Supplementary Methods

Study 1. Discrimination of Facial Configurations

1.1 Proportion of participants exhibiting significant oddball discrimination responses across age groups

After averaging the z-scores across all conditions and participants, we observed that the mean z-scores at 3.6Hz and 4.8Hz were consistently significant (z-score > 1.64, *ps* < .05, one-tailed). Consequently, we calculated the average z-scores at these two frequencies for each participant. To further explore potential developmental effects, we analyzed the proportion of participants in each age group who exhibited significant oddball discrimination responses at the individual level by averaging z-scores across all conditions for each participant. The results showed that 86.67% of participants in the 5–6 years group, 84.21% in the 7–8 years group, 66.67% in the 9–10 years group, and 84.85% in the young adult group achieved significant oddball discrimination responses. The fact that more than two-thirds of participants in each group met the threshold supports the validity of the selected harmonics for capturing reliable oddball responses.

1.2 The reason for choosing the signal-to-noise ratio

Previous studies have typically compared baseline-corrected amplitude between participants as an indicator for discerning changes in facial configurations[28,29,36]. We also calculated the baseline-corrected amplitude for each participant across different conditions. The detailed experimental results and post hoc analyses are provided in Supplementary Table 3-6. We then conducted a correlation analysis between baseline-corrected amplitude and signal-to-noise ratio across different age groups. The results showed that the correlation was significant in the 5–6 years group (r (45) = 0.336, $p = 0.024$, 95% CI [0.005, 0.686]), 7–8 years group (r (37) = 0.547, $p < 0.001$, 95% CI [0.318, 0.744]) and 9–10 years group (r (39) = 0.748, $p < 0.001$, 95% CI [0.462, 0.907]), but not stasistically significant in the young adults group (r (33) = 0.038, $p = 0.834$, 95% CI [-0.251, 0.790]). We attribute these findings to the young adults group, where the thicker skulls may attenuate and smooth neural signals, thereby reducing the variability of baseline-corrected amplitude values and potentially

leading to an underestimation of the correlation with the signal-to-noise ratio. Additionally, we observed an age-related decline in EEG energy in the baseline-corrected analysis results ($F(3,150) = 17.072$, $p < .001$, $\eta_p^2 = 0.255$, 95% CI [0.133, 0.352], see Supplementary Table 6 and Supplementary Figure 2), which can be partially attributed to age-related generalized brain atrophy and increased scalp thickness. Consequently, we consider that baseline-corrected amplitude may not be comparable across different age groups.

1.3 Orthogonal behavioral task in the FPVS experiment

The behavioral task in the FPVS experiment resulted in usable data from 118 children (M_{age} = 7.81 SD = 1.89 range 5.00 – 11.75 female N = 55) and 38 young adults (M_{age} = 20.84 SD = 1.84 range 18 – 25 female 19), excluding participants with missing data. The average accuracy across age groups was 90.30% (SD = 0.22), with an average response time (RT) of 0.64 s (SD = 0.49) for correct detections. An ANOVA analysis with emotion pair (6 level: happiness-fear, happiness-anger, happiness-sadness, fear-anger, fear-sadness, and anger-sadness) and age group (4 levels: 5-6 years, 7-8 years, 9-10 years, and 18-25 years [young adults]) revealed a main effect of age, $F(3,149) = 28.311$, $p < .001$, $\eta_p^2 = 0.363$, 95% CI [0.235, 0.456]. Post-hoc comparisons with Bonferroni correction showed that the 5-6 years group (M = 0.818, SD = 0.012) exhibited a lower accuracy compared to the other three groups (7-8 years group: M = 0.912, SD = 0.014; 9-10 years group: M = 0.948, SD = 0.013; young adults: M = 0.962, SD = 0.013). The main effect of emotion pair was significant, $F(4.129, 615.268) = 8.981$, $p < .001$, $\eta_p^2 = 0.057$, 95% CI [0.022, 0.090]. Post-hoc comparisons revealed that recognition accuracy for the happiness-fear pair ($M = 0.846$, $SD = 0.015$) was significantly lower than for other emotion pairs (happiness-anger: M = 0.917, SD = 0.012; happiness-sadness: M = 0.931, SD = 0.010; fear-anger: M = 0.908, SD = 0.013; fear-sadness: M = 0.945, SD = 0.011; anger-sadness: M = 0.912, SD = 0.012). The interaction between emotion pair and group was not significant, $F(12.388,615.268) = 1.133$, $p = .125$, $\eta_p^2 = 0.028$, 95% CI [0, 0.028].The ANOVA of RT also revealed a main effect of age, $F(3,114) = 5.150$, $p < .001$, $\eta_p^2 = 0.413$, , 95% CI [0.018, 0.218], such that the 5-6 years group (M = 0.844s, SD = 0.032) and the young adult group (M = 0.455s, SD = 0.033)

demonstrated a slower and faster RT, compared to the other groups, respectively (7-8 years group: M = 0.714s, SD = 0.037; 9-10 years group: M = 0.586s, SD = 0.032). There was no effect of emotion pair (F(2.773,316.147) = 1.634, p = .185, η_p^2 = 0.014, 95% CI [0, 0.043]), nor an interaction between the two factors (F(8.320,316.147) = 1.108, p = .377, η_p^2 = 0.028, , 95% CI [0, 0.046]). These behavioral results suggest that the participants were thoroughly engaged in the FVPS presentation and the orthogonal behavioral task.

1.4 Oddball responses in upright and inverted conditions

A repeated-measures ANOVA was conducted with variables of emotion pair, age group, orientation and ROI (Supplementary Table 13). There was an interaction between orientation and ROI (F(1.872,76.747) = 4.304, p = .019, η_p^2 = 0.095, 95% CI [0.002, 0.219]). Simple effects test showed that the attenuation in oddball responses due to face inversion was mainly found in the TO_R region (Supplementary Figure 4A, Supplementary Table 14). In addition, a significant interaction between age group and ROI was observed, F(5.817, 79.493) = 3.023, p = .011, ηp^2 = 0.181, 95% CI [0.012, 0.278]. Post-hoc analysis indicated that the differences in responses across ROIs were more pronounced in the young adults group, with the largest responses particularly observed in the right regions (Supplementary Table 15). In addition, the interaction between orientation and age group (F(3,41) = 12.379, p < .001, η_p^2 = 0.475, 95% CI [0.212, 0.605], Supplementary Table 16), as well as the interaction between orientation and emotion, were both significant (F(3.894,159.635) = 2.603, p = .039, η_p^2 = 0.06, 95% CI [0, 0.123], Supplementary Table 17-18). There was a main effect of orientation (F(1,41) = 71.806, p < .001, η_p^2 = 0.637, 95% CI [0.436, 0.742]), with greater oddball responses found for the upright than the inverted condition (Supplementary Figure 4B, Supplementary Table 19). Main effects were also found for ROI (F(1.939, 79.493) = 7.276, p = .001, η_p^2 = 0.151, 95% CI [0.026, 0.282], Supplementary Table 20) , emotion pair (F(3.855, 158.073) = 7.522, p < .001, η_p^2 = 0.15, 95% CI [0.051, 0.241], Supplementary Table 21), and age group (F(3, 41) = 3.173, p = .034, η_p^2 = 0.188, 95% CI [0, 0.347], Supplementary Table 22), with post-hoc comparisons corroborating the previously noted patterns observed from the analysis only involving upright faces (Supplementary Figure 4C).

Study 2. Conceptual Knowledge of Emotions

2.1 The development of conceptual similarity between different emotions validated using regressions

We first averaged the correlation scores in the happiness-fear, happiness-anger and happiness-sadness conditions as a conceptual similarity indicator of happiness and negative emotions. In addition, the correlation scores in fear-anger, fear-sadness and anger-sadness conditions were averaged as an indicator of conceptual similarity among negative emotions. To enhance the precision of age-related analyses, we calculated each participant's age in months. Then we used linear regression to explore the predictive effect of age on those conceptual similarity indicators. The results showed that the conceptual similarity between happiness and negative emotions did not exhibit a statistically significant with age (B = -0.050, SE = 0.011, t = –0.596, p = .552, 95% CI [-0.027, 0.013]) (Supplementary Figure 5A). However, the similarity among negative emotions increased significantly with age (B = 0.246, SE = 0.011, t = 3.024, p =.003, 95% CI [-0.014, 0.054]) (Supplementary Figure 5B).

2.2 Multidimensional scaling analysis of children's conceptual knowledge of emotions

To further explore the lower-dimensional representation of different emotions in conceptual knowledge, we additionally applied multidimensional scaling (MDS) to examine the pairwise distances between different emotions across age groups in a low-dimensional space. Using Euclidean distances, we computed dissimilarity matrices for each participant, capturing the perceived conceptual dissimilarities between emotion pairs, and reduced them to a two-dimensional representation (mean stress < 0.1, Supplementary Figure 6A). From the MDS results, we extracted the pairwise distances between emotions for each participant and analyzed these distances across three age groups (5-6 years group, 7–8 years group, and 9-10 years group) using repeated measures ANOVA (Supplementary Table 23). Results revealed a significant interaction between age and emotion pairs (F(10.413, 621.300) = 2.223, p = .014, η_p^2 = 0.036, 95% CI [0.001, 0.052]). Post-hoc analyses demonstrated that the conceptual dissimilarities between negative emotions (e.g., fear-anger, anger-sadness) decreased with age, suggesting greater conceptual similarity among these emotions as participants grew older

(Supplementary Figure 6B, Supplementary Table 24). In contrast, the distances between positive and negative emotions (e.g., happy-fear, happy-anger, happy-sad) remained relatively stable across age groups. A significant main effect of emotion pair was also observed, $F(3.471, 621.300) = 358.640$, $p < .001$, $\eta_p^2 = 0.667$, 95% CI [0.627, 0.698], with happiness consistently perceived as the most distinct from negative emotion categories (Table 25). These findings extend prior research that predominantly utilized correlation-based methods by offering a finer-grained analysis of the developmental trajectories in the conceptual organization of emotions.

2.3 Analysis of the relationship between emotional vocabulary comprehension and conceptual similarity rating task performance

To explore whether children's emotional vocabulary comprehension influenced their conceptual understanding of emotions, we utilized a parent-reported child word comprehension questionnaire. This questionnaire included vocabulary items specifically associated with the four emotion categories examined in our study (happiness, fear, anger, sadness). Guardians were asked to rate their child's comprehension of each word on a scale from 1 ("do not understand") to 3 ("clearly understand"). Data were collected from 89 children (M_{age} = 7.39, SD = 1.80, range: 5.00–11.00, 50 female). To assess whether children with better emotional word comprehension demonstrated greater conceptual similarity to adults in the conceptual similarity rating task, we calculated Pearson correlation coefficients between parent-reported word comprehension scores and children's self-rated conceptual similarity ratings. Age was included as a covariate to control for developmental effects. The analysis revealed no statistically significant correlations between emotional vocabulary comprehension and conceptual similarity ratings across all emotion categories: happiness ($r(85) = -0.055$, $p = .610$, 95% CI [-0.225, 0.123]), fear ($r(85) = -0.023$, $p = .829$, 95% CI [-0.217, 0.164]), anger ($r(85) = 0.004$, $p = .972$, 95% CI [-0.188, 0.181]), and sadness ($r(85) = -0.124$, $p = .251$, 95% CI [-0.305, 0.161]).

Study 3. Assessment of Emotion Judgments

3.1 Accuracy for the sorting and matching tasks

Results from analyzing the sorting task (Supplementary Table 32) revealed a significant interaction between emotion and age (F(7.046, 422.780) = 2.240, p = .030, η_p^2 = 0.036, 95% CI [0, 0.061]). Specifically, the differences for sadness were more pronounced between the 5–6 age group and the other age groups (Supplementary Table 33). A significant main effect of age group was also found (F(3,180) = 13.453, p < .001, η_p^2 = 0.183, 95% CI [0.083, 0.271]). Specifically, 5-6 years group (M = 0.729, SD = 0.014) had lower accuracy in judging emotions compared to all the other groups, and 7-8 years group (M = 0.793, SD = 0.017) had significantly lower accuracy compared to adult groups (M = 0.867, SD = 0.018) (Supplementary Figure 8A, Supplementary Table 34). Accuracy also varied across different emotions, (F(2.349,422.780) = 131.126, p < .001, η_p^2 = 0.421, 95% CI [0.352, 0.479]), with the highest accuracy observed in judging happiness (M = 0.961, SD = 0.006), followed by fear (M = 0.804, SD = 0.013), anger (M = 0.787, SD = 0.014), and the lowest for sadness (M = 0.653, SD = 0.015) (Supplementary Table 35).

The analysis of the recognition accuracy of the maching task (Supplementary Table 36) revealed a significant interaction between emotion and age group (F(6.511,388.486) = 5.211, p < .001, η_p^2 = 0.080, 95% CI [0.025, 0.122]). The 5-6 years group showed lower accuracy compared to the young adults group in the conditions of fear, anger, and sadness. However, no significant difference was found in the happiness condition (Supplementary Figure 8B, Supplementary Table 37). We also found a significant improvement in the judgment of different emotions with increasing age (F(3,179) = 11.362, p < .001, η_p^2 = 0.160, 95% CI [0.065, 0.246]). To be specific, 5-6 years group (M = 0.797, SD= 0.013) had significantly lower accuracy in judging emotions compared to young adult group (M = 0.899, SD= 0.017) (Supplementary Table 38). Additionally, there were significant differences in scores among different emotions, F(2.170,388.486) = 455.772, p < .001, η_p^2 = 0.718, 95% CI [0.674, 0.751]. Post-hoc comparisons showed the accuracy in judgment was highest for happiness (M = 0.971, SD = 0.006), followed by fear (M = 0.880, SD = 0.009), anger (M = 0.743, SD = 0.011), and lowest for sadness (M = 0.689, SD = 0.011) (Supplementary Table 39).

3.2 Behavioral Performance in the sorting and matching tasks

For the sorting task, we calculated the number of facial images that were sorted into "incorrect" emotion categories (e.g., facial configurations that should be categorized as "happiness" but were sorted by a child as representing "sadness"). A repeated measures ANOVA revealed a main effect of age ($F(3,180) = 11.512$, $p < .001$, $\eta_p^2 = 0.161$, 95% CI [0.066, 0.247]), such that the 5-6 years group manifested greater confusion on average across expressions compared to 9-10 years and young adult groups, and the 7-8 years group showed greater confusion than the young adult group, indicating an increase in confusion in judging different emotions in general with age (Supplementary Figure 7A). A main effect was also found for emotion pair, $F(3.301, 594.137) = 260.936$, $p < .001$, $\eta_p^2 = 0.592$, 95% CI [0.544, 0.629]. Post-hoc comparisons revealed that the confusion scores among negative emotions (in the order of anger-sadness > fear-sadness > fear-anger) were all greater than the happiness-negative emotion pairs (in the order of happiness-fear > happiness-sadness = happiness-anger). There was no statistically significant interaction between emotion pair and age group, $F(9.902, 594.137) = 1.116$, $p = .337$, $\eta_p^2 = 0.018$, 95% CI [0, 0.027].

For the matching task, we calculated a maximum deviation (MD) parameter, a well-validated index of the co-activation of unselected category responses during perception. MD reflects the maximum perpendicular deviation from an ideal straight line between the mouse starting and ending points. Greater MD values between two emotion categories in the matching task indicate greater similarity in judgment and understanding between those categories. The repeated measures ANOVA analysis of the MD values in the matching task revealed an interaction between emotion pair and age group, $F(13.866, 827.327) = 2.847$, $p < .001$, $\eta_p^2 = 0.046$, 95% CI [0.009, 0.060] Post-hoc comparisons revealed that the MDs between negative emotions (e.g., anger-sadness and fear-sadness) were greater than those between happiness-negative pairs for the 5-6 years group. However, these differences decregujased with age, i.e., for the 7-8 years and 9-10 years groups, except for anger-sadness, which still elicited the highest MD value (Supplementary Figure 7B). There was also a main effect of emotion pair, $F(4.622,827.327) = 321.351$, $p < .001$, $\eta_p^2 = 0.642$, 95% CI [0.606,

0.671], with differences in MDs found between most emotion pairs. The MDs, ranked from highest to lowest—anger-sadness > fear-sadness > fear-anger > happiness-fear > happiness-sadness > happiness-anger—mirrors the pattern of the confusion scores from the sorting task. The main effect of group was also significant, $F(3,179) = 3.267$, $p = .023$, $\eta_p^2 = 0.052$, 95% CI [0, 0.114]. However, pairwise comparisons revealed that none of the differences between age groups were statistically significant.

RSA: Relative Contributions of Discrimination and Conceptual Knowledge to Emotion Judgments

4.1 Representational Similarity Analysis for adults

In analyzing the representational similarity matrices of different tasks for adults, we employed a GEE multilevel regression, controlling for the similarity of low-level facial features (FACS) to examine the predictive effects of spontaneous discrimination (measured by FPVS) and conceptual knowledge representation (measured by conceptual similarity rating task) for values of emotion judgment similarity measured by sorting and matching task, respectively.

Regarding the prediction of emotion judgments measured by the sorting task, perceptual discrimination was not a statistically significant predictor of emotion judgment ($B = 0.039$, SE = 0.021, $Z = 1.884$, $p = .060$, 95% CI [-0.002, 0.079]), but conceptual knowledge was significantly associated with the results of emotion judgment ($B = 0.061$, SE = 0.006, $Z = 9.482$, $p < .001$, 95% CI [0.049, 0.074]) (Supplementary Figure 12A, 12B). For the results of the prediction to the emotion judgments measured by the matching task, perceptual discrimination was not a statistically significant predictor of the outcomes ($B = 0.073$, SE = 0.056, $Z = 1.309$, $p = .191$, 95% CI [-0.036, 0.181]), whereas conceptual knowledge had a significant predictive effect on the emotion judgment ($B = 0.114$, SE = 0.022, $Z = 5.177$, $p < .001$, 95% CI [0.071, 0.157]) (Supplementary Figure 12C, 12D).

To further explore whether controlling for FACS variables impacted the predictive relationships, we conducted additional analyses excluding FACS from the model. When

FACS was removed, the main effect of perceptual discrimination on the sorting task became statistically significant (B = 0.046, SE = 0.023, Z = 1.981, p = .048, 95% CI [0.000, 0.092]), suggesting that FACS-defined visual similarity partially accounts for the effect of perceptual discrimination. Conceptual knowledge, however, remained significantly associated with emotion judgment (B = 0.058, SE = 0.008, Z = 7.625, p < .001, 95% CI [0.043, 0.073]). For the matching task, the main effect of perceptual discrimination remained statistically non-significant even after removing FACS (B = 0.087, SE = 0.024, Z = 1.462, p = .144, 95% CI [-0.030, 0.203]), while conceptual knowledge continued to show a significant predictive effect on emotion judgment (B = 0.108, SE = 0.024, Z = 4.564, p < .001, 95% CI [0.061, 0.154]). These results underscore the importance of controlling for FACS to avoid low-level visual features confounding the roles of perceptual and conceptual predictors in emotion judgment tasks, while also demonstrating that the inclusion of FACS does not explain away all commonalities between neural and behavioural facial expression discrimination tasks.

4.2 Predicting perceptual discrimination from conceptual knowledge among children and young adults

we employed GEE multilevel regression, controlling for the similarity of low-level facial features (FACS) to examine how the predictive effects of conceptual knowledge (measured by rating task) for perceptual discrimination (measured by FPVS) among children and young adults, respectively. The GEE model for children showed that conceptual knowledge cannot statistically predict perceptual discrimination (B = 0.079, SE = 0.078, Z = 1.021, p = .307, 95% CI [-0.073, 0.231]) (Supplementary Figure 13A). The interaction between values of age and conceptual knowledge was not statistically significant, B = -0.006, SE = 0.009, Z = -0.597, p = .550, 95% CI [-0.024, 0.013]. The GEE model for adults also showed that conceptual knowledge cannot statistically predict perceptual discrimination (B = -.004, SE = 0.025, Z = -0.160, p = .873, 95% CI [-0.053, 0.045]) (Supplementary Figure 13B).

4.3 Response at the oddball frequency in the 30 seconds of each block across 7-10 age groups and young adults

A repeated measures ANOVA was used to examine the signal-to-noise ratio at the selected oddball harmonics by using 30 seconds of each block across 7-10 years groups and young adults (Supplementary Table 44). There was an interaction between ROI and age, $F(4.858, 244.503) = 6.369$, $p < .001$, $\eta_p^2 = 0.112$, 95% CI [0.045, 0.162], as the age-related differences in oddball responses primarily shown in the central and right regions (Supplementary Figure 14B, Supplementary Table 45). In addition, we found a significant interaction between emotion pair and ROI, $F(6.593,995.614) = 2.997$, $p = .005$, $\eta_p^2 = 0.019$, 95% CI [0.003, 0.030] (Supplementary Table 46).The interaction between emotion pair and age was not statistically significant, $F(13.034,656.069) = 1.115$, $p = .342$, $\eta_p^2 = 0.022$, 95% CI [0, 0.022]. Beyond the interactions, the analysis revealed a main effect of emotion pair, $F(4.345,656.069) = 33.373$, $p < .001$, $\eta_p^2 = 0.181$, 95% CI [0.135, 0.220]. Specifically, the brain exhibited heightened discrimination responses between happiness and negative emotions, with the exception of the fear-anger pair (Supplementary Table 47). Additionally, we observed significant differences in EEG activity across different ROIs ($F(1.619, 244.503) = 34.418$, $p < .001$, $\eta_p^2 = 0.186$, 95% CI [0.115, 0.253]), with stronger activity in the central and right temporal cortical regions (Supplementary Table 48). Furthermore, while a main effect of age emerged, $F(3,151) = 4.956$, $p = .003$, $\eta_p^2 = 0.090$, 95% CI [0.020, 0.154], post-hoc comparisons revealed no significant differences among the three child groups but a notable distinction when comparing the 5-6 year-old groups to the young adult group (Supplementary Table 49).

We then used multiple regression RSA to investigated the predictive effects of perceptual discrimination (measured by FPVS) and conceptual knowledge (measured by the rating task) of children's emotion judgments measured by the sorting and matching tasks, respectively. The results are similar to those obtained using 20 seconds responses for each block in the children aged 7-10 years and young adults in the FPVS task.

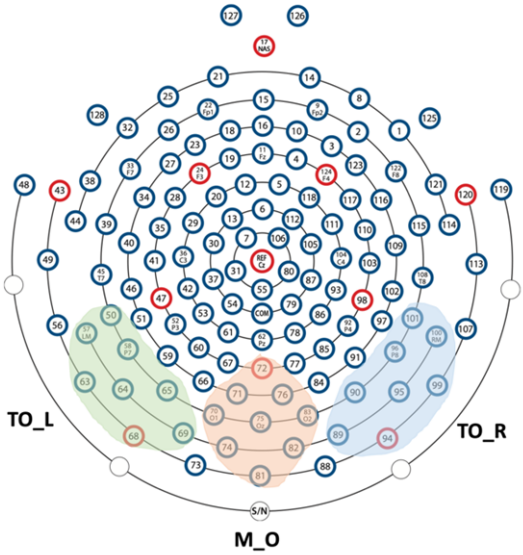
We firstly regressed values of perceptual discrimination and conceptual knowledge onto values of emotion judgment which were measured by the sorting task. The results indicated a significant interaction between age and perceptual discrimination, $B = -0.030$, SE = 0.001, Z

= -3.235, p = .003, 95% CI [-0.041, -0.010] (Supplementary Figure 14C). Simple slope tests revealed that perceptual discrimination predicted emotion judgement in the younger and middle-age groups (younger children: B = 0.183, SE = 0.047, Z = 3.894, p < .001, 95% CI [0.091, 0.276]; middle-aged: B = 0.162, SE = 0.028, Z = 5.847, p < .001, 95% CI [0.108, 0.216]). However, the effect was not statistically significant in the older children (B = 0.019, SE = 0.027, Z = 0.705, p = .481, 95% CI [-0.034, 0.072]) (Supplementary Figure 14D). Additionally, main effects of conceptual knowledge (B = 0.089, SE = 0.036, Z = 2.440, p = .026, 95% CI [0.017, 0.160]) and perceptual discrimination (B = 0.290, SE = 0.067, Z = 4.309, p < .001, 95% CI [0.158, 0.422]) were observed, suggesting that conceptual knowledge and spontaneous discrimination of emotions both have an impact on emotion judgment performance in general. The interaction between age and conceptual knowledge was not significant (B < .001, SE = 0.004, Z = 0.006, p = .995, 95% CI [-0.008, 0.008]).

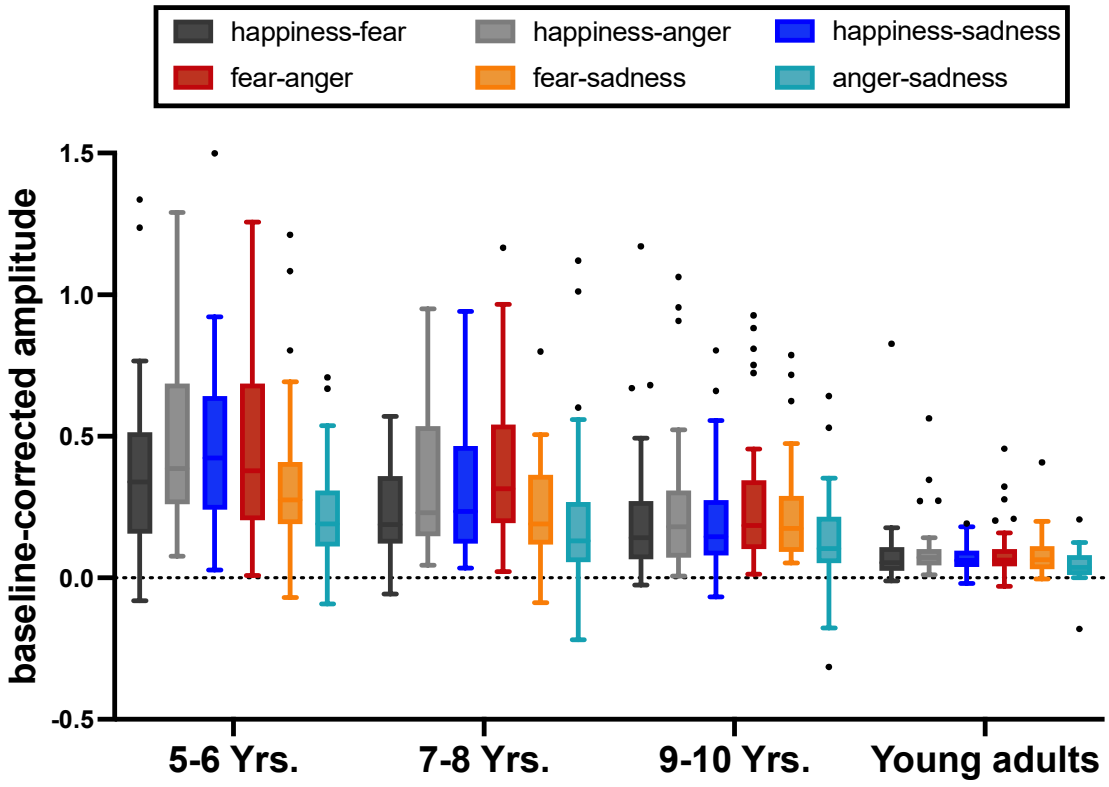
The prediction of values of emotion judgment measured by the matching task also revealed an interaction between age and perceptual discrimination, B = -0.048, SE = 0.024, Z = -1.971, p = .049, 95% CI [-0.095, -0.000] (Supplementary Figure 14E). Simple slope tests revealed that perceptual discrimination predicted emotion judgement in the younger and middle-age groups (younger children: B = 0.248, SE = 0.111, Z = 2.239, p = .025, 95% CI [0.031, 0.465]; middle-aged: B = 0.344, SE = 0.059, Z = 5.792, p < .001, 95% CI [0.227, 0.460]). However, the effect was not statistically significant in the older children (B = -0.018, SE = 0.080, Z = -0.229, p = .819, 95% CI [-0.176, 0.139]) (Supplementary Figure 14F). Furthermore, the interaction beween age and conceptual knowledge was significant, B = 0.025, SE = 0.010, Z = 2.501, p = .022, 95% CI [0.005, 0.045] (Supplementary Figure 14G). Conceptual knowledge predicts emotion judgment in all three groups, with the predicted values progressively increasing (younger children*:* B = 0.081, SE = 0.039, Z = 2.076, p = .038, 95% CI [0.005, 0.157]; middle-aged: B = 0.172, SE = 0.024, Z = 7.098, p < .001, 95% CI [0.125, 0.220]; older children: B = 0.239, SE = 0.042, Z = 5.667, p < .001, 95% CI [0.156, 0.322]) (Supplementary Figure 14H). Perceptual discrimination positively predicted emotion judgment (B = 0.538, SE = 0.196, Z = 2.749, p = .014, 95% CI [0.155, 0.922]), while

values of conceptual knowledge could not predict emotion judgment (B = -0.041, SE = 0.080, Z = -0.499, p = .618, 95% CI [-0.197, 0.117]).

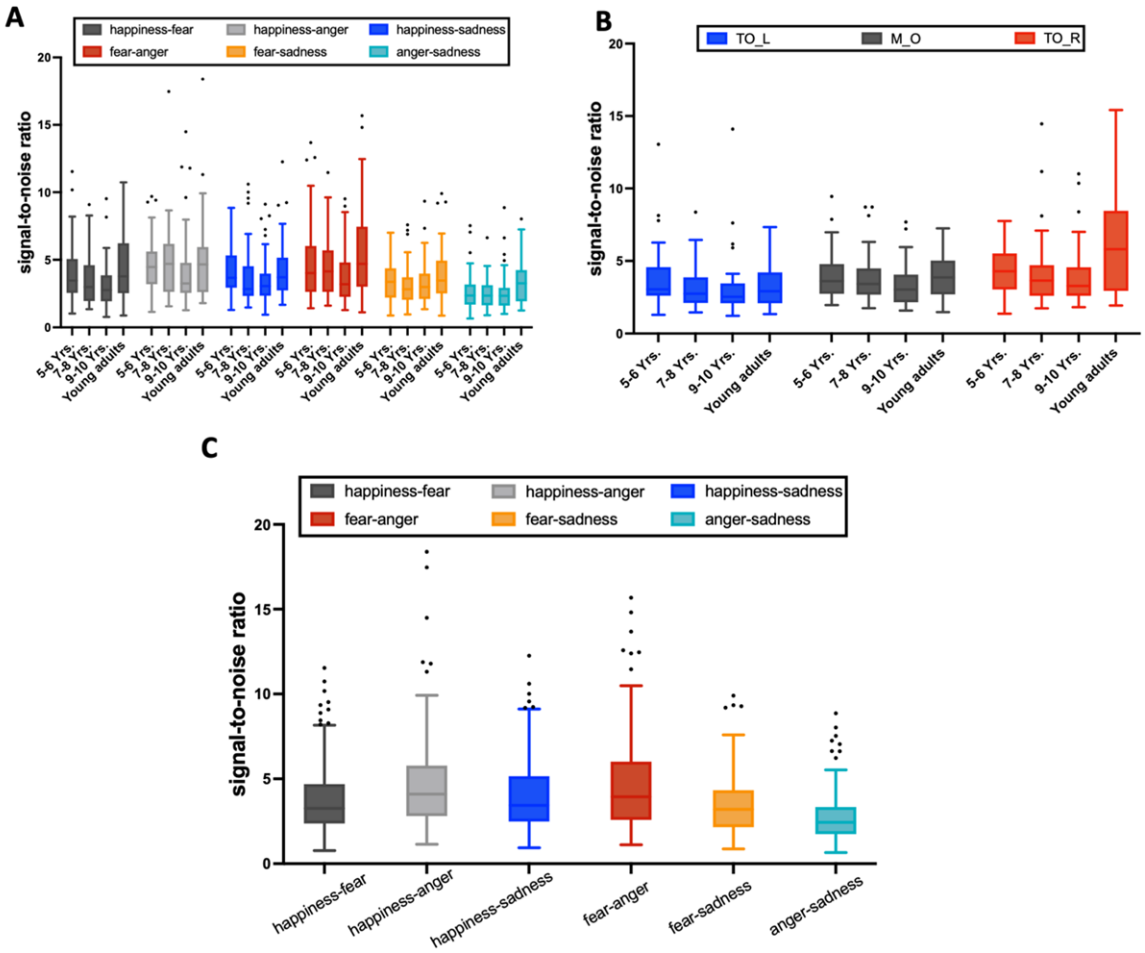
Supplementary Figure 1. Bird's eye view of the electrode clusters created with HGSN electrodes. The 2D map shows the locations and the names of the 3 electrode clusters. The green area is left temporal-occipital region (TO_L: 89, 90, 94, 95, 96, 99, 100, 101), the orange area is middle occipital region (M_O: 70, 71, 72, 74, 75, 76, 81, 82, 83), and the blue area is right temporal-occipital region (TO_R: 50, 57, 58, 63, 64, 65, 68, 69).



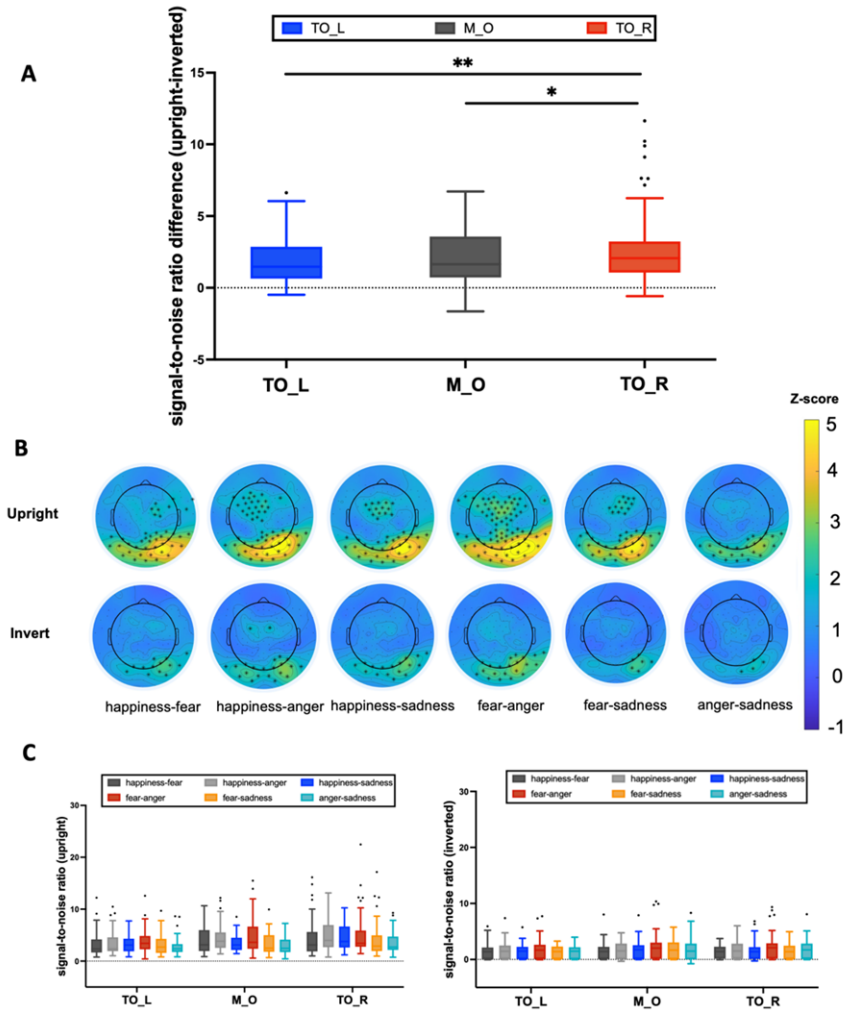
Supplementary Figure 2. Box plots show the distribution of baseline-corrected oddball amplitudes across four age groups (5–6 years, 7–8 years, 9–10 years, and young adults) for each emotion pair. Each box represents the median (centre line) and the 25th and 75th percentiles (box bounds), with whiskers extending to the most extreme values within 1.5× the interquartile range, in accordance with Tukey's method. Dots represent individual outliers. Individual dots represent data from biologically independent participants (n = 122 children: 5–6 years, n = 45; 7–8 years, n = 38; 9–10 years, n = 39; and n = 33 adults), with no technical replicates. Colour coding corresponds to the six emotion pairs as indicated in the legend. A repeated-measures ANOVA revealed a significant age-related decline in EEG amplitude ($F(3, 150) = 17.072$, $p < .001$, $\eta_p^2 = 0.255$, 95% CI [0.133, 0.352]).



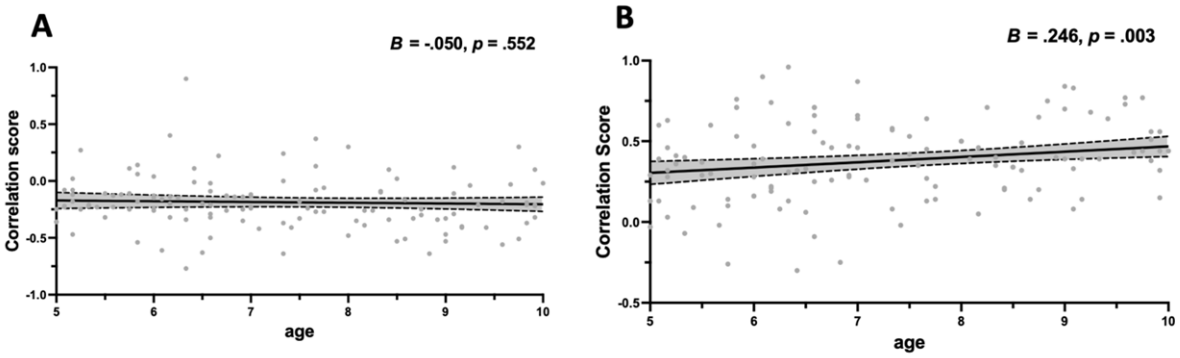
Supplementary Figure 3. Oddball responses to changes of facial configurations in the FPVS experiment. Each box indicates the median (centre line), the 25th and 75th percentiles (box bounds), and whiskers extend to the most extreme data points within 1.5× the interquartile range, according to Tukey's method. Dots represent individual outliers. Individual dots represent data from biologically independent participants (n = 122 children: 5–6 years, n = 45; 7–8 years, n = 38; 9–10 years, n = 39; and n = 33 adults). (A). The signal-to-noise ratio for different age groups across emotion pair conditions. Responses were averaged over 3.6 Hz and 4.8 Hz. No significant interaction between emotion pair and age group (F(12.964, 652.521) = 0.702, p = .762, η_p^2 = 0.014, 95% CI [0, 0.013]) was found. (B). Bar graphs of the averaged oddball responses for different ROIs presented separately for different age groups (5-6 years, 7-8 years, 9-10 years, and young adults. A significant interaction was observed between ROI and age group (F(4.909, 247.104) = 6.411, p < .001, η_p^2 = 0.113, 95% CI [0.037, 0.175]). (C). The average signal-to-noise ratio for different emotion pairs. A repeated-measures ANOVA revealed significant main effects of emotion pair (F(4.321, 652.521) = 27.549, p < .001, η_p^2 = 0.154, 95% CI [0.103, 0.200]). The oddball response significantly decreased across emotion pairs except for the transitions from happiness-anger to fear-anger and from happiness-fear to happiness-sadness.



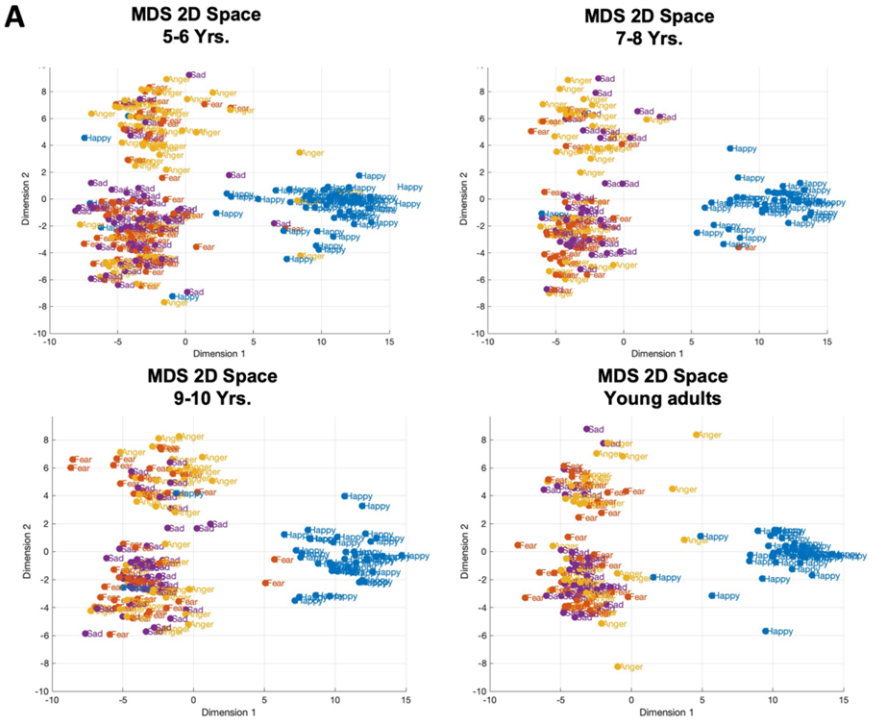
Supplementary Figure 4. Oddball responses in upright and inverted conditions. Box plots (A, C) represent the signal-to-noise ratio of EEG responses, calculated at 3.6 Hz and 4.8 Hz. Each box indicates the median (centre line), the 25th and 75th percentiles (box bounds), and whiskers extend to the most extreme data points within 1.5× the interquartile range, according to Tukey's method. Dots represent individual outliers. Individual dots represent data from biologically independent participants (n = 122 children: 5–6 years, n = 45; 7–8 years, n = 38; 9–10 years, n = 39; and n = 33 adults). (A). The signal-to-noise ratio differences between the upright and inverted conditions in the three ROIs. There was an interaction between orientation and ROI ($F(1.872,76.747) = 4.304$, $p = .019$, $\eta_p^2 = 0.095$, 95% CI [0.002, 0.219]). Simple effects test showed that the attenuation in oddball responses due to face inversion was mainly found in the TO_R region. (B). Topographical maps of the oddball responses. Channels with significant responses are marked with a star. (C). The summed baseline-corrected harmonics of the oddball rate (3.6Hz and 4.8Hz) for the TO_L (left temporal-occipital), TO_R (right temporal-occipital) and M_O (middle occipital) are shown for different orientations (Upright and Inverted). There was a main effect of orientation ($F(1,41) = 71.806$, $p < .001$, $\eta_p^2 = 0.637$, 95% CI [0.436, 0.742]), with greater oddball responses found for the upright than the inverted condition.

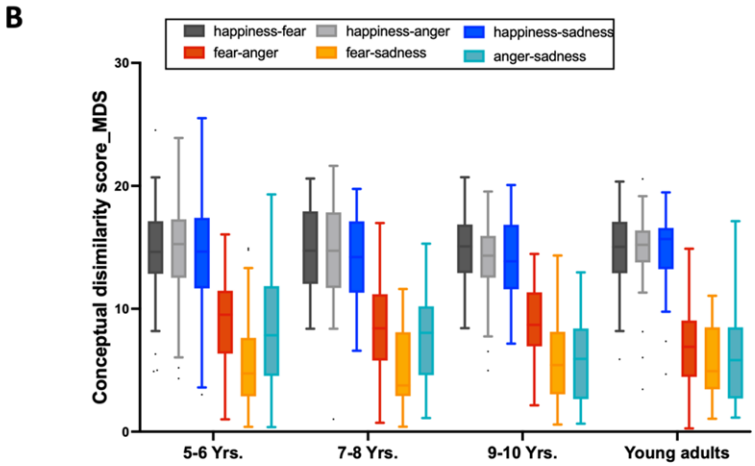


Supplementary Figure 5. Prediction of age on the correlation scores measured by the conceptual similarity rating task. Linear regression analyses were conducted to examine how age predicts conceptual similarity scores based on participants' emotion ratings. For each participant, average correlation scores were calculated for (A) happiness versus negative emotions (happiness–fear, happiness–anger, happiness–sadness) and (B) between negative emotions (fear–anger, fear–sadness, anger–sadness). In both panels, solid black lines represent the fitted regression lines, with shaded areas indicating 95% confidence intervals. Each dot reflects data from a biologically independent participant; no technical replicates were used. All tests were two-sided, and p-values were adjusted for multiple comparisons using FDR correction.

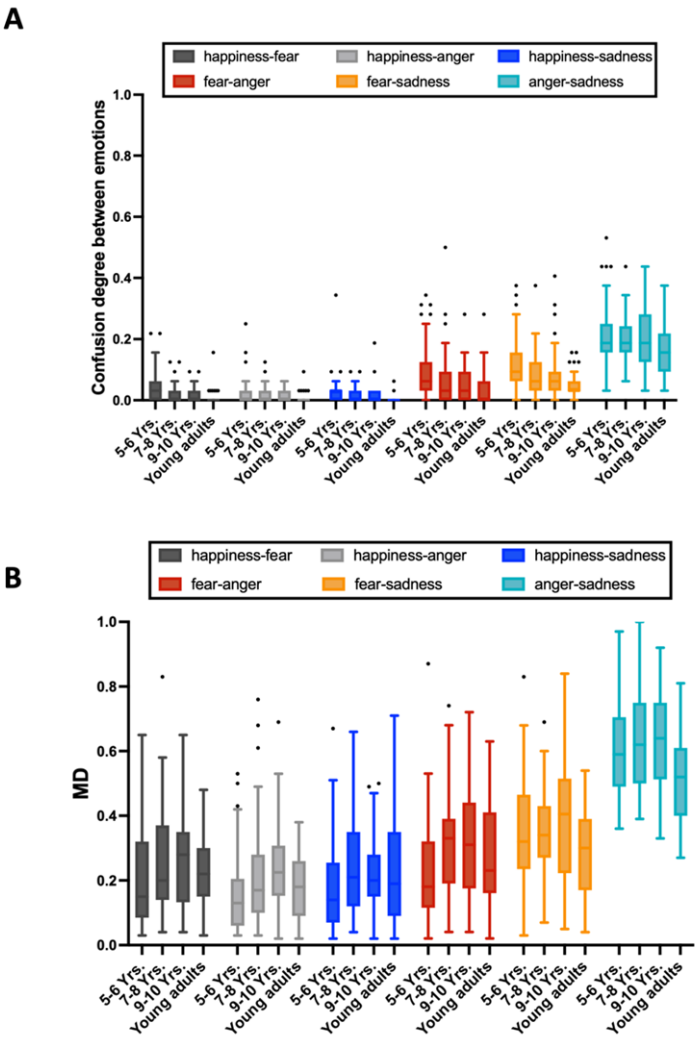


Supplementary Figure 6. Multidimensional scaling (MDS) analysis of children's conceptual knowledge of emotions using Euclidean distances. (A). Distribution of different emotions in the two-dimensional MDS space by age group. (B). Scores of conceptual dissimilarities between emotion pairs across different age groups based on MDS results. Higher values indicate reduced conceptual similarity between two emotions. Each box represents the median (centre line) and the 25th and 75th percentiles (box bounds), with whiskers extending to the most extreme values within 1.5× the interquartile range, according to Tukey's method. Dots represent individual outliers. Data were derived from biologically independent participants, with no technical replicates (n = 144 children: 5–6 years, n = 61; 7–8 years, n = 39; 9–10 years, n = 44; and n = 39 adults), with no technical replicates. A repeated-measures ANOVA revealed a significant interaction between emotion pair and age group ($F(10.413, 621.300) = 2.223$, $p = .014$, $\eta_p^2 = 0.036$, 95% CI [0.001, 0.052]).

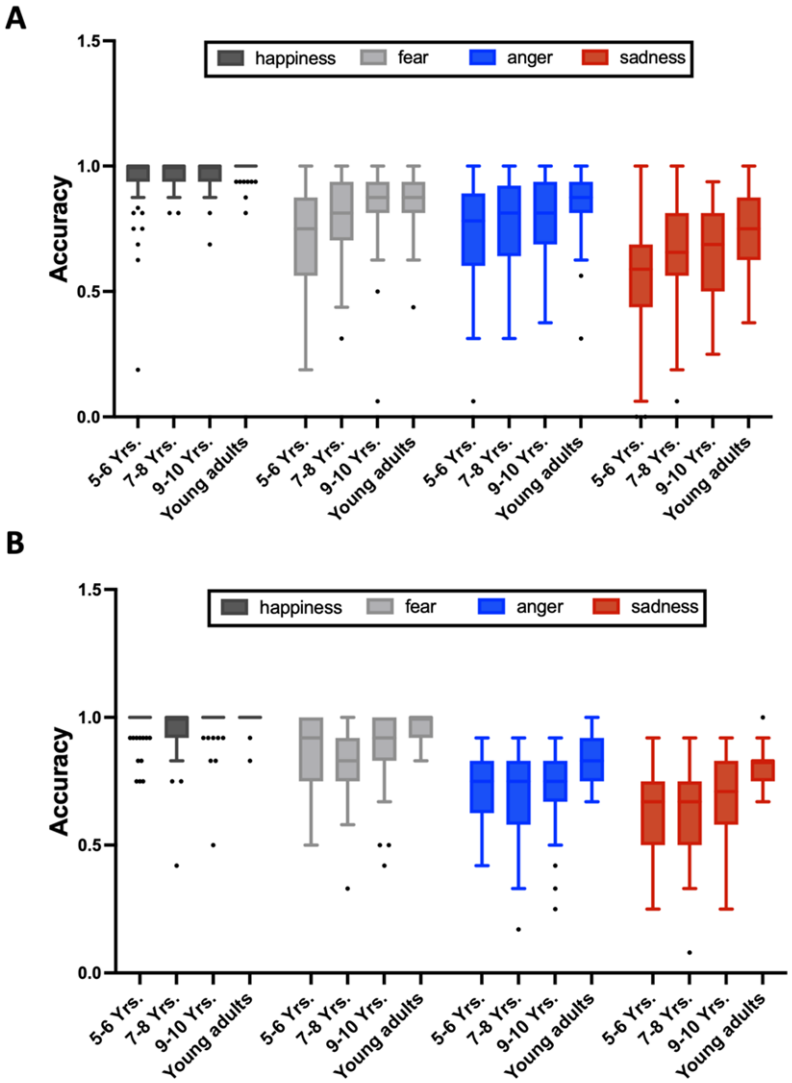




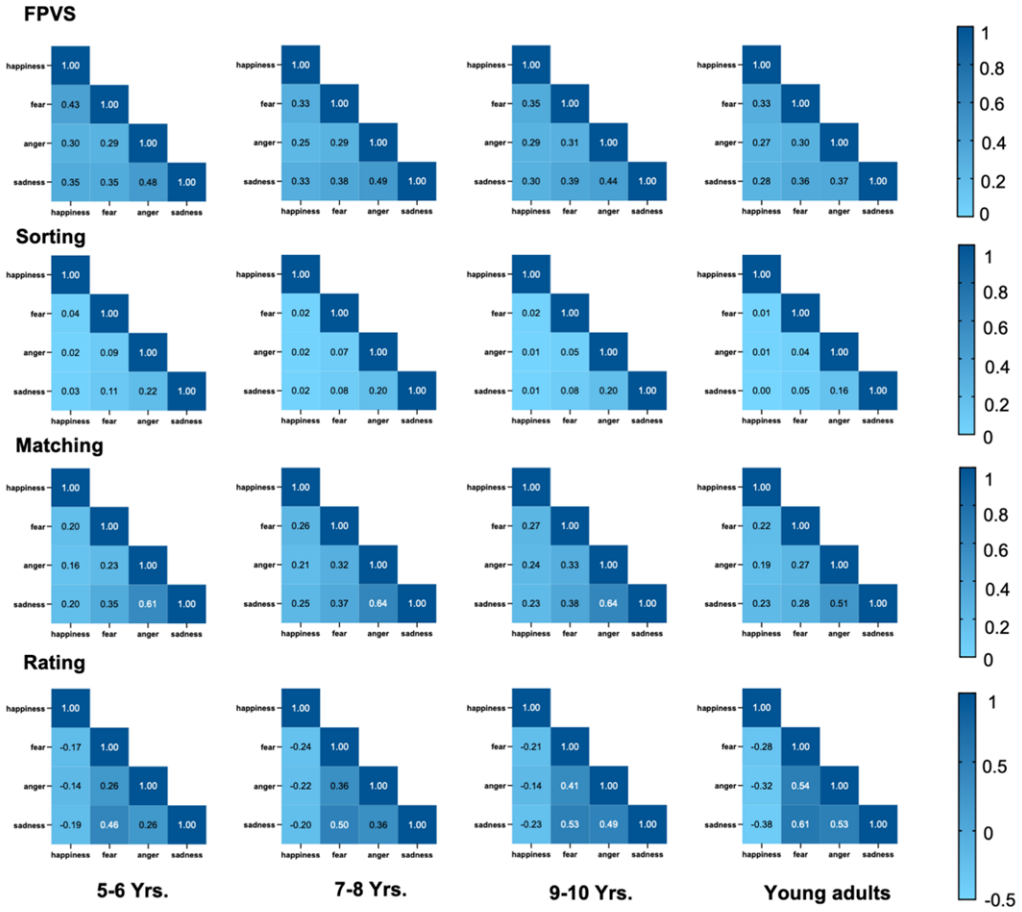
Supplementary Figure 7. Participants' performance for the similarity between different emotions in the two behavioral tasks for emotion judgments. Each box represents the median (centre line) and the 25th and 75th percentiles (box bounds), with whiskers extending to the most extreme values within 1.5× the interquartile range, according to Tukey's method. Dots represent individual outliers. (A). Confusion degrees between emotion pairs for different age groups in the sorting task. Data were derived from biologically independent participants, with no technical replicates (n = 145 children: 5–6 years, n = 62; 7–8 years, n = 40; 9–10 years, n = 43; and n = 39 adults), with no technical replicates. A repeated-measures ANOVA revealed a significant interaction between emotion pair and age group ($F(9.902, 594.137) = 1.116$, $p = .337$, $\eta_p^2 = 0.018$, 95% CI [0, 0.027]). (B). Maximum deviations (MD) of mouse trajectories between emotion pairs for different age groups in the matching task. Data were derived from biologically independent participants, with no technical replicates (n = 144 children: 5–6 years, n = 61; 7–8 years, n = 39; 9–10 years, n = 44; and n = 39 adults), with no technical replicates. A repeated-measures ANOVA revealed a significant interaction between emotion pair and age group ($F(13.866, 827.327) = 2.847$, $p < .001$, $\eta_p^2 = 0.046$, 95% CI [0.009, 0.060]).



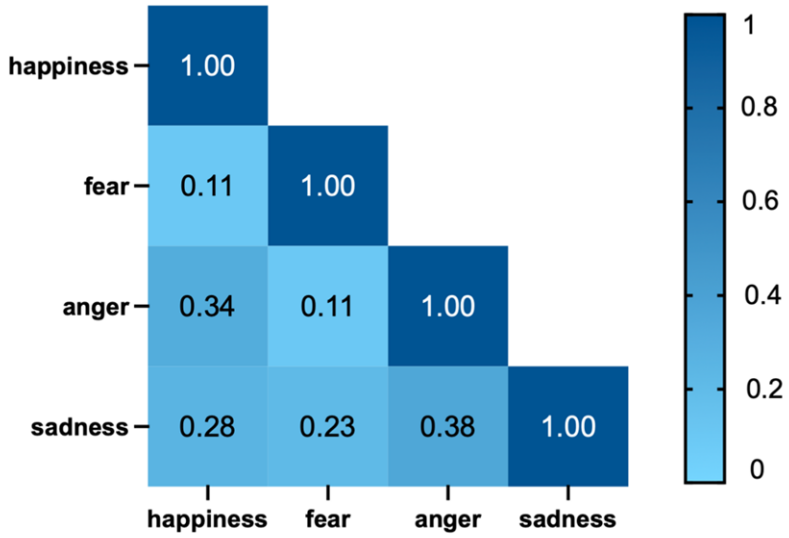
Supplementary Figure 8. Performance of different behavioral tasks for emotion judgment. Error bars represent standard errors of the mean. Each box represents the median (centre line) and the 25th and 75th percentiles (box bounds), with whiskers extending to the most extreme values within 1.5× the interquartile range, according to Tukey's method. Dots represent individual outliers. (A). Accuracy of different age groups in classifying emotions in the sorting task. Data were derived from biologically independent participants, with no technical replicates (n = 145 children: 5–6 years, n = 62; 7–8 years, n = 40; 9–10 years, n = 43; and n = 39 adults), with no technical replicates. A repeated-measures ANOVA revealed a significant interaction between emotion pair and age group ($F(7.046, 422.780) = 2.240$, $p = .030$, $\eta_p^2 = 0.036$, 95% CI [0, 0.061]). (B). Accuracy of different age groups in judging emotions in the matching task. Data were derived from biologically independent participants, with no technical replicates (n = 144 children: 5–6 years, n = 61; 7–8 years, n = 39; 9–10 years, n = 44; and n = 39 adults), with no technical replicates. A repeated-measures ANOVA revealed a significant interaction between emotion pair and age group ($F(6.511,388.486) = 5.211$, $p < .001$, $\eta_p^2 = 0.080$, 95% CI [0.025, 0.122]).



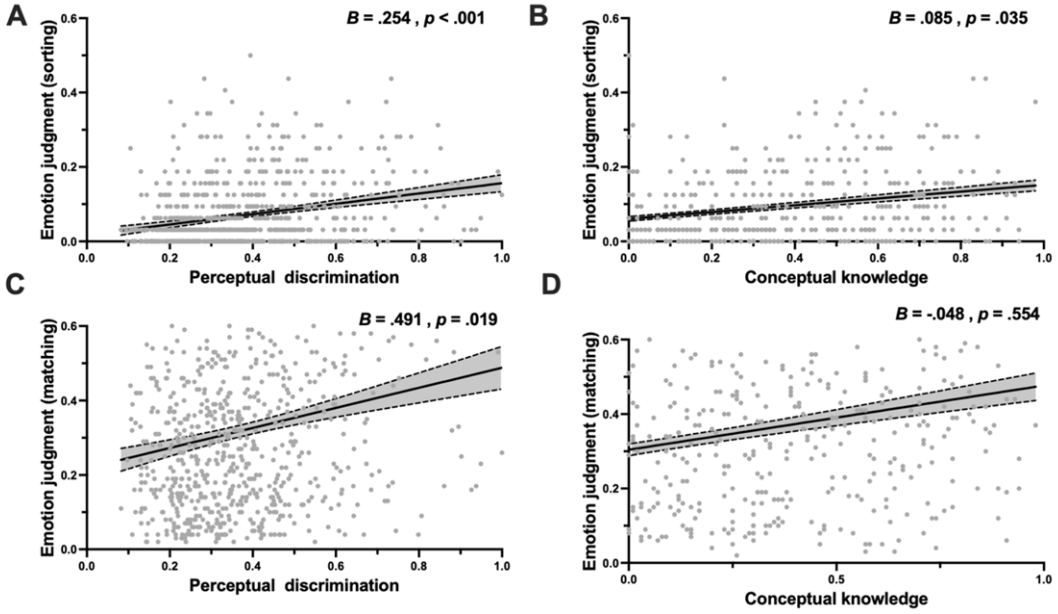
Supplementary Figure 9. Representational Similarity Matrices for different tasks across ages. The darker the color, the more similar the two stereotypical emotions are. The diagonal values were presented for illustrative purposes only, and were not included in the final analysis.



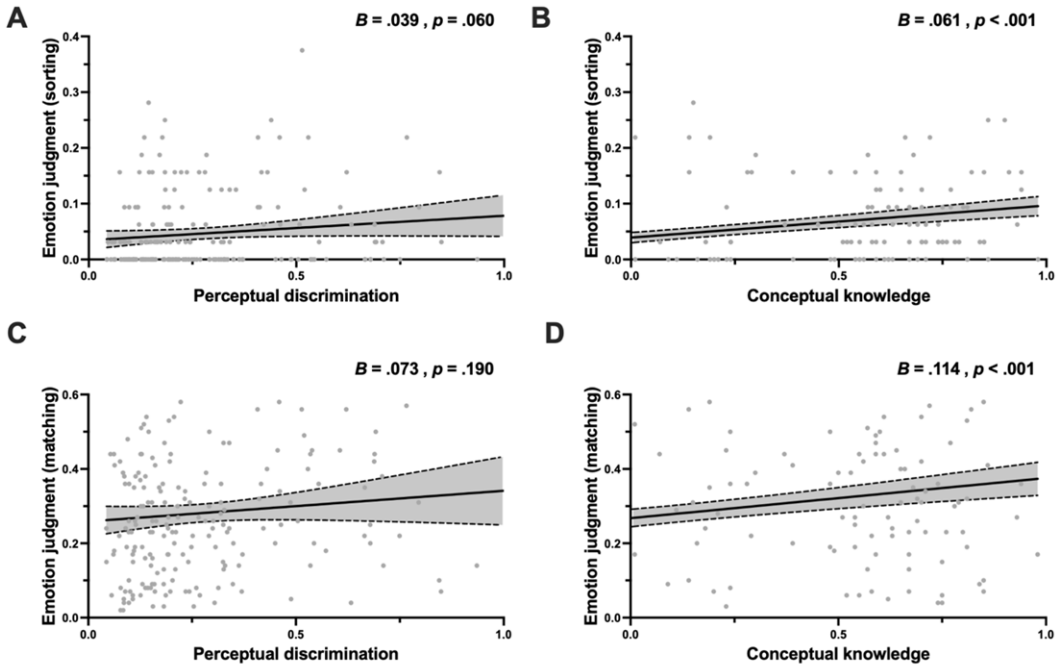
Supplementary Figure 10. Representational Similarity Matrices for FACS. After the face action units (AUs) of each image are encoded, the similarity between each two images is calculated, and averaged within different emotion conditions.



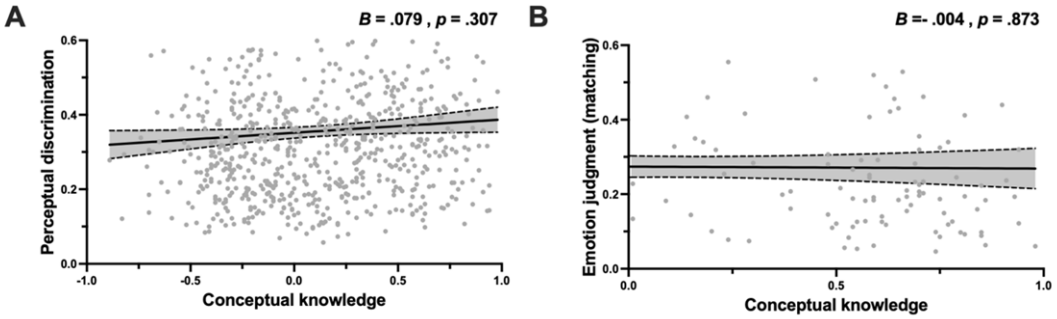
Supplementary Figure 11. The main effects for the predictive modeling of the emotion judgment performance in both the sorting (A, B) and matching (C, D) tasks for children. GEE models were used to estimate the main effects of predictors on emotion judgment performance. In each panel, solid black lines represent the fitted regression lines, with shaded areas indicating 95% confidence intervals. Each dot reflects data from a biologically independent participant; no technical replicates were used. All tests were two-sided, and p-values were adjusted for multiple comparisons using FDR correction. (A). Main effect of perceptual discrimination for the prediction of emotion judgment measured by the sorting task, error bars depicted with dashed lines. (B). Main effect of conceptual knowledge for the prediction of emotion judgment measured by the sorting task, error bars depicted with dashed lines. (C). Main effect of perceptual discrimination for the prediction of emotion judgment measured by the matching task, error bars depicted with dashed lines. (D). Main effect of conceptual knowledge for the prediction of emotion judgment measured by the matching task, error bars depicted with dashed lines.



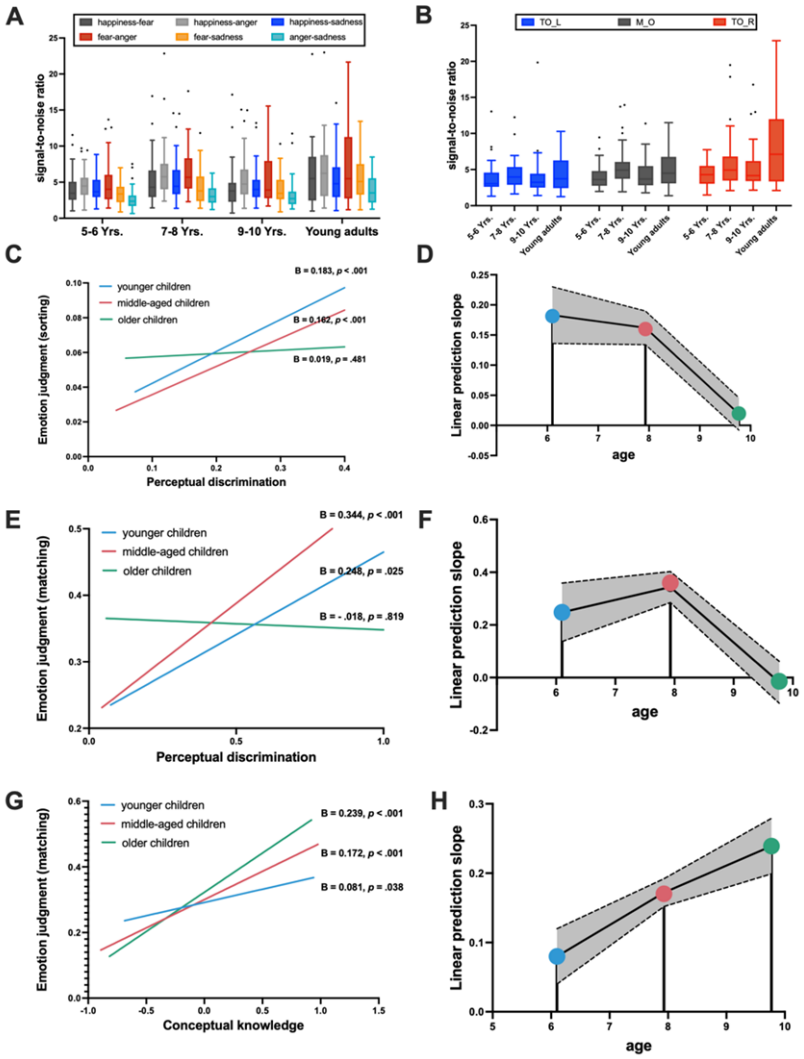
Supplementary Figure 12. Predictive effects of different components on emotion judgment performance for adults. Analyses were conducted using GEE multilevel regression. In each panel, solid black lines represent the fitted regression lines, with shaded areas indicating 95% confidence intervals. Each dot reflects data from a biologically independent participant; no technical replicates were used. All tests were two-sided, and p-values were adjusted for multiple comparisons using FDR correction. (A). Main effect of perceptual discrimination for the prediction of emotion judgment measured by the sorting task. (B). Main effect of conceptual knowledge for the prediction of emotion judgment measured by the sorting task. (C). Main effect of perceptual discrimination for the prediction of emotion judgment measured by the matching task. (D). Main effect of conceptual knowledge for the prediction of emotion judgment measured by the matching task, error bars depicted with dashed lines.



Supplementary Figure 13. Predicting perceptual discrimination from conceptual knowledge. GEE models were used to estimate the main effects of predictors on emotion judgment performance. In each panel, solid black lines represent the fitted regression lines, with shaded areas indicating 95% confidence intervals. Each dot reflects data from a biologically independent participant; no technical replicates were used. All tests were two-sided, and p-values were adjusted for multiple comparisons using FDR correction. (A). Main effect of conceptual knowledge for the prediction of perceptual discrimination in children. (B). Main effect of conceptual knowledge for the prediction of perceptual discrimination in adults, error bars depicted with dashed lines.



Supplementary Figure 14. Box plots (A–B) show averaged oddball responses at 3.6 Hz and 4.8 Hz for six emotion pairs across four age groups (5–6 years, 7–8 years, 9–10 years, and adults). Each box represents the median (centre line), 25th and 75th percentiles (box bounds), and whiskers extend to the most extreme values within 1.5× the interquartile range (Tukey's method). Dots represent individual outliers. Data were collected from biologically independent participants (n = 122 children: 5–6 years, n = 45; 7–8 years, n = 38; 9–10 years, n = 39; and n = 33 adults); no technical replicates were used. Colours denote emotion pairs, as shown in the legend. (A) No significant interaction was found between age group and emotion pair (F(13.034, 656.069) = 1.115, p = .342, η_p^2 = 0.022, 95% CI [0, 0.022]). (B) A significant effect of ROI was observed across age groups (F(4.858, 244.503) = 6.369, p < .001, η_p^2 = 0.112, 95% CI [0.045, 0.162]). Panels C–H show results from predictive modeling of emotion judgment during the 30-second task period. (C, E, G) Interactions between age and perceptual discrimination (C, E) or conceptual knowledge (G) were tested using generalized estimating equations (GEE), with two-sided tests and FDR correction for multiple comparisons. (D, F, H) Each point indicates the group-level mean of the linear prediction slope across age, with error bars reflecting ±1 SEM based on biologically independent participants.



Supplementary Table1. Participants' Information for Different Tasks

	5-6			7-8			9-10			adult		
	N	M_{age}	SD	N	M_{age}	SD	N	M_{age}	SD	N	M_{age}	SD
sorting	62(F= 28)	5.93	0.59	40(F= 21)	7.96	0.64	43(F= 21)	10.04	0.71	39(F= 20)	20.77	1.87
MT	61(F= 28)	5.93	0.60	39(F= 21)	7.97	0.65	44(F= 22)	10.05	0.71	39(F= 20)	20.77	1.87
rating	61(F= 28)	5.94	0.59	39(F= 21)	7.96	0.65	44(F= 22)	10.05	0.71	39(F= 20)	20.77	1.87
FPVS	45(F= 23)	5.93	0.58	38(F= 19)	7.95	0.63	39(F= 19)	10.08	0.70	33(F= 15)	20.91	1.89

Supplementary Table2. Google frequency of the words in the rating task

Words	English translation	Frequency
叫喊	Yelling	7930000
转身离去	Turning away	19000000
赛跑	Running	20600000
睁大眼睛	Wide eyes	24500000
哭泣	Crying	47100000
跳跃	Jumping	62500000
生病	Sickness	64300000
愤怒	Rage	96900000
恶心	Nausea	102000000
冷静	Calm	114000000
头痛	Headache	126000000
尖叫	Screaming	131000000
出汗	Sweating	240000000
紧张	Tense	269000000
热	Heat	1450000000
温暖	Warmth	198000000
喜爱	Loving	236000000
微笑	Smiling	317000000
兴奋	Excitement	362000000
大笑	Laughing	450000000

Supplementary Table 3. Repeated Measures ANOVA Results of baseline-corrected analysis across different ROIs for various emotion pairs in different age groups. All tests were two-sided. Degrees of freedom were adjusted using the Greenhouse–Geisser correction when the assumption of sphericity was violated, as indicated by Mauchly's test.

Effect	F(*df*)	*p*	η_p^2	95%CI
Emotion pairs	2.945 (2.347, 352.069)	.045	.019	[0, 0,052]
ROI	3.900 (1.979, 296.838)	.022	.025	[0, 0,066]
Age groups	17.072 (3, 150)	<.001	.255	[0.152, 0.373]
Emotion pairs * Age groups	0.806 (7.041, 352.069)	.583	.016	[0, 0.028]
ROI * Age groups	1.010 (5.938, 296.838)	.418	.020	[0, 0,040]
Emotion pairs * ROI	0.609 (4.287, 643.064)	.668	.004	[0, 0,012]
Emotion pairs * ROI * Age groups	0.954 (12.861, 643.064)	.495	.019	[0, 0.022]

Supplementary Table 4. Multiple comparisons of the main effect of emotion pair in the Repeated Measures ANOVA of baseline-corrected analysis. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
Happiness-fear	-	Happiness-anger	-.061	.026	.336	-0.140	0.018
Happiness-fear	-	Happiness-sadness	-.073	.071	1.000	-0.286	0.140
Happiness-fear	-	Fear-anger	-.118	.039	.049	-0.235	0.000
Happiness-fear	-	Fear-sadness	.007	.028	1.000	-0.075	0.090
Happiness-fear	-	Anger-sadness	.046	.039	1.000	-0.071	0.163
Happiness-anger	-	Happiness-sadness	-.012	.069	1.000	-0.217	0.193
Happiness-anger	-	Fear-anger	-.057	.035	1.000	-0.163	0.049
Happiness-anger	-	Fear-sadness	.068	.019	.008	0.011	0.126
Happiness-anger	-	Anger-sadness	.107	.032	.015	0.012	0.203
Happiness-sadness	-	Fear-anger	-.045	.075	1.000	-0.268	0.179
Happiness-sadness	-	Fear-sadness	.080	.068	1.000	-0.123	0.284
Happiness-sadness	-	Anger-sadness	.119	.074	1.000	-0.100	0.339
Fear-anger	-	Fear-sadness	.125	.039	.024	0.009	0.241
Fear-anger	-	Anger-sadness	.164	.050	.019	0.015	0.313
Fear-sadness	-	Anger-sadness	.039	.034	1.000	-0.062	0.140

Supplementary Table 5. Multiple comparisons of the main effect of ROI in the Repeated Measures ANOVA of baseline-corrected analysis. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
left	-	right	-.074	.029	.033	-0.143	-0.005
left	-	middle	-.018	.028	1.000	-0.085	0.050
right	-	middle	.056	.026	.103	-0.007	0.119

Supplementary Table 6. Multiple comparisons of the main effect of age group in the Repeated Measures ANOVA of baseline-corrected analysis. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
5-6	-	7-8	.170	.053	.009	0.030	0.310
5-6	-	9-10	.253	.052	.000	0.114	0.391
5-6	-	Young adults	.371	.054	.000	0.226	0.516
7-8	-	9-10	.083	.054	.773	-0.062	0.228
7-8	-	Young adults	.201	.057	.003	0.049	0.352
9-10	-	Young adults	.118	.056	.221	-0.032	0.268

Supplementary Table 7. Signal-to-noise ratios for EEG oddball responses across different emotion pairs and age groups

Age groups	Emotion pairs	Signal-to-noise ratio
5-6	Happiness-fear	3.990
	Happiness-anger	4.647
	Happiness-sadness	4.178
	Fear-anger	4.894
	Fear-sadness	3.497
	Anger-sadness	2.740
7-8	Happiness-fear	3.552
	Happiness-anger	4.843
	Happiness-sadness	3.934
	Fear-anger	4.497
	Fear-sadness	3.201
	Anger-sadness	2.598
9-10	Happiness-fear	3.150
	Happiness-anger	4.277
	Happiness-sadness	3.653
	Fear-anger	3.847
	Fear-sadness	3.359
	Anger-sadness	2.652
Young adults	Happiness-fear	4.489
	Happiness-anger	5.051
	Happiness-sadness	4.380
	Fear-anger	5.583
	Fear-sadness	4.028
	Anger-sadness	3.386

Supplementary Table 8. Repeated Measures ANOVA results of signal-to-noise ratio across different ROIs for various emotion pairs in different age groups. All tests were two-sided. Degrees of freedom were adjusted using the Greenhouse–Geisser correction when the assumption of sphericity was violated, as indicated by Mauchly's test.

Effect	F (*df*)	*p*	η_p^2	95%CI
Emotion pairs	27.549 (4.321, 652.521)	<.001	.154	[0.103, 0.200]
ROI	34.640 (1.636, 247.104)	<.001	.187	[0.105, 0.268]
Age groups	2.329 (3,151)	.077	.044	[0, 0,108]
Emotion pairs * Age groups	0.702 (12.964, 652.521)	.762	.014	[0, 0,013]
ROI * Age groups	6.411 (4.909, 247.104)	<.001	.113	[0.037, 0.175]
Emotion pairs * ROI	3.106 (6.801, 1026.884)	.003	.020	[0.002, 0.034]
Emotion pairs * ROI * Age groups	1.412 (20.402, 1026.884)	.105	.027	[0, 0,029]

Supplementary Table 9. Post-hoc analysis of the ROI × age group interaction in the Repeated Measures ANOVA of signal-to-noise ratio. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

ROI	Contrast	Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
Left region	5-6 - 7-8	.551	.416	1.000	-0.560	1.663
	5-6 - 9-10	.513	.413	1.000	-0.590	1.617
	5-6 - young adults	.389	.432	1.000	-0.767	1.545
	7-8 - 9-10	-.038	.430	1.000	-1.188	1.112
	7-8 - young adults	-.162	.449	1.000	-1.363	1.038
	9-10 - young adults	-.124	.446	1.000	-1.317	1.069
Right region	5-6 - 7-8	.024	.540	1.000	-1.419	1.468
	5-6 - 9-10	.398	.536	1.000	-1.035	1.831
	5-6 - young adults	-1.962	.562	.004	-3.464	-0.461
	7-8 - 9-10	.374	.559	1.000	-1.120	1.867
	7-8 - young adults	-1.986	.583	.005	-3.545	-0.427
	9-10 - young adults	-2.360	.580	.000	-3.910	-0.811
Middle region	5-6 - 7-8	.085	.357	1.000	-0.868	1.038
	5-6 - 9-10	.594	.354	.574	-0.353	1.540
	5-6 - young adults	.088	.371	1.000	-0.903	1.080
	7-8 - 9-10	.509	.369	1.000	-0.478	1.495
	7-8 - young adults	.003	.385	1.000	-1.027	1.032
	9-10 - young adults	-.506	.383	1.000	-1.529	0.518

Supplementary Table 10. Post-hoc Analysis of the emotion pair × ROI interaction in the Repeated Measures ANOVA of signal-to-noise ratio. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Emotion pairs	Contrast	Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
happiness-fear	left - right	-1.324	.264	.000	-1.964	-0.684
	left - middle	-.403	.153	.027	-0.773	-0.033
	right - middle	.920	.206	.000	0.422	1.419
happiness-anger	left - right	-1.989	.382	.000	-2.913	-1.065
	left - middle	-.819	.232	.002	-1.380	-0.258
	right - middle	1.170	.328	.001	0.376	1.964
happiness-sadness	left - right	-1.133	.303	.001	-1.867	-0.399
	left - middle	-.311	.196	.341	-0.785	0.162
	right - middle	.822	.225	.001	0.278	1.367
fear-anger	left - right	-1.578	.306	.000	-2.318	-0.838
	left - middle	-.900	.255	.002	-1.518	-0.283
	right - middle	.678	.230	.011	0.121	1.235
fear-sadness	left - right	-1.126	.195	.000	-1.598	-0.655
	left - middle	-.201	.145	.508	-0.552	0.151
	right - middle	.926	.183	.000	0.482	1.369
anger-sadness	left - right	-.840	.187	.000	-1.292	-0.388
	left - middle	.032	.128	1.000	-0.277	0.341
	right - middle	.872	.126	.000	0.567	1.178

Supplementary Table 11. Multiple comparisons of the main effect of emotion pair in the Repeated Measures ANOVA of signal-to-noise ratio. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
Happiness-fear	-	Happiness-anger	-.909	.220	.001	-1.567	-0.252
Happiness-fear	-	Happiness-sadness	-.241	.180	1.000	-0.777	0.294
Happiness-fear	-	Fear-anger	-.910	.207	.000	-1.528	-0.292
Happiness-fear	-	Fear-sadness	.274	.167	1.000	-0.223	0.771
Happiness-fear	-	Anger-sadness	.951	.160	.000	0.474	1.428
Happiness-anger	-	Happiness-sadness	.668	.212	.029	0.037	1.300
Happiness-anger	-	Fear-anger	-.001	.226	1.000	-0.674	0.673
Happiness-anger	-	Fear-sadness	1.183	.188	.000	0.624	1.743
Happiness-anger	-	Anger-sadness	1.861	.195	.000	1.278	2.443
Happiness-sadness	-	Fear-anger	-.669	.221	.043	-1.327	-0.011
Happiness-sadness	-	Fear-sadness	.515	.184	.087	-0.034	1.064
Happiness-sadness	-	Anger-sadness	1.192	.164	.000	0.703	1.681
Fear-anger	-	Fear-sadness	1.184	.211	.000	0.554	1.814
Fear-anger	-	Anger-sadness	1.861	.208	.000	1.242	2.480
Fear-sadness	-	Anger-sadness	.677	.134	.000	0.277	1.077

Supplementary Table 12. Multiple comparisons of the main effect of ROI in the Repeated Measures ANOVA of signal-to-noise ratio. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast	Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
left - right	-1.332	.197	.000	-1.808	-0.855
left - middle	-.434	.133	.004	-0.757	-0.111
right - middle	.898	.153	.000	0.528	1.268

Supplementary Table 13. Repeated Measures ANOVA results of oddball responses in upright and inverted conditions. All tests were two-sided. Degrees of freedom were adjusted using the Greenhouse–Geisser correction when the assumption of sphericity was violated, as indicated by Mauchly's test.

Effect	F (*df*)	*p*	η_p^2	95%CI
Orientation	71.806 (1, 41)	<.001	.637	[0.436, 0.742]
Emotion pairs	7.522 (3.855, 158.073)	<.001	.155	[0.051, 0.241]
ROI	7.276 (1.939, 79.493)	.001	.151	[0.026, 0.282]
Age groups	3.173 (3, 41)	.034	.188	[0, 0.347]
Orientation * Age groups	12.379 (3, 41)	<.001	.475	[0.212, 0.605]
Emotion pairs * Age groups	1.149 (11.566, 158.073)	.315	.078	[0, 0.098]
ROI * Age groups	3.023 (5.817, 79.493)	.011	.181	[0.012, 0.278]
Orientation * Emotion pairs	2.603 (3.894, 159.635)	.039	.006	[0, 0.123]
Orientation * ROI	4.304 (1.872, 76.747)	.019	.095	[0.002, 0.219]
Emotion pairs * ROI	0.931 (6.757, 277.056)	.497	.022	[0, 0.041]
Orientation * ROI*Age groups	4.376 (5.616, 76.747)	.001	.243	[0.051, 0.347]
Orientation * Emotion pairs * Age groups	0.422 (11.681, 159.635)	.950	.030	[0, 0.012]
Emotion pairs * ROI * Age groups	1.465 (20.272, 277.056)	.092	.097	[0, 0.100]
Orientation * Emotion pairs * ROI	2.168 (7.298, 299.225)	.035	.005	[0, 0.083]
Orientation * Emotion pairs * ROI * Age groups	1.569 (21.895, 299.225)	.053	.103	[0, 0.105]

Supplementary Table 14. Post-hoc analysis of the orientation × ROI interaction in the Repeated Measures ANOVA of oddball responses in upright and inverted conditions. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Orientation	Contrast	Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
Upright	left - right	-.942	.282	.005	-1.646	-0.238
	left - middle	-.570	.226	.046	-1.134	-0.007
	right - middle	.372	.265	.508	-0.291	1.034
Inverted	left - right	-.236	.116	.145	-0.525	0.053
	left - middle	-.278	.120	.078	-0.579	0.022
	right - middle	-.042	.105	1.000	-0.305	0.220

Supplementary Table 15. Post-hoc analysis of the age group × ROI interaction in the Repeated Measures ANOVA of oddball responses in upright and inverted conditions. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Age groups	Contrast	Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
5-6	left - right	.183	.359	1.000	-0.714	1.080
	left - middle	-.094	.309	1.000	-0.865	0.678
	right - middle	-.276	.328	1.000	-1.095	0.542
7-8	left - right	-.578	.359	.346	-1.475	0.319
	left - middle	-.690	.309	.093	-1.462	0.082
	right - middle	-.112	.328	1.000	-0.930	0.706
9-10	left - right	-.742	.359	.136	-1.639	0.155
	left - middle	-.748	.309	.060	-1.519	0.024
	right - middle	-.006	.328	1.000	-0.824	0.812
Young adults	left - right	-1.219	.293	.000	-1.951	-0.486
	left - middle	-.166	.252	1.000	-0.796	0.464
	right - middle	1.053	.268	.001	0.385	1.721

Supplementary Table 16. Post-hoc analysis of the age group × orientation interaction in the Repeated Measures ANOVA of oddball responses in upright and inverted conditions. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Age groups	Contrast	Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
Upright	5-6 - 7-8	.286	.755	1.000	-1.808	2.379
	5-6 - 9-10	.340	.755	1.000	-1.753	2.434
	5-6 - Young adults	-.283	.689	1.000	-2.194	1.628
	7-8 - 9-10	.055	.755	1.000	-2.038	2.148
	7-8 - Young adults	-.568	.689	1.000	-2.479	1.343
	9-10 - Young adults	-.623	.689	1.000	-2.534	1.288
Inverted	5-6 - 7-8	.020	.261	1.000	-0.705	0.744
	5-6 - 9-10	-.431	.261	.639	-1.156	0.293
	5-6 - Young adults	2.286	.239	.000	1.625	2.948
	7-8 - 9-10	-.451	.261	.552	-1.176	0.274
	7-8 - Young adults	2.267	.239	.000	1.605	2.928
	9-10 - Young adults	2.718	.239	.000	2.056	3.379

Supplementary Table 17. Post-hoc analysis of the orientation× emotion pair interaction in the Repeated Measures ANOVA of oddball responses in upright conditions. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
Happiness-fear	-	Happiness-anger	-.474	.352	1.000	-1.570	0.623
Happiness-fear	-	Happiness-sadness	-.019	.307	1.000	-0.977	0.939
Happiness-fear	-	Fear-anger	-.891	.306	.088	-1.845	0.064
Happiness-fear	-	Fear-sadness	.284	.351	1.000	-0.811	1.379
Happiness-fear	-	Anger-sadness	.707	.311	.422	-0.261	1.676
Happiness-anger	-	Happiness-sadness	.454	.259	1.000	-0.354	1.263
Happiness-anger	-	Fear-anger	-.417	.417	1.000	-1.718	0.884
Happiness-anger	-	Fear-sadness	.758	.315	.312	-0.225	1.740
Happiness-anger	-	Anger-sadness	1.181	.290	.003	0.276	2.086
Happiness-sadness	-	Fear-anger	-.871	.364	.319	-2.005	0.263
Happiness-sadness	-	Fear-sadness	.303	.292	1.000	-0.606	1.213
Happiness-sadness	-	Anger-sadness	.727	.246	.077	-0.040	1.493
Fear-anger	-	Fear-sadness	1.175	.407	.094	-0.095	2.445
Fear-anger	-	Anger-sadness	1.598	.400	.004	0.352	2.844
Fear-sadness	-	Anger-sadness	.423	.299	1.000	-0.510	1.356

Supplementary Table 18. Post-hoc analysis of the orientation× emotion pair interaction in the Repeated Measures ANOVA of oddball responses in inverted conditions. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
Happiness-fear	-	Happiness-anger	-.271	.181	1.000	-0.836	0.293
Happiness-fear	-	Happiness-sadness	-.142	.159	1.000	-0.638	0.353
Happiness-fear	-	Fear-anger	-.732	.231	.043	-1.451	-0.014
Happiness-fear	-	Fear-sadness	-.082	.142	1.000	-0.524	0.361
Happiness-fear	-	Anger-sadness	-.212	.153	1.000	-0.688	0.264
Happiness-anger	-	Happiness-sadness	.129	.169	1.000	-0.396	0.655
Happiness-anger	-	Fear-anger	-.461	.216	.579	-1.133	0.211
Happiness-anger	-	Fear-sadness	.190	.171	1.000	-0.344	0.723
Happiness-anger	-	Anger-sadness	.059	.197	1.000	-0.554	0.672
Happiness-sadness	-	Fear-anger	-.590	.223	.174	-1.286	0.106
Happiness-sadness	-	Fear-sadness	.060	.129	1.000	-0.342	0.462
Happiness-sadness	-	Anger-sadness	-.070	.166	1.000	-0.588	0.448
Fear-anger	-	Fear-sadness	.650	.227	.097	-0.056	1.357
Fear-anger	-	Anger-sadness	.520	.258	.752	-0.283	1.323
Fear-sadness	-	Anger-sadness	-.130	.157	1.000	-0.620	0.360

Supplementary Table 19. Multiple comparisons of the main effect of orientation in the Repeated Measures ANOVA of oddball responses in upright and inverted conditions. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
Upright	-	Inverted	-1.975	.233	.000	1.504	2.446

Supplementary Table 20. Multiple comparisons of the main effect of ROI in the Repeated Measures ANOVA of oddball responses in upright and inverted conditions. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
left	-	right	-.589	.172	.004	-1.018	-0.159
left	-	middle	-.424	.148	.020	-0.794	-0.055
right	-	middle	.165	.157	.901	-0.227	0.556

Supplementary Table 21. Multiple comparisons of the main effect of emotion pair in the Repeated Measures ANOVA of oddball responses in upright and inverted conditions. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
Happiness-fear	-	Happiness-anger	-.372	.202	1.000	-1.001	0.256
Happiness-fear	-	Happiness-sadness	-.081	.166	1.000	-0.599	0.438
Happiness-fear	-	Fear-anger	-.811	.213	.007	-1.474	-0.149
Happiness-fear	-	Fear-sadness	.101	.193	1.000	-0.500	0.703
Happiness-fear	-	Anger-sadness	.248	.166	1.000	-0.269	0.765
Happiness-anger	-	Happiness-sadness	.292	.178	1.000	-0.262	0.846
Happiness-anger	-	Fear-anger	-.439	.252	1.000	-1.225	0.347
Happiness-anger	-	Fear-sadness	.474	.186	.219	-0.105	1.052
Happiness-anger	-	Anger-sadness	.620	.175	.015	0.075	1.165
Happiness-sadness	-	Fear-anger	-.731	.227	.038	-1.439	-0.023
Happiness-sadness	-	Fear-sadness	.182	.161	1.000	-0.320	0.684
Happiness-sadness	-	Anger-sadness	.328	.155	.596	-0.153	0.810
Fear-anger	-	Fear-sadness	.913	.239	.007	0.167	1.658
Fear-anger	-	Anger-sadness	1.059	.253	.002	0.270	1.848
Fear-sadness	-	Anger-sadness	.146	.158	1.000	-0.347	0.640

Supplementary Table 22. Multiple comparisons of the main effect of age group in the Repeated Measures ANOVA of oddball responses in upright and inverted conditions. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
5-6	-	7-8	.153	.448	1.000	-1.089	1.394
5-6	-	9-10	-.046	.448	1.000	-1.287	1.196
5-6	-	Young adults	1.002	.409	.112	-0.132	2.136
7-8	-	9-10	-.198	.448	1.000	-1.440	1.044
7-8	-	Young adults	.849	.409	.265	-0.284	1.983
9-10	-	Young adults	1.047	.409	.085	-0.086	2.181

Supplementary Table 23. Repeated Measures ANOVA results of conceptual similarity rating task. All tests were two-sided. Degrees of freedom were adjusted using the Greenhouse–Geisser correction when the assumption of sphericity was violated, as indicated by Mauchly's test.

Effect	F (*df*)	*p*	η_p^2	95%CI
Emotion pairs	402.854 (2.187, 391.481)	<.001	.692	[0.645, 0.728]
Age groups	1.544 (3, 179)	.205	.025	[0, 0.072]
Emotion pairs * Age groups	6.925 (6.561, 391.481)	<.001	.104	[0.042, 0.150]

Supplementary Table 24. Multiple comparisons of the main effect of emotion pair in the Repeated Measures ANOVA of conceptual similarity rating task. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
Happiness-fear	-	Happiness-anger	-.023	.019	1.000	-0.078	0.032
Happiness-fear	-	Happiness-sadness	.020	.014	1.000	-0.021	0.062
Happiness-fear	-	Fear-anger	-.620	.029	.000	-0.708	-0.533
Happiness-fear	-	Fear-sadness	-.754	.028	.000	-0.836	-0.672
Happiness-fear	-	Anger-sadness	-.637	.030	.000	-0.726	-0.549
Happiness-anger	-	Happiness-sadness	.043	.016	.089	-0.003	0.089
Happiness-anger	-	Fear-anger	-.598	.033	.000	-0.697	-0.499
Happiness-anger	-	Fear-sadness	-.731	.031	.000	-0.822	-0.639
Happiness-anger	-	Anger-sadness	-.615	.032	.000	-0.711	-0.518
Happiness-sadness	-	Fear-anger	-.641	.031	.000	-0.733	-0.548
Happiness-sadness	-	Fear-sadness	-.774	.029	.000	-0.860	-0.688
Happiness-sadness	-	Anger-sadness	-.658	.031	.000	-0.750	-0.565
Fear-anger	-	Fear-sadness	-.133	.017	.000	-0.185	-0.082
Fear-anger	-	Anger-sadness	-.017	.018	1.000	-0.071	0.037
Fear-sadness	-	Anger-sadness	.116	.020	.000	0.057	0.176

Supplementary Table 25. Post-hoc analysis of the emotion pair × age group interaction in the Repeated Measures ANOVA of conceptual similarity rating task. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Emotion pairs	Contrast	Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
happiness-fear	5-6 - 7-8	.069	.052	1.000	-0.071	0.209
	5-6 - 9-10	.038	.051	1.000	-0.097	0.173
	5-6 - young adults	.109	.052	.232	-0.031	0.249
	7-8 - 9-10	-.031	.056	1.000	-0.181	0.119
	7-8 - young adults	.040	.058	1.000	-0.114	0.194
	9-10 - young adults	.071	.056	1.000	-0.079	0.221
happiness-anger	5-6 - 7-8	.085	.058	.856	-0.069	0.238
	5-6 - 9-10	-.003	.055	1.000	-0.151	0.145
	5-6 - young adults	.184*	.058	.010	0.031	0.338
	7-8 - 9-10	-.088	.062	.942	-0.252	0.077
	7-8 - young adults	.099	.064	.716	-0.070	0.269
	9-10 - young adults	.187	.062	.017	0.023	0.352
happiness-sadness	5-6 - 7-8	.010	.054	1.000	-0.135	0.154
	5-6 - 9-10	.036	.052	1.000	-0.104	0.175
	5-6 - young adults	.184	.054	.005	0.040	0.329
	7-8 - 9-10	.026	.058	1.000	-0.129	0.181
	7-8 - young adults	.175	.060	.023	0.015	0.334
	9-10 - young adults	.149	.058	.067	-0.006	0.304
fear-anger	5-6 - 7-8	-.094	.057	.582	-0.245	0.057
	5-6 - 9-10	-.144	.055	.054	-0.290	0.001
	5-6 - young adults	-.281	.057	.000	-0.432	-0.130
	7-8 - 9-10	-.050	.061	1.000	-0.212	0.112
	7-8 - young adults	-.186	.062	.020	-0.353	-0.020
	9-10 - young adults	-.136	.061	.154	-0.298	0.025
fear-sadness	5-6 - 7-8	-.040	.049	1.000	-0.172	0.092
	5-6 - 9-10	-.074	.048	.737	-0.201	0.053
	5-6 - young adults	-.153	.049	.014	-0.284	-0.021
	7-8 - 9-10	-.034	.053	1.000	-0.175	0.108
	7-8 - young adults	-.112	.055	.247	-0.258	0.033
	9-10 - young adults	-.079	.053	.839	-0.220	0.063
anger-sadness	5-6 - 7-8	-.096	.064	.802	-0.266	0.074
	5-6 - 9-10	-.225	.061	.002	-0.388	-0.061
	5-6 - young adults	-.262	.064	.000	-0.431	-0.092
	7-8 - 9-10	-.129	.068	.365	-0.311	0.053
	7-8 - young adults	-.166	.070	.116	-0.353	0.022
	9-10 - young adults	-.037	.068	1.000	-0.219	0.145

Supplementary Table 26. Repeated Measures ANOVA results of conceptual similarity rating task on MDS results. All tests were two-sided. Degrees of freedom were adjusted using the Greenhouse–Geisser correction when the assumption of sphericity was violated, as indicated by Mauchly's test.

Effect	F (*df*)	*p*	η_p^2	95%CI
Emotion pairs	358.640 (3.471, 621.300)	<.001	.667	[0.627, 0.698]
Age groups	0.625 (3, 179)	.600	.010	[0, 0.041]
Emotion pairs * Age groups	2.223 (10.413, 621.300)	.014	.036	[0.001, 0.052]

Supplementary Table 27. Post-hoc analysis of the emotion pair × age group interaction in the Repeated Measures ANOVA of conceptual similarity rating task on MDS results. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Emotion pairs	Contrast	Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
happiness-fear	5-6 - 7-8	-.251	.694	1.000	-2.103	1.601
	5-6 - 9-10	-.204	.670	1.000	-1.991	1.582
	5-6 - young adults	-.226	.694	1.000	-2.078	1.626
	7-8 - 9-10	.047	.745	1.000	-1.940	2.034
	7-8 - young adults	.025	.767	1.000	-2.020	2.071
	9-10 - young adults	-.021	.745	1.000	-2.008	1.965
happiness-anger	5-6 - 7-8	.044	.737	1.000	-1.921	2.010
	5-6 - 9-10	.826	.711	1.000	-1.070	2.722
	5-6 - young adults	.117	.737	1.000	-1.849	2.082
	7-8 - 9-10	.782	.790	1.000	-1.327	2.890
	7-8 - young adults	.072	.814	1.000	-2.098	2.243
	9-10 - young adults	-.709	.790	1.000	-2.817	1.399
happiness-sadness	5-6 - 7-8	.232	.742	1.000	-1.747	2.211
	5-6 - 9-10	.287	.716	1.000	-1.622	2.196
	5-6 - young adults	-.436	.742	1.000	-2.415	1.543
	7-8 - 9-10	.055	.796	1.000	-2.068	2.178
	7-8 - young adults	-.668	.819	1.000	-2.854	1.518
	9-10 - young adults	-.723	.796	1.000	-2.846	1.400
fear-anger	5-6 - 7-8	.913	.705	1.000	-0.969	2.794
	5-6 - 9-10	.284	.680	1.000	-1.531	2.099
	5-6 - young adults	2.326	.705	.007	0.445	4.207
	7-8 - 9-10	-.628	.756	1.000	-2.646	1.389
	7-8 - young adults	1.414	.779	.427	-0.664	3.491
	9-10 - young adults	2.042	.756	.046	0.024	4.060
fear-sadness	5-6 - 7-8	.143	.683	1.000	-1.679	1.966
	5-6 - 9-10	-.409	.659	1.000	-2.168	1.349
	5-6 - young adults	-.215	.683	1.000	-2.038	1.608
	7-8 - 9-10	-.553	.733	1.000	-2.508	1.403
	7-8 - young adults	-.358	.755	1.000	-2.372	1.655
	9-10 - young adults	.194	.733	1.000	-1.761	2.150
anger-sadness	5-6 - 7-8	-.097	.793	1.000	-2.212	2.018
	5-6 - 9-10	2.102	.765	.040	0.062	4.142
	5-6 - young adults	1.625	.793	.251	-0.490	3.740
	7-8 - 9-10	2.199	.850	.063	-0.069	4.468
	7-8 - young adults	1.722	.876	.304	-0.614	4.058
	9-10 - young adults	-.477	.850	1.000	-2.745	1.791

Supplementary Table 28. Multiple comparisons of the main effect of emotion pair in the Repeated Measures ANOVA of conceptual similarity rating task on MDS results. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
Happiness-fear	-	Happiness-anger	.312	.169	.995	-0.190	0.814
Happiness-fear	-	Happiness-sadness	.482	.153	.028	0.028	0.936
Happiness-fear	-	Fear-anger	6.637	.309	.000	5.716	7.557
Happiness-fear	-	Fear-sadness	9.220	.320	.000	8.269	10.172
Happiness-fear	-	Anger-sadness	7.859	.341	.000	6.844	8.873
Happiness-anger	-	Happiness-sadness	.170	.167	1.000	-0.326	0.666
Happiness-anger	-	Fear-anger	6.325	.340	.000	5.313	7.337
Happiness-anger	-	Fear-sadness	8.909	.369	.000	7.811	10.007
Happiness-anger	-	Anger-sadness	7.547	.339	.000	6.538	8.557
Happiness-sadness	-	Fear-anger	6.155	.346	.000	5.126	7.183
Happiness-sadness	-	Fear-sadness	8.739	.348	.000	7.704	9.774
Happiness-sadness	-	Anger-sadness	7.377	.342	.000	6.359	8.395
Fear-anger	-	Fear-sadness	2.584	.357	.000	1.522	3.646
Fear-anger	-	Anger-sadness	1.222	.347	.008	0.190	2.254
Fear-sadness	-	Anger-sadness	-1.362	.396	.011	-2.540	-0.183

Supplementary Table 29. Repeated Measures ANOVA results of sorting task. All tests were two-sided. Degrees of freedom were adjusted using the Greenhouse–Geisser correction when the assumption of sphericity was violated, as indicated by Mauchly's test.

Effect	F (*df*)	*p*	η_p^2	95%CI
Emotion pairs	260.936 (3.301, 594.137)	<.001	.592	[0.544, 0.629]
Age groups	11.512 (3, 180)	<.001	.161	[0.066, 0.247]
Emotion pairs * Age groups	1.116 (9.902, 594.137)	.337	.018	[0, 0.027]

Supplementary Table 30. Multiple comparisons of the main effect of emotion pair in the Repeated Measures ANOVA of sorting task. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
Happiness-fear	-	Happiness-anger	.008	.003	.017	0.001	0.016
Happiness-fear	-	Happiness-sadness	.008	.003	.195	-0.001	0.017
Happiness-fear	-	Fear-anger	-.038	.006	.000	-0.056	-0.020
Happiness-fear	-	Fear-sadness	-.059	.006	.000	-0.076	-0.042
Happiness-fear	-	Anger-sadness	-.170	.007	.000	-0.191	-0.149
Happiness-anger	-	Happiness-sadness	-.001	.002	1.000	-0.008	0.006
Happiness-anger	-	Fear-anger	-.046	.006	.000	-0.064	-0.029
Happiness-anger	-	Fear-sadness	-.067	.006	.000	-0.084	-0.050
Happiness-anger	-	Anger-sadness	-.178	.007	.000	-0.198	-0.158
Happiness-sadness	-	Fear-anger	-.046	.006	.000	-0.065	-0.027
Happiness-sadness	-	Fear-sadness	-.066	.006	.000	-0.084	-0.049
Happiness-sadness	-	Anger-sadness	-.178	.007	.000	-0.198	-0.157
Fear-anger	-	Fear-sadness	-.021	.006	.023	-0.040	-0.002
Fear-anger	-	Anger-sadness	-.132	.008	.000	-0.154	-0.109
Fear-sadness	-	Anger-sadness	-.111	.008	.000	-0.135	-0.088

Supplementary Table 31. Multiple comparisons of the main effect of age group in the Repeated Measures ANOVA of sorting task. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
5-6	-	7-8	.018	.007	.079	-0.001	0.037
5-6	-	9-10	.024	.007	.004	0.006	0.043
5-6	-	Young adults	.041	.007	.000	0.022	0.061
7-8	-	9-10	.006	.008	1.000	-0.014	0.027
7-8	-	Young adults	.023	.008	.022	0.002	0.045
9-10	-	Young adults	.017	.008	.187	-0.004	0.038

Supplementary Table 32. Repeated Measures ANOVA results of matching task

Effect	F (*df*)	*p*	η_p^2	95%CI
Emotion pairs	321.351 (4.622, 827.327)	<.001	.642	[0.606, 0.671]
Age groups	3.267 (3, 179)	.023	.052	[0, 0.114]
Emotion pairs * Age groups	2.847 (13.866, 827.327)	<.001	.046	[0.009, 0.060]

Supplementary Table 33. Post-hoc analysis of the emotion pairs × age group interaction in the Repeated Measures ANOVA of maching task. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Emotion pairs	Contrast	Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
happiness-fear	5-6 - 7-8	-.056	.032	.460	-0.141	0.028
	5-6 - 9-10	-.070	.030	.141	-0.151	0.012
	5-6 - young adults	-.022	.032	1.000	-0.106	0.062
	7-8 - 9-10	-.013	.034	1.000	-0.104	0.077
	7-8 - young adults	.034	.035	1.000	-0.059	0.127
	9-10 - young adults	.047	.034	.978	-0.043	0.138
happiness-anger	5-6 - 7-8	-.054	.029	.378	-0.131	0.023
	5-6 - 9-10	-.078	.028	.033	-0.152	-0.004
	5-6 - young adults	-.026	.029	1.000	-0.103	0.050
	7-8 - 9-10	-.024	.031	1.000	-0.023	0.131
	7-8 - young adults	.027	.032	1.000	-0.057	0.112
	9-10 - young adults	.052	.031	.583	-0.031	0.134
happiness-sadness	5-6 - 7-8	-.051	.033	.725	-0.138	0.036
	5-6 - 9-10	-.036	.032	1.000	-0.120	0.048
	5-6 - young adults	-.038	.033	1.000	-0.125	0.050
	7-8 - 9-10	.015	.035	1.000	-0.078	0.109
	7-8 - young adults	.013	.036	1.000	-0.083	0.110
	9-10 - young adults	-.002	.035	1.000	-0.095	0.092
fear-anger	5-6 - 7-8	-.084	.034	.087	-0.176	0.007
	5-6 - 9-10	-.097	.033	.021	-0.185	-0.009
	5-6 - young adults	-.043	.034	1.000	-0.134	0.048
	7-8 - 9-10	-.013	.037	1.000	-0.111	0.085
	7-8 - young adults	.041	.038	1.000	-0.060	0.142
	9-10 - young adults	.054	.037	.849	-0.044	0.152
fear-sadness	5-6 - 7-8	-.014	.035	1.000	-0.107	0.080
	5-6 - 9-10	-.033	.034	1.000	-0.123	0.057
	5-6 - young adults	.076	.035	.186	-0.017	0.169
	7-8 - 9-10	-.019	.038	1.000	-0.119	0.081
	7-8 - young adults	.090	.039	.129	-0.013	0.193
	9-10 - young adults	.109	.038	.025	0.009	0.209
anger-sadness	5-6 - 7-8	-.031	.030	1.000	-0.111	0.050
	5-6 - 9-10	-.032	.029	1.000	-0.110	0.046
	5-6 - young adults	.091	.030	.018	0.010	0.171
	7-8 - 9-10	-.001	.032	1.000	-0.087	0.085
	7-8 - young adults	.121	.033	.002	0.033	0.210
	9-10 - young adults	.123	.032	.001	0.036	0.209

Supplementary Table 34. Multiple comparisons of the main effect of emotion pair in the Repeated Measures ANOVA of matching task. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
Happiness-fear	-	Happiness-anger	.040	.010	.002	0.009	0.070
Happiness-fear	-	Happiness-sadness	.013	.011	1.000	-0.020	0.047
Happiness-fear	-	Fear-anger	-.048	.012	.001	-0.083	-0.013
Happiness-fear	-	Fear-sadness	-.104	.012	.000	-0.141	-0.067
Happiness-fear	-	Anger-sadness	-.358	.013	.000	-0.397	-0.320
Happiness-anger	-	Happiness-sadness	-.026	.009	.057	-0.053	0.000
Happiness-anger	-	Fear-anger	-.088	.010	.000	-0.118	-0.058
Happiness-anger	-	Fear-sadness	-.144	.011	.000	-0.177	-0.111
Happiness-anger	-	Anger-sadness	-.398	.012	.000	-0.434	-0.362
Happiness-sadness	-	Fear-anger	-.062	.011	.000	-0.095	-0.028
Happiness-sadness	-	Fear-sadness	-.118	.012	.000	-0.153	-0.082
Happiness-sadness	-	Anger-sadness	-.372	.013	.000	-0.410	-0.334
Fear-anger	-	Fear-sadness	-.056	.011	.000	-0.090	-0.022
Fear-anger	-	Anger-sadness	-.310	.012	.000	-0.347	-0.274
Fear-sadness	-	Anger-sadness	-.254	.013	.000	-0.293	-0.215

Supplementary Table 35. Multiple comparisons of the main effect of age group in the Repeated Measures ANOVA of matching task. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
5-6	-	7-8	-.048	.025	.316	-0.114	0.018
5-6	-	9-10	-.058	.024	.102	-0.121	0.006
5-6	-	Young adults	.006	.025	1.000	-0.060	0.072
7-8	-	9-10	-.009	.027	1.000	-0.080	0.062
7-8	-	Young adults	.055	.027	.287	-0.019	0.128
9-10	-	Young adults	.064	.027	.105	-0.007	0.135

Supplementary Table 36. Repeated Measures ANOVA results of accuracy of sorting task. All tests were two-sided. Degrees of freedom were adjusted using the Greenhouse–Geisser correction when the assumption of sphericity was violated, as indicated by Mauchly's test.

Effect	F (*df*)	*p*	η_p^2	95%CI
Emotion	131.126 (2.349, 422.780)	<.001	.421	[0.352, 0.479]
Age groups	13.453 (3, 180)	<.001	.183	[0.083, 0.271]
Emotion * Age groups	2.240 (7.046, 422.780)	.030	.036	[0, 0.061]

Supplementary Table 37. Post-hoc analysis of the emotion × age group interaction in the Repeated Measures ANOVA of accuracy of sorting task. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Emotion pairs	Contrast	Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
happiness	5-6 - 7-8	-.024	.017	1.000	-0.070	0.022
	5-6 - 9-10	-.034	.017	.273	-0.080	0.011
	5-6 - young adults	-.049	.018	.037	-0.095	-0.002
	7-8 - 9-10	-.010	.019	1.000	-0.060	0.040
	7-8 - young adults	-.025	.019	1.000	-0.076	0.027
	9-10 - young adults	-.014	.019	1.000	-0.065	0.036
fear	5-6 - 7-8	-.084	.035	.115	-0.178	0.011
	5-6 - 9-10	-.131	.035	.001	-0.224	-0.039
	5-6 - young adults	-.166	.036	.000	-0.261	-0.071
	7-8 - 9-10	-.048	.038	1.000	-0.150	0.054
	7-8 - young adults	-.083	.039	.217	-0.187	0.022
	9-10 - young adults	-.035	.039	1.000	-0.138	0.068
anger	5-6 - 7-8	-.029	.039	1.000	-0.132	0.074
	5-6 - 9-10	-.056	.038	.856	-0.156	0.045
	5-6 - young adults	-.127	.039	.008	-0.230	-0.023
	7-8 - 9-10	-.027	.042	1.000	-0.138	0.085
	7-8 - young adults	-.098	.043	.138	-0.212	0.016
	9-10 - young adults	-.071	.042	.548	-0.183	0.041
sadness	5-6 - 7-8	-.118	.040	.020	-0.224	-0.012
	5-6 - 9-10	-.123	.039	.011	-0.227	-0.019
	5-6 - young adults	-.207	.040	.000	-0.314	-0.100
	7-8 - 9-10	-.005	.043	1.000	-0.120	0.110
	7-8 - young adults	-.089	.044	.272	-0.207	0.029
	9-10 - young adults	-.084	.043	.324	-0.200	0.032

Supplementary Table 38. Multiple comparisons of the main effect of age group in the Repeated Measures ANOVA of accuracy of sorting task. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
5-6	-	7-8	-.064	.022	.028	-0.123	-0.004
5-6	-	9-10	-.086	.022	.001	-0.144	-0.028
5-6	-	Young adults	-.137	.022	.000	-0.197	-0.078
7-8	-	9-10	-.022	.024	1.000	-0.087	0.042
7-8	-	Young adults	-.074	.025	.019	-0.139	-0.008
9-10	-	Young adults	-.051	.024	.216	-0.116	0.013

Supplementary Table 39. Multiple comparisons of the main effect of emotion in the Repeated Measures ANOVA of accuracy of sorting task. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
Happiness	-	Fear	.157	.012	.000	0.124	0.189
Happiness	-	Anger	.174	.014	.000	0.136	0.212
Happiness	-	Sadness	.307	.015	.000	0.268	0.346
Fear	-	Anger	.017	.015	1.000	-0.022	0.057
Fear	-	Sadness	.151	.016	.000	0.108	0.193
Anger	-	Sadness	.133	.020	.000	0.079	0.188

Supplementary Table 40. Repeated Measures ANOVA results of accuracy of matching task. All tests were two-sided. Degrees of freedom were adjusted using the Greenhouse–Geisser correction when the assumption of sphericity was violated, as indicated by Mauchly's test.

Effect	F (*df*)	*p*	η_p^2	95%CI
Emotion	455.772 (2.170, 388.486)	<.001	.718	[0.674, 0.751]
Age groups	11.262 (3, 179)	<.001	.160	[0.064, 0.245]
Emotion * Age groups	5.211 (6.511, 388.486)	<.001	.008	[0.025, 0.122]

Supplementary Table 41. Post-hoc analysis of the emotion × age group interaction in the Repeated Measures ANOVA of accuracy of matching task. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Emotion pairs	Contrast	Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
happiness	5-6 - 7-8	.026	.016	.602	-0.016	0.068
	5-6 - 9-10	.001	.015	1.000	-0.040	0.042
	5-6 - young adults	-.021	.016	1.000	-0.063	0.021
	7-8 - 9-10	-.025	.017	.851	-0.070	0.020
	7-8 - young adults	-.047	.017	.046	-0.094	0.000
	9-10 - young adults	-.022	.017	1.000	-0.067	0.023
fear	5-6 - 7-8	.031	.025	1.000	-0.036	0.099
	5-6 - 9-10	-.037	.024	.818	-0.102	0.029
	5-6 - young adults	-.114	.025	.000	-0.182	-0.046
	7-8 - 9-10	-.068	.027	.081	-0.141	0.005
	7-8 - young adults	-.145	.028	.000	-0.220	-0.070
	9-10 - young adults	-.077	.027	.030	-0.150	-0.005
anger	5-6 - 7-8	.028	.029	1.000	-0.049	0.106
	5-6 - 9-10	-.016	.028	1.000	-0.091	0.059
	5-6 - young adults	-.110	.029	.001	-0.188	-0.033
	7-8 - 9-10	-.045	.031	.933	-0.128	0.039
	7-8 - young adults	-.139	.032	.000	-0.225	-0.053
	9-10 - young adults	-.094	.031	.018	-0.178	-0.011
sadness	5-6 - 7-8	.030	.030	1.000	-0.051	0.111
	5-6 - 9-10	-.036	.029	1.000	-0.114	0.042
	5-6 - young adults	-.160	.030	.000	-0.241	-0.079
	7-8 - 9-10	-.066	.032	.258	-0.153	0.020
	7-8 - young adults	-.190	.033	.000	-0.279	-0.101
	9-10 - young adults	-.124	.032	.001	-0.211	-0.037

Supplementary Table 42. Multiple comparisons of the main effect of age group in the Repeated Measures ANOVA of accuracy of sorting task. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
5-6	-	7-8	.029	.022	1.000	-0.028	0.086
5-6	-	9-10	-.022	.021	1.000	-0.077	0.033
5-6	-	Young adults	-.101	.022	.000	-0.159	-0.044
7-8	-	9-10	-.051	.023	.172	-0.113	0.011
7-8	-	Young adults	-.130	.024	.000	-0.194	-0.067
9-10	-	Young adults	-.079	.023	.004	-0.141	-0.018

Supplementary Table 43. Multiple comparisons of the main effect of emotion in the Repeated Measures ANOVA of accuracy of sorting task. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
Happiness	-	Fear	.092	.007	.000	0.072	0.111
Happiness	-	Anger	.228	.009	.000	0.203	0.253
Happiness	-	Sadness	.282	.010	.000	0.255	0.309
Fear	-	Anger	.136	.009	.000	0.111	0.161
Fear	-	Sadness	.190	.008	.000	0.169	0.212
Anger	-	Sadness	.054	.006	.000	0.038	0.070

Supplementary Table 44. Repeated Measures ANOVA results of SNR across different ROIs for various emotion pairs in different age groups by 30 seconds. All tests were two-sided. Degrees of freedom were adjusted using the Greenhouse–Geisser correction when the assumption of sphericity was violated, as indicated by Mauchly's test.

Effect	F (*df*)	*p*	η_p^2	95%CI
Emotion pairs	3.373 (4.345, 656.069)	<.001	.181	[0.002, 0.043]
ROI	34.418 (1.619, 244.503)	<.001	.186	[0.103, 0.267]
Age groups	4.956 (3, 151)	.003	.090	[0.013, 0.171]
Emotion pairs * Age groups	1.115 (13.034, 656.069)	.342	.022	[0, 0.027]
ROI * Age groups	6.369 (4.858, 244.503)	<.001	.112	[0.036, 0.175]
Emotion pairs * ROI	2.997 (6.593, 995.614)	.005	.019	[0.002, 0.033]
Emotion pairs * ROI * Age groups	1.541 (19.780, 995.614)	.061	.030	[0, 0.032]

Supplementary Table 45. Post-hoc analysis of the ROI × age group interaction in the Repeated Measures ANOVA of SNR by 30 seconds. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

ROI	Contrast	Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
Left region	5-6 - 7-8	-.623	.541	1.000	-2.069	0.823
	5-6 - 9-10	-.285	.537	1.000	-1.721	1.151
	5-6 - young adults	-.695	.563	1.000	-2.199	0.809
	7-8 - 9-10	.337	.560	1.000	-1.159	1.833
	7-8 - young adults	-.073	.584	1.000	-1.634	1.489
	9-10 - young adults	-.410	.581	1.000	-1.962	1.143
Right region	5-6 - 7-8	-1.659	.778	.207	-3.739	0.420
	5-6 - 9-10	-.951	.772	1.000	-3.016	1.114
	5-6 - young adults	-3.955	.809	.000	-6.118	-1.792
	7-8 - 9-10	.708	.805	1.000	-1.443	2.860
	7-8 - young adults	-2.296	.840	.042	-4.542	-0.050
	9-10 - young adults	-3.004	.835	.003	-5.236	-0.772
Middle region	5-6 - 7-8	-1.554	.495	.012	-2.878	-0.231
	5-6 - 9-10	-.340	.491	1.000	-1.654	0.974
	5-6 - young adults	-.982	.515	.349	-2.359	0.394
	7-8 - 9-10	1.215	.512	.114	-0.154	2.584
	7-8 - young adults	.572	.535	1.000	-0.857	2.001
	9-10 - young adults	-.643	.531	1.000	-2.063	0.778

Supplementary Table 46. Post-hoc Analysis of the emotion pair × ROI interaction in the Repeated Measures ANOVA of SNR by 30 seconds. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Emotion pairs	Contrast	Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
happiness-fear	left - right	-1.829	.384	.000	-2.759	-0.900
	left - middle	-.635	.226	.017	-1.182	-0.089
	right - middle	1.194	.271	.000	0.538	1.850
happiness-anger	left - right	-2.729	.503	.000	-3.947	-1.511
	left - middle	-1.214	.280	.000	-1.892	-0.535
	right - middle	1.515	.442	.002	0.446	2.585
happiness-sadness	left - right	-1.841	.370	.000	-2.736	-0.946
	left - middle	-.432	.228	.180	-0.984	0.120
	right - middle	1.409	.300	.000	0.682	2.136
fear-anger	left - right	-1.985	.414	.000	-2.988	-0.983
	left - middle	-.856	.323	.027	-1.639	-0.074
	right - middle	1.129	.350	.005	0.282	1.976
fear-sadness	left - right	-1.416	.255	.000	-2.032	-0.799
	left - middle	-.358	.195	.204	-0.830	0.113
	right - middle	1.057	.238	.000	0.480	1.635
anger-sadness	left - right	-1.138	.231	.000	-1.697	-0.579
	left - middle	-.024	.163	1.000	-0.420	0.371
	right - middle	1.113	.168	.000	0.707	1.520

Supplementary Table 47. Multiple comparisons of the main effect of emotion pair in the Repeated Measures ANOVA of SNR by 30 seconds. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
Happiness-fear	-	Happiness-anger	-.970	.279	.010	-1.800	-0.139
Happiness-fear	-	Happiness-sadness	-.069	.237	1.000	-0.775	0.637
Happiness-fear	-	Fear-anger	-1.216	.297	.001	-2.101	-0.331
Happiness-fear	-	Fear-sadness	.496	.242	.628	-0.225	1.218
Happiness-fear	-	Anger-sadness	1.528	.235	.000	0.827	2.230
Happiness-anger	-	Happiness-sadness	.901	.227	.002	0.225	1.577
Happiness-anger	-	Fear-anger	-.246	.266	1.000	-1.040	0.547
Happiness-anger	-	Fear-sadness	1.466	.237	.000	0.759	2.173
Happiness-anger	-	Anger-sadness	2.498	.239	.000	1.784	3.212
Happiness-sadness	-	Fear-anger	-1.147	.260	.000	-1.922	-0.373
Happiness-sadness	-	Fear-sadness	.565	.220	.167	-0.090	1.221
Happiness-sadness	-	Anger-sadness	1.597	.189	.000	1.035	2.159
Fear-anger	-	Fear-sadness	1.712	.274	.000	0.895	2.530
Fear-anger	-	Anger-sadness	2.744	.265	.000	1.954	3.534
Fear-sadness	-	Anger-sadness	1.032	.176	.000	0.508	1.555

Supplementary Table 48. Multiple comparisons of the main effect of ROI in the Repeated Measures ANOVA of SNR by 30 seconds. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
left	-	right	-1.823	.268	.000	-2.473	-1.173
left	-	middle	-.587	.173	.003	-1.005	-0.169
right	-	middle	1.236	.222	.000	0.700	1.773

Supplementary Table 49. Multiple comparisons of the main effect of age group in the Repeated Measures ANOVA of SNR by 30 seconds. All tests were two-sided, and p-values were adjusted for multiple comparisons using bonferroni correction.

Contrast			Mean differences	SE	p-value	lower bound of 95%CI	upper bound of 95%CI
5-6	-	7-8	-1.279	.506	.075	-2.632	0.074
5-6	-	9-10	-.525	.503	1.000	-1.869	0.818
5-6	-	Young adults	-1.878	.526	.003	-3.285	-0.470
7-8	-	9-10	.753	.524	.913	-0.646	2.153
7-8	-	Young adults	-.599	.547	1.000	-2.060	0.862
9-10	-	Young adults	-1.352	.543	.083	-2.805	0.100