .279 ($SD = .207$) for angry, .348 ($SD = .196$) for sad, .465 ($SD = .209$) for neutral, and .537 ($SD = .203$) for happy eye cues. All six pairwise emotion contrasts survived FDR correction. Happy cues produced more investment than angry ($\Delta = .258$, $d_z = 1.04$, $q < .001$), sad ($\Delta = .190$, $d_z = .96$, $q < .001$), and neutral cues ($\Delta = .072$, $d_z = .37$, $q = .011$). Neutral cues produced more investment than angry ($\Delta = .186$, $d_z = 1.02$, $q < .001$) and sad cues ($\Delta = .117$, $d_z = .87$, $q < .001$), and sad cues produced more investment than angry cues ($\Delta = .068$, $d_z = .43$, $q = .004$).

The main effect of gaze direction was also significant, $F(1,400) = 9.68$, $p = .002$. Direct gaze increased investment by .054 relative to averted gaze, 95% CI [.032, .077], $t(51) = 4.83$, $q < .001$, $d_z = .67$. The gaze-by-emotion interaction was not significant, $F(3,400) = 0.39$, $p = .759$.

The main effect of social-anxiety group was not significant, $F(1,400) = 0.20$, $p = .658$. Overall investment rates were .4071 in the low-anxiety group and .4075 in the high-anxiety group, $d = .002$. Anxiety-by-gaze, anxiety-by-emotion, and the three-way interaction were all nonsignificant ($p = .510$, .190, and .237, respectively), indicating that the emotion gradient and direct-gaze advantage were similar across groups. The full model is summarized in Table 2.

In the log reaction-time model, the main effects of gaze, emotion, and anxiety group were nonsignificant, $F(1,400)=2.01$, $p = .157$; $F(3,400)=0.30$, $p = .829$; and $F(1,400)=2.18$, $p = .140$, respectively. All interactions were also nonsignificant ($p \geq .304$), and none of the six pairwise emotion contrasts survived FDR correction ($q \geq .503$).

Note. The response was the number of investments with valid trials as the binomial denominator. A logit link and participant random intercept were used. Random-intercept SD = 0.716.

Cue-locked ERPs

No social-anxiety main effect or anxiety-related interaction survived within-family FDR correction for the theory-constrained occipitotemporal N170 or frontocentral P2. The high-minus-low group difference in N170 mean amplitude was $0.230 \mu\text{V}$, 95% CI $[-0.187, 0.647]$, $p = .272$, $q = .704$; group differences in peak amplitude and latency were likewise nonsignificant. The P2 mean-amplitude group difference was $-0.449 \mu\text{V}$, 95% CI $[-1.502, 0.604]$, $p = .396$, $q = .704$. The angry-minus-happy P2 contrast was nonsignificant. Its interaction with group reached $p = .048$ before correction, in the direction opposite to the prediction, but not after correction ($q = .222$).

Centroparietal LPP amplitudes at 370–500, 500–600, and 600–700 ms showed no corrected anxiety-group effect or anxiety-by-cue interaction. A sensitivity specification for right occipitotemporal N170 peak latency showed an emotion main effect, $F(3,350)=5.68$, $p < .001$, $q = .046$, and a gaze-by-emotion interaction, $F(3,350)=6.30$, $p < .001$, $q = .040$. Neither involved anxiety and neither supports altered early eye-cue encoding in the high-anxiety group. Primary ROI waveforms are shown in Fig. 2.

Decision-locked ERPs

The occipital P100 showed no corrected effect of group, invest versus keep, or their interaction. For the centroparietal P300, the keep-minus-invest contrast was $-0.261 \mu\text{V}$, 95% CI $[-0.529, 0.007]$, $p = .056$, $q = .222$. Group modulation of this contrast reached $p = .021$ before correction, estimate $-0.611 \mu\text{V}$, 95% CI $[-1.126, -0.097]$, but did not survive FDR correction ($q = .168$) and was opposite to the predicted direction.

At the LPP, keep-minus-invest contrasts were nonsignificant at 550–600 and 600–650 ms. At 650–700 ms, the keep-minus-invest contrast was $-0.446 \mu\text{V}$, 95% CI $[-0.729, -0.163]$, $t(51)=-3.16$, $p = .003$, $q = .042$, $d_z=-.44$, indicating a larger late positivity for invest decisions. After excluding the four participants with few epochs, the estimate remained in the same direction ($-0.386 \mu\text{V}$) but no longer survived correction ($q = .128$).

The theory-based centroparietal ROI showed a directionally consistent high-greater-than-low anxiety effect at 550–650 ms: $0.857 \mu\text{V}$, 95% CI $[0.082, 1.632]$, $p = .031$, multiverse $q = .310$. In the orthogonal P4/Cz/P1/P2 functional ROI, mean amplitude was $1.589 \mu\text{V}$ in the high-anxiety group and $0.467 \mu\text{V}$ in the low-anxiety group, yielding a difference of $1.122 \mu\text{V}$, 95% CI $[0.127, 2.116]$, Welch $t(37.61) = 2.28$, $p = .028$. A 20,000-permutation test gave $p = .026$, but the result did not survive multiverse correction ($q = .300$). The 20% trimmed-mean, Mann–Whitney, and Brunner–Munzel tests were nonsignificant ($p =$

.212–.246), Levene's test indicated unequal variance ($p = .015$), and exclusion of low-epoch participants yielded Welch $p = .073$ and permutation $p = .069$. The late group difference was therefore classified as exploratory and sensitive to high-amplitude observations and inclusion rules (Fig. 3).

Cluster tests identified a 530–660 ms centroparietal high-minus-low anxiety cluster, $p_{\text{cluster}} = .054$, and anxiety-by-decision clusters at 110–130 ms and 230–340 ms, $p_{\text{cluster}} = .039$ and $.041$. None survived FDR correction across cluster tests (all $q = .215$).

Exploratory spectral results

No anxiety main effect or anxiety-related interaction survived within-family FDR correction in the theory-constrained cue-locked or decision-locked spectral measures. Cue-locked frontocentral theta at 300–800 ms showed an uncorrected group effect, $p = .045$, and group-by-gaze interaction, $p = .038$, but both had $q = .626$. Uncorrected emotion and gaze-by-emotion effects in frontal alpha also failed FDR correction. Spectral analysis therefore provided no stable anxiety-related evidence beyond the ERP results.

MVPA results

Decision/response-related invest-versus-keep classification achieved a mean balanced accuracy of .647 ($SD = .090$) across 52 participants. Performance exceeded .50 chance by .147, 95% CI [.122, .172], $t(51) = 11.74$, $p < .001$, $q < .001$. Mean recalls for invest and keep were .648 and .651, respectively, indicating that performance was not driven by one class. After excluding the four low-epoch participants, balanced accuracy remained .646 ($q < .001$). Performance was .648 in the low-anxiety group and .646 in the high-anxiety group, Welch $p = .928$ (Fig. 4).

Gaze-direction classification was at chance, $BA = .503$, $t(51) = 0.91$, $q = .369$. Four-class eye-emotion classification reached $BA = .261$, only 1.1 percentage points above .25 chance, 95% CI [.006, .017], $t(51) = 4.01$, $q < .001$. Neutral-cue recall was highest (.280), whereas the other classes were close to chance. This result supports only weak distributed information about eye emotion. Cue-locked EEG prediction of the subsequent invest/keep response reached $BA = .513$, $q = .030$, in the full sample but decreased to .509, $q = .105$, after low-epoch exclusions and was further limited by cue-response alignment uncertainty; it was not included in the core conclusions. Behavioral features, cue-locked ERPs, and their combination did not classify anxiety group reliably (balanced accuracy .384–.447; permutation $p \geq .495$).

Note. A dash indicates that the compact summary does not repeat the full model statistic. The functional-ROI permutation test yielded $p = .026$, but multiverse $q = .300$.

Discussion

This study combined behavior, theory-constrained ERPs, exploratory spectral analysis, and within-participant MVPA to examine how people with different levels of social anxiety use emotional eye cues

during trust decisions. Two findings were well supported. Eye emotion and gaze direction influenced investment, and invest and keep responses were associated with discriminable decision/response-related EEG patterns. Social anxiety, by contrast, showed little reliable modulation of behavior, cue-locked ERPs, spectral measures, or decoding performance. The larger 550–650 ms late positivity in the high-anxiety group did not survive multiverse correction and was sensitive to robust estimation and low-trial exclusions. It should be tested in an independent sample rather than treated as a confirmed group difference.

Emotional eye cues shape investment

Eye emotion produced the most stable behavioral effect. Investment was highest for happy cues, followed by neutral, sad, and angry cues, and all six pairwise contrasts survived FDR correction. Even when only the eyes and eyebrows were visible, participants extracted affective information relevant to anticipated reciprocity and betrayal risk. Happy eyes generally signal approach, affiliation, or low threat, whereas angry eyes more directly signal hostility and potential loss. Gaze and emotion can interact in perceived social meaning [3, 4], but their behavioral interaction was nonsignificant here, suggesting that the emotion gradient generalized across direct and averted gaze.

Direct gaze increased investment by approximately 5.4 percentage points. Direct gaze can enhance self-relevance and social approach processing [2]; in the present task, it may also have increased the subjective sense that the trustee was engaged with the participant. Averted gaze may signal attentional withdrawal or exclusion and thereby reduce expected cooperation [5]. The gaze effect was supported by both the binomial mixed model and the within-participant marginal contrast and was not accompanied by a reliable reaction-time difference. Because left- and right-averted gaze were combined, future studies should model them separately and control head orientation to distinguish social meaning from low-level visual asymmetry.

Limited modulation of trust behavior by social anxiety

The two anxiety groups had nearly identical overall investment rates, and neither the emotion gradient nor the direct-gaze advantage differed reliably between groups. This finding does not support the broad claim that high social anxiety necessarily reduces investment. It is consistent with more specific trust-game evidence: social anxiety may reduce reciprocity after a person receives trust while leaving initial trusting transfers intact [16]. Clinical and control groups can also invest at similar rates while differing in mentalizing-related brain activity [17]. Under fixed rules, single-trial choices, and a transparent payoff structure, emotion valence and gaze direction may provide stronger proximal information than trait anxiety.

The null group differences should be interpreted in light of measurement precision. The extreme-groups design increased separation in LSAS scores but discarded continuous individual-difference information, and the sample could mainly detect large effects in simple between-group comparisons. The present results support the conclusion that no stable group difference of a magnitude detectable in this study

was observed; they do not establish that social anxiety has no influence across all trust contexts. Dynamic reciprocity, genuine online interaction, reputation learning, or contexts with stronger social-evaluation risk may be more sensitive to anxiety-related behavioral differences.

From cue encoding to decision/response-related EEG

Theory-constrained N170, P2, and cue-locked LPP measures showed no corrected anxiety effect. Prior gaze studies vary in the stage and direction of social-anxiety effects [8–10], and the N170 literature emphasizes moderation by task and stimulus features [11]. The present study displayed only the eye region, and participants used the cues for an economic choice rather than explicitly judging gaze or emotion. This context may reduce early group differences in structural encoding. The right-occipitotemporal N170 latency effects of emotion and gaze-by-emotion did not involve anxiety and therefore indicate sensitivity to the stimulus combination rather than anxiety-related abnormality.

In decision-locked ERPs, invest trials were more positive than keep trials at 650–700 ms, and this contrast survived FDR correction in the full sample. P300/LPP activity is associated with task-relevant evaluation, context updating, and sustained processing of motivationally relevant information [19, 20]. Investing relinquishes a certain payoff and involves waiting for a potential return, which may require more sustained evaluation of social risk and reward. This interpretation should remain at the level of decision/response-related processing because time zero was aligned to the choice response and invest and keep corresponded to different keys. Counterbalancing response position, mapping, and hand across participants reduced systematic group-level lateralization but could not fully separate choice formation, motor execution, and post-response evaluation within participants.

MVPA provided stronger evidence of decision-stage task information than any single ERP contrast. Invest-versus-keep balanced accuracy reached 64.7%, recalls were similar for both classes, and performance remained essentially unchanged after excluding participants with few epochs. Predefined ROI-by-window patterns therefore contained reliable invest/keep information. Equivalent performance in the two anxiety groups further indicates that decodability of task-response information did not vary systematically with anxiety. However, the analysis used response-aligned windows and random stratified epoch-level cross-validation; it neither isolated pre-response choice formation nor tested generalization across buttons, blocks, or repeated face identities. The decoded information may therefore include motor execution, response marking, temporal autocorrelation, and post-response monitoring [21, 30].

Exploratory anxiety difference at the late decision-evaluation stage

The larger 550–650 ms late positivity in the high-anxiety group was the only directionally consistent anxiety-related candidate. It was a group main effect collapsed across invest and keep trials, not an anxiety-by-decision interaction. At most, it suggests that high-anxiety participants may show greater sustained evaluation or arousal after a choice; it does not indicate selective enhancement of invest or keep processing. More importantly, conventional tests in both the theory ROI and orthogonal functional

ROI yielded uncorrected $p < .05$, but multiverse q values were approximately .30. Robust tests and the low-epoch exclusion did not preserve the result. The current evidence does not justify interpreting the effect as compensation, a diagnostic marker, or a stable neural phenotype.

The candidate nevertheless provides a specific target for future work. An independent study could preregister a 550–650 ms centroparietal ROI, retain continuous LSAS scores, and control depressive symptoms, trait anxiety, and sex. A design that separates pre-response, response, and pre-feedback intervals could determine whether the late positivity reflects decision commitment, post-motor monitoring, or anticipation of the social outcome. Mechanistic interpretation would be warranted only if the effect replicates under these constraints and covaries with symptom dimensions or adaptive behavior.

Methodological implications

The present findings illustrate how electrode and time-window selection changes the strength of an EEG conclusion. The N170 has an occipitotemporal distribution, whereas P300/LPP activity is typically centroparietal. Applying one frontal electrode set to all components would mix distinct processes and increase dependence on incidental waveforms. The present analysis specified component-appropriate ROIs and treated window mean voltage as the primary outcome, while peak measures, wider windows, functional ROIs, spectral indices, and time clusters occupied separate evidence tiers. This structure reduces false-positive risk from selecting electrodes or windows after inspecting the observed group difference [14, 15]. FDR correction and robustness analyses likewise prevented an uncorrected late group difference from being presented as confirmatory.

Limitations

Several limitations constrain inference. First, participants were a nonclinical university extreme-groups sample; 86.5% were women, and the sample had limited sensitivity to small or moderate between-group effects. Continuous LSAS scores, item-level scale data, and age variation by group were unavailable for analysis. Second, the task used static eye-region images and a fixed single-trial choice structure; the findings may therefore not generalize to dynamic reciprocal interactions in which reputation and partner behavior evolve over time. Finally, scalp EEG cannot directly identify neural generators. Functional interpretations of late potentials require more selective experimental manipulations and source-space evidence, and future studies should combine ecologically richer interaction paradigms with methods offering stronger spatial localization.

Conclusions

Emotional eye cues reliably shaped investment in the trust game: happy and neutral cues promoted investment, sad and angry cues reduced investment, and direct gaze elicited more investment than averted gaze. Decision/response-related EEG reliably discriminated invest from keep trials, indicating a distributed and decodable electrophysiological pattern associated with social choice. High- and low-

anxiety groups nevertheless showed broadly similar behavior, theory-constrained cue-locked ERPs, spectral measures, and decoding performance. A larger late positivity in the high-anxiety group remains an exploratory candidate.

Abbreviations

AUC, area under the curve; BA, balanced accuracy; CI, confidence interval; EEG, electroencephalography; ERP, event-related potential; FDR, false discovery rate; ICA, independent component analysis; LPP, late positive potential; LSAS, Liebowitz Social Anxiety Scale; MVPA, multivariate pattern analysis; ROI, region of interest; RT, reaction time.

Declarations

Ethics approval and consent to participate

The human-participant procedures were reviewed and approved by the Ethics Committee of Beijing Normal University (approval no. BNU202410210180) and conducted in accordance with local legislation and institutional requirements. All participants provided written informed consent before participation. The present secondary analysis used de-identified data from a public repository and involved no new participant recruitment, intervention, or data collection.

Consent for publication

Not applicable.

Availability of data and materials

The datasets analysed during the current study are available in the Science Data Bank repository at <https://doi.org/10.57760/sciencedb.17657>.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

ZJ contributed to validation, resources, data curation, writing - review and editing, supervision, project administration, and funding acquisition. ZM contributed to conceptualization, methodology, software, formal analysis, investigation, data curation, writing - original draft, writing - review and editing, and visualization. Both authors read and approved the final manuscript.

Authors' information

Not applicable.

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Tables

Table 1. Sample characteristics and EEG data quality.

Measure	Low anxiety	High anxiety	Overall or group test
Sample size	26	26	N = 52
LSAS total, M ± SD	35.46 ± 11.96	122.62 ± 18.88	t(50) = 19.88, p < .001
LSAS inclusion cutoff	≤ 51	≥ 106	Extreme 27% groups
Sex (men / women)	3 / 23	4 / 22	7 / 45
Age, years	Not retained by group	Not retained by group	M = 20.13, range 17–25
Retained epochs, M ± SD	732.1 ± 213.4	726.3 ± 204.7	t(49.91) = -0.10, p = .922
Retained-epoch range	152–955	112–954	Four participants < 265

Table 2. Investment fixed effects.

Fixed effect	F	df1	df2	p
Gaze direction	9.68	1	400	.002
Eye emotion	93.63	3	400	< .001
Social-anxiety group	0.20	1	400	.658
Gaze × emotion	0.39	3	400	.759
Gaze × group	0.43	1	400	.510
Emotion × group	1.59	3	400	.190
Gaze × emotion × group	1.42	3	400	.237

Table 3. Key EEG and MVPA results from event-related potential and decoding analyses.

Analysis	Estimate	Statistic	p	q	Interpretation
Decision LPP, 650–700 ms: keep–invest	-0.446 μ V	t(51) = -3.16	.003	.042	Corrected invest-greater-than-keep effect
Decision P300: group × (keep–invest)	-0.611 μ V	t(43.17) = -2.39	.021	.168	Did not survive FDR
Theory ROI LPP, 550–650 ms: high–low	0.857 μ V	—	.031	.310	Exploratory
Functional ROI LPP, 550–650 ms: high–low	1.122 μ V	t(37.61) = 2.28	.028	.300	Sensitive to robustness analyses
Cue gaze MVPA	BA = .503	t(51) = 0.91	.369	.369	Chance performance
Cue emotion MVPA	BA = .261	t(51) = 4.01	< .001	< .001	Very small above-chance effect
Decision/response MVPA	BA = .647	t(51) = 11.74	< .001	< .001	Robust task information
Decision MVPA group difference	Δ BA = -.002	Welch test	.928	.928	No group difference

Figures

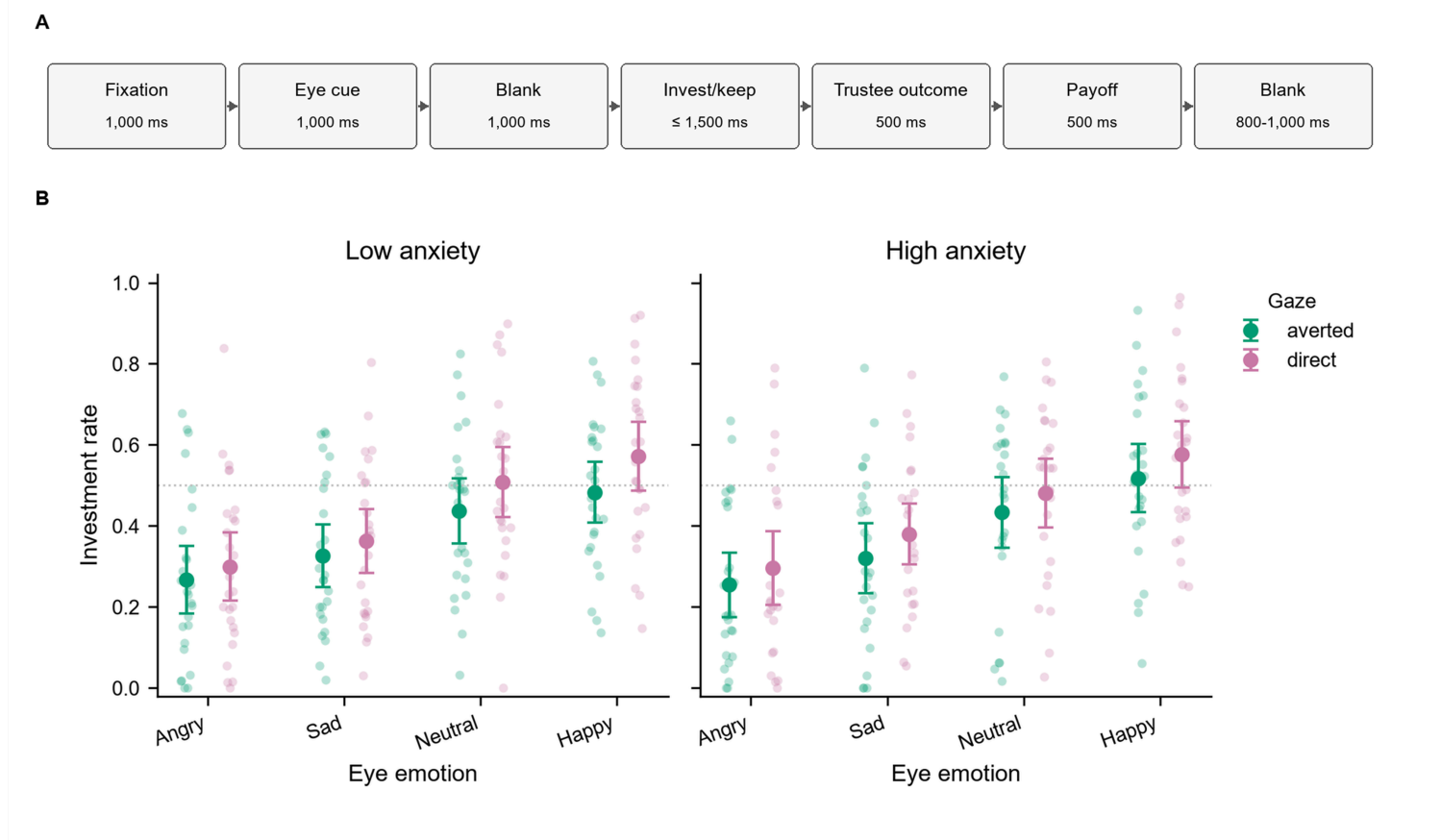


Figure 1

Task structure and investment behavior. (A) Sequence of events in a single trial. (B) Participant investment rates by social-anxiety group, eye emotion, and gaze direction. Small points represent individuals; solid points and error bars represent means and 95% confidence intervals. Overall, investment was higher for direct than averted gaze and increased from angry to happy eye cues, with similar patterns in the two anxiety groups.

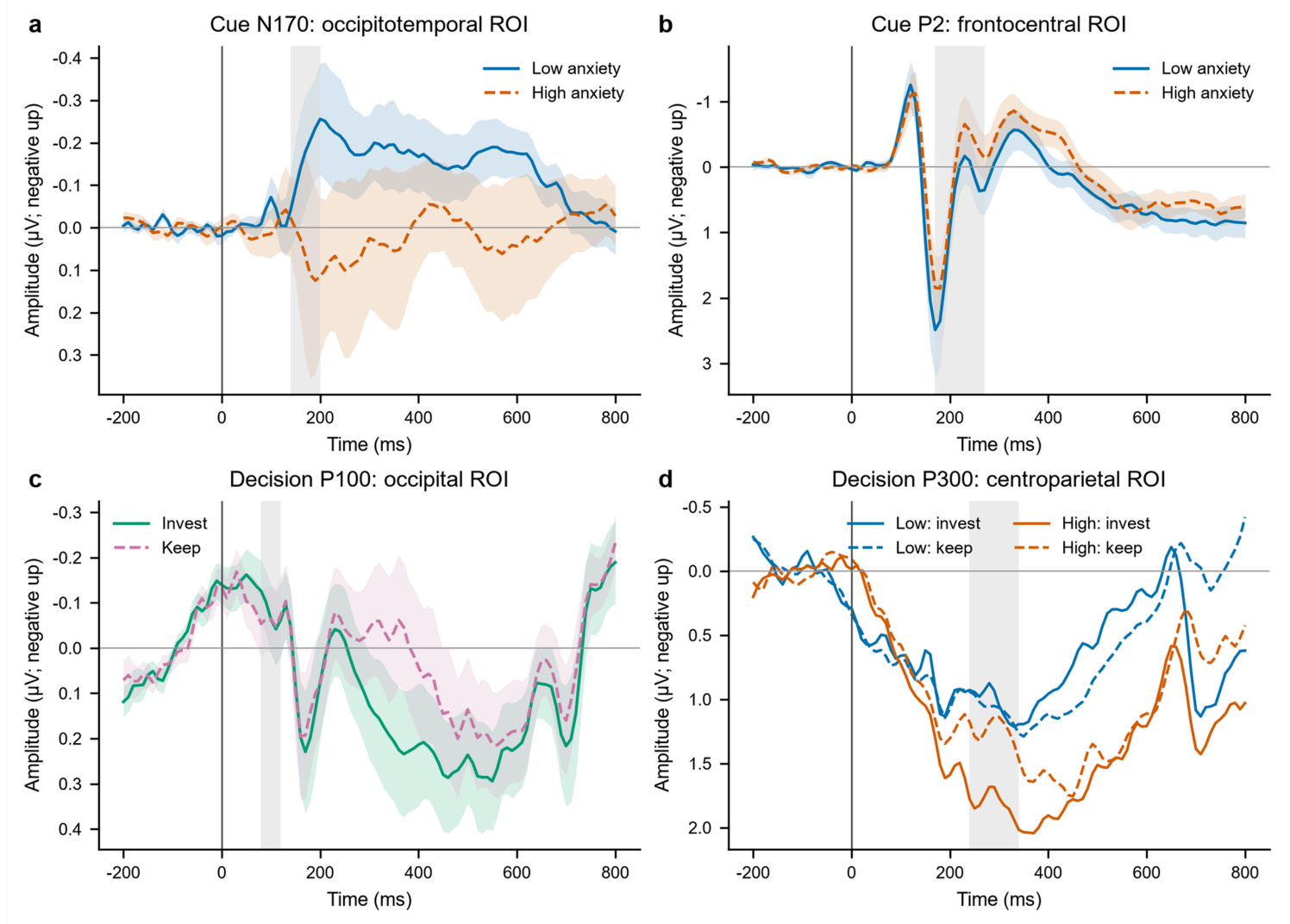


Figure 2

Theory-constrained cue-locked and decision-locked ERP waveforms. (A) Occipitotemporal N170; (B) frontocentral P2; (C) decision-locked occipital P100; and (D) decision-locked centroparietal P300. Gray regions indicate the primary component windows; negative voltage is plotted upward. No anxiety-related cue-locked ERP effect survived FDR correction.

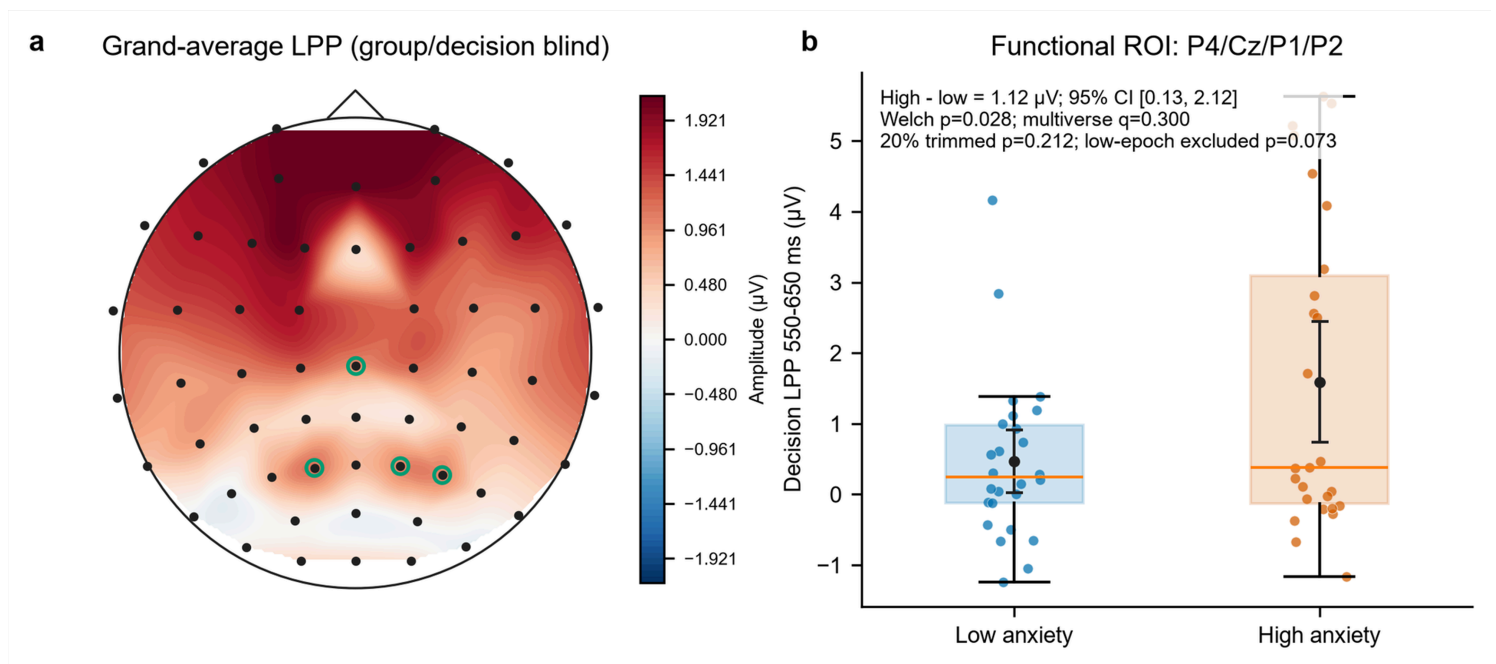


Figure 3

Exploratory decision-locked late-positive group difference. (A) Grand-average 550-650 ms topography collapsed across anxiety group and invest/keep conditions, with the orthogonally selected P4/Cz/P1/P2 ROI; (B) participant distributions by group. Conventional Welch and permutation tests produced uncorrected $p < .05$, but multiverse q values were .310 for the theory ROI and .300 for the functional ROI; robust tests and the low-epoch exclusion were nonsignificant.

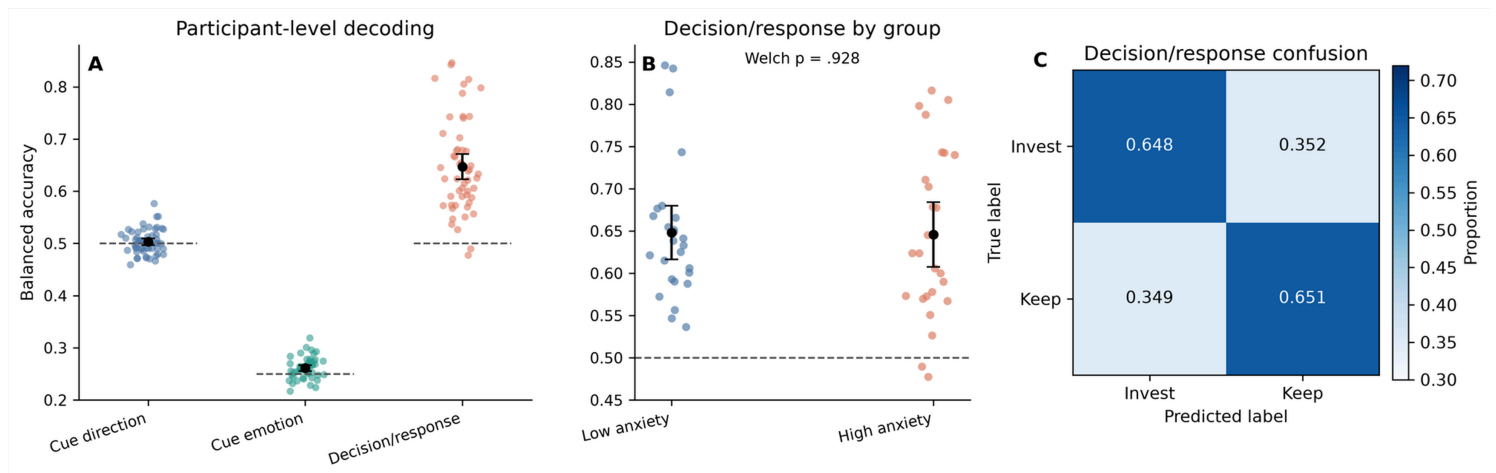


Figure 4

Window-feature MVPA. (A) Participant-level balanced accuracy for the three primary tasks, with dashed lines indicating chance; (B) decision/response invest-versus-keep classification by anxiety group; and (C) mean normalized confusion matrix. Decision/response classification was reliably above chance, but performance did not differ between anxiety groups.