The Influence of Deviant-Standard Stimulus Pairs and Emotion Types on EMMN: Evidence from Meta-Analysis

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Abstract

Automatically detecting changes in facial emotions is crucial for individual survival. Numerous studies employing event-related potential (ERP) technology have demonstrated that the emotional mismatch negativity (EMMN) can serve as an index for detecting automatic processing of facial emotions. Previous research has indicated that deviant-standard stimulus pairs (different/same) and emotion types (negative/positive) influence the EMMN effect, yet the conclusions remain controversial. The present study conducted a meta-analysis of 36 studies using EMMN as an index (totaling 733 participants). The results revealed: (1) Significant EMMN effects were observed in both early (0-200 ms) and late (200-400 ms) time windows, with occasionally presented emotional faces eliciting more negative ERPs within both temporal windows, indicating that EMMN reflects the probability effect of early and late ERP components related to facial emotion processing; (2) The type of deviant-standard stimulus pair modulated the early but not the late EMMN effect: within the early interval, different deviant-standard stimulus pairs elicited larger EMMN; (3) In studies employing identical deviant-standard stimulus pairs, no significant differences were found between equiprobable and non-equiprobable conditions for EMMN effects in either time window; (4) Both early and late EMMN exhibited a negativity bias, that is, EMMN elicited by negative emotions was significantly larger than that elicited by positive emotions. These results demonstrate that the EMMN effect is influenced by experimental variables such as deviant-standard stimulus pairs and emotion types.

EMMN Varies with Deviant-Standard Stimulus Pair Type and Emotion Type: Evidence from a Meta-Analysis

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Abstract

[**Objective**] The automatic detection of changes in facial emotion is crucial for survival. Numerous studies using event-related potential (ERP) techniques have demonstrated that the emotion-related visual mismatch negativity (EMMN) can serve as an indicator of automatic processing of facial emotions. Previous research suggests that both deviant-standard stimulus (D-S) pair type (different/same) and emotion type (negative/positive) may modulate the EMMN effect, yet the evidence remains mixed.

[**Methods**] We conducted a meta-analysis of 36 studies (totaling 733 participants) that examined EMMN.

Results The findings revealed: (1) Significant EMMN effects emerged in both early (0–200 ms) and late (200–400 ms) time windows, with infrequently presented emotional faces eliciting more negative ERPs in both intervals, indicating that EMMN reflects the probability effect of early- and late-stage emotion-related ERP components; (2) D-S pair type moderated the EMMN effect in the early but not the late stage—specifically, different D-S pairs elicited larger EMMN effects during the early interval; (3) In studies using same D-S pairs, no significant differences were found between equiprobable and non-equiprobable paradigms in either time window; and (4) Both early and late EMMN exhibited a negative bias, with negative emotions eliciting significantly larger EMMN amplitudes than positive emotions.

[**Conclusion**] These results demonstrate that the EMMN effect is influenced by experimental manipulations such as D-S pair type and emotion type.

Keywords: Emotion-related visual mismatch negativity (EMMN), Meta-analysis, Negative bias, Deviant-standard stimulus pair

Emotion represents crucial information in faces, reflecting an individual' s internal affective states and playing a vital role in social communication. Facial information within our visual field reveals the status and attributes of people around us. Automatic detection of emotional information changes may be particularly important—for instance, rapid and automatic identification of fear or anger signals that threaten survival is highly adaptive. While numerous behavioral and neuroscience studies have shown that facial emotion processing occurs automatically, rapidly, and without task relevance, this automatic processing is considered an evolutionary adaptation due to the importance of facial emotions for both understanding internal states and maintaining interpersonal relationships.

To investigate the neural mechanisms underlying automatic processing of facial emotions, researchers have employed event-related potentials (ERPs) with high temporal resolution to examine brain activity in response to incidentally presented emotional faces under conditions of inattention. A key finding is that the visual mismatch negativity (vMMN)—an ERP difference wave component—emerges based on stimulus probability, reflecting automatic detection of information changes. The vMMN represents the ERP difference between frequently presented standards and infrequently presented deviants (i.e., an oddball sequence: O/O/O/O/X/···, where X denotes the infrequent deviant stimulus and O represents the frequent standard stimulus). This component typically manifests as a negative wave distributed over right posterior parieto-occipital regions with a peak latency between 150–400 ms, and can be elicited by various visual features including line orientation, spatial frequency, color, and socially meaningful complex visual information such as gender, faces, and emotions. Considered a mechanism for automatic detection of visual information changes, vMMN research on facial emotion processing has proliferated between 2006–2020. Studies on emotion-related vMMN (EMMN) demonstrate that this automatic detection mechanism extends to real-world social information processing, suggesting that emotional information receives automatic neural processing even without attention. Previous EMMN research has identified several critical factors influencing automatic detection of facial emotion changes: emotion type (negative/positive), D-S pair type (same/different in equiprobable paradigms, collectively referred to as D-S pairs in this paper), and the time window of interest (reflecting automatic processing at different temporal stages, divided into early/late).

2.1 Temporal Course of EMMN

As a difference wave, EMMN time windows are typically defined by intervals where the difference wave amplitude is significant, though findings vary across studies. Some research has identified significant early and late mismatch negativities, while others have found only early or only late effects. One study even reported continuous significant EMMN between 100–500 ms. Given that ERP components evoked by facial stimuli (e.g., P1, N170, N2) share similar spatiotemporal distributions with EMMN, EMMN is thought to be associated with subcomponents active within its time window. Some researchers propose that these subcomponents may reflect different effects of MMN on visual stimuli, with early MMN (100–150 ms) reflecting visual refractoriness and late MMN (200–250 ms) reflecting change detection. The memory-based comparison hypothesis suggests that vMMN reflects activation of change-specific neural populations resulting from comparison between current information and memory traces of previous information, whereas the visual refractoriness hypothesis posits that vMMN reflects greater activation of afferent neural populations to infrequently presented stimuli (i.e., lower refractoriness). The equiprobable paradigm, added to the oddball paradigm, can dissociate these competing hypotheses. In one EMMN study using this approach, researchers found that while different emotions elicited significant N170, EMMN appeared in the P250 window but not the N170 window, leading them to conclude that automatic processing of facial emotions occurs after face identification. However, contradictory results from other studies using similar paradigms suggest that mismatch activity in different time windows may depend on experimental paradigm. Therefore, a meta-analysis is necessary to determine whether automatic processing of facial emotion information across different temporal stages is influenced by experimental paradigm.

2.2 Effects of Deviant-Standard Stimulus Pairs and Probability on EMMN

In traditional oddball paradigms studying EMMN, frequently presented neutral faces serve as standard stimuli (S), while occasionally presented emotional faces function as deviant stimuli (D). In oddball sequences, S occurs much more frequently than D (e.g., 80% vs. 20%). Although this paradigm often yields MMN, some researchers argue this does not reflect pure MMN but rather a composite of visual N1 and visual MMN elicited by visual refractoriness, as D and S differ not only in frequency but also in low-level physical properties (different D-S pair MMN). To exclude refractoriness effects, some studies have employed equiprobable paradigms, where various emotional faces (neutral, sad, surprised, happy, fearful) are each presented at 20% frequency. By subtracting ERPs to sad faces in the equiprobable sequence from ERPs to sad faces in the oddball sequence, researchers obtain same D-S pair EMMN (control-EMMN), finding it appears only in the late window (210–310 ms), whereas oddball-EMMN appears in both early (110–210 ms) and late windows, suggesting that controlling for physical properties and probability reveals EMMN effects only in the late window.

Alternative paradigms such as the reverse block paradigm and roving standard paradigm define S and D differently. In reverse block paradigms, S and D switch proportions across blocks—for example, one oddball sequence might use neutral faces as S and angry faces as D, while another uses neutral faces as D and angry faces as S. In roving standard paradigms, the same stimulus is repeated across consecutive trials (e.g., 7–13 identical emotional faces per sequence), with the first stimulus in each sequence considered D and subsequent stimuli as S. EMMN obtained through these paradigms is calculated by subtracting ERPs to angry faces as S from ERPs to angry faces as D, with both ERPs elicited by physically identical facial stimuli, thereby avoiding low-level physical property influences (same D-S EMMN)—a feature lacking in traditional oddball paradigms. However, this issue is often overlooked, potentially leading to overestimation of EMMN effects. While some researchers have examined visual refractoriness effects, they typically compare equiprobable same D-S pairs with non-equiprobable different D-S pairs, confounding physical property and probability differences. Yet many studies using non-equiprobable same D-S pairs (e.g., 20% emotional vs. 80% emotional faces) have yielded similar results to non-equiprobable different D-S pair studies. Combined with the temporal considerations discussed in 2.1, these findings suggest that experimental manipulations of D-S pair type or probability may influence EMMN effects, warranting further verification through meta-analysis.

2.3 Negative Bias in EMMN

Early ERP studies demonstrated stronger brain activity for negative compared to non-negative images, termed negative bias. EMMN studies using facial emotions have shown that angry, sad, and fearful stimuli elicit larger EMMN amplitudes than neutral or happy faces. However, contradictory findings have also emerged, with some studies reporting no significant differences between EMMN elicited by angry, sad, or fearful emotions versus happy emotions. Kovarski et al. (2017) suggested that refractoriness and physical property differences might explain these discrepancies. Their study combining oddball and equiprobable paradigms found that in the early window (100–200 ms), control-EMMN (10% emotional ERP minus 16% emotional ERP) was significantly larger than oddball-EMMN (10% emotional ERP minus 80% neutral ERP) only in angry conditions, with the difference between these EMMN types lying in whether they were elicited by physically identical and equiprobable faces. The researchers thus attributed differences between control-EMMN and oddball-EMMN to refractoriness and physical property differences. Given the numerous but inconclusive studies examining negative bias in EMMN, a meta-analytic integration of evidence is warranted.

2.4 Purpose of the Current Meta-Analysis

Numerous studies have used EMMN as an indicator of automatic detection of facial emotion changes. As discussed above, previous research suggests that D-S pair type, probability, and emotion type significantly influence EMMN effects. However, few studies have directly compared the effects of D-S pair type or probability on EMMN, and their conclusions are contradictory. Most studies have not considered how D-S pair type affects EMMN, and findings regarding EMMN emotion effects remain inconsistent. Meta-analysis provides more compelling evidence than traditional review methods by aggregating effect sizes and analyzing moderator effects. Additionally, given the wide variation in sample sizes across previous studies (ranging from 5 to 38 participants), small-sample studies may have limited statistical power. Meta-analysis is a powerful statistical method that can identify trends across many small-sample studies based on effect sizes. Therefore, this study aims to clarify whether D-S pair type, probability differences, and emotion type influence automatic processing of facial emotions in early and late time windows through meta-analysis, specifically examining whether EMMN amplitude as an indicator of automatic facial emotion processing is affected by these factors.

3.1 Literature Search

We searched Web of Science, PubMed, and EBSCO databases using the keywords: (fac* OR express*) AND (emotion* OR affect*) AND (MMN OR (mismatch negativity)). Additionally, we examined reference lists from three recent reviews on emotional mismatch and two early EMMN studies. When relevant literature could not be obtained from these databases, Google Scholar was used. Furthermore, reference lists of all included articles were reviewed to ensure no relevant studies were missed. When study results were unclear or insufficient for meta-analysis (e.g., lacking information needed to calculate effect sizes), we contacted corresponding authors to request specific data. The search period spanned from January 2004 (when we identified the first relevant study) to April 20, 2020.

3.2 Study Selection

Studies were included based on the following criteria: (1) Participants were healthy adults (without abnormal traits or disorders) with independently analyzed data; (2) Emotional faces served as task-irrelevant standard and deviant stimuli; (3) Studies explicitly examined visual mismatch negativity; (4) Studies provided sufficient information for effect size calculation; and (5) Studies were published in peer-reviewed journals. All included studies were published between 2004–2020, with titles and abstracts of potentially relevant articles manually reviewed to ensure compliance with these criteria.

3.3 Data Extraction

Data were extracted by three graduate students and one undergraduate student. For each article, we extracted: first author, publication year, sample size and gender ratio, mean age and standard deviation, data for effect size calculation (means and standard deviations, t-values, F-values, or p-values), experimental paradigm, emotion type, time window, deviant-standard stimulus pair, task relevance, electrode/ROI, face type, number of images presented per trial, and image presentation duration. When data for effect size calculation were reported separately for multiple conditions (e.g., left and right hemispheres), multiple datasets were combined into a single dataset for overall effect size calculation.

3.3.1 EMMN Time Windows Different researchers have employed varying time window criteria, with some focusing on a single mismatch activity window and others examining two windows simultaneously. While some two-window studies suggest early mismatch activity reflects N170 differences and late activity reflects P250 or P2 differences, other research indicates mismatch activity is most pronounced at non-ERP component peaks or at other component peaks such as N250 or N2 in the late window. However, since most studies report mismatch activity across two time windows with relatively consistent interval characteristics, dividing time windows into early and late intervals is feasible.

In this study, time windows with medians before 200 ms were classified as early, and those with medians after 200 ms as late. The data showing the most significant MMN within each window served as the effect size for that interval' s mismatch activity. If a study reported three or more time windows, the early window classification remained consistent with other studies, while the late window was selected as the first window after 200 ms, as most included studies reported late windows between 200–350 ms. If a study' s time window spanned substantial portions of both our defined early and late intervals, results were placed in the most appropriate interval based on reported ERP waveforms and data.

3.3.2 Deviant-Standard Stimulus Pairs We classified D-S pairs as same or different based on whether physically identical emotional faces served as deviant and standard stimuli when calculating difference waves. Generally, same D-S pair paradigms include equiprobable, reverse oddball, and roving standard paradigms, while different D-S pair paradigms include classic oddball paradigms. When studies did not explicitly state whether difference waves were calculated from identical emotional face stimuli (e.g., [17]), classification depended on contextual description. If a study reported results for both same and different D-S pairs, effect sizes for both types of MMN were listed separately.

3.3.3 Equiprobable and Non-equiprobable Paradigms The distinction between equiprobable and non-equiprobable studies was not based entirely on whether the paradigm was equiprobable, as visual refractoriness studies often use equal probabilities for deviants and standards, while some EMMN studies with equiprobable sequences may have large probability differences between equiprobable sequence stimuli and deviants (e.g., [46]). In this study, research with equal or similar deviant-standard probabilities (differences of 0%-6%) was defined as equiprobable, while studies with large probability differences (35%-90%) were defined as non-equiprobable.

3.3.4 Emotion Type Data were extracted based on the facial emotion types used in each study, typically described as angry, fearful, happy, sad, neutral, negative, or positive. Given our interest in whether automatic processing of facial emotions exhibits a negative bias, angry, fearful, and sad faces were classified as negative stimuli, while happy faces were classified as positive stimuli. To examine negative bias in EMMN, only studies using emotion type as a within-subjects factor were included in the meta-analysis, as this approach yields more reliable conclusions. Extracted data are presented in Table 1 .

3.4 Analysis Plan

In this study, all eligible EMMN research was included in the meta-analysis to examine how D-S pair type and probability influence automatic facial emotion processing, with moderator effects subsequently investigated. For calculating EMMN negative bias, only studies reporting EMMN effect sizes for both emotion types within the same participant sample or reporting effect sizes for the difference between two EMMN types were included. Both meta-analyses were conducted separately for the early interval (0–200 ms) and late interval (200–400 ms).

3.5 Meta-Analytic Methods

In the current study, Hedges'g served as the effect size index, calculated as: . For calculating negative bias, the following formula was used: . When relevant data (means and standard deviations) were not reported, Hedges' g was calculated from t-values or F-values using: . If required data were unavailable, p-values from t-tests or F-tests were converted to t-values and effect sizes calculated using the above formula [54]. For results reported as significant or $p < 0.05$, $p = 0.05$ was used to convert to the corresponding two-tailed t-value. For results reported as $p < 0.1$ or similar, $p = 0.1$ or the corresponding value was used for two-tailed t-value conversion. For non-significant results or ANOVAs without reported statistics, $t = 0$ was assigned [55].

Fixed-effect and random-effects models represent two commonly used statistical models in meta-analysis, selected based on different assumptions [56]. Under random-effects models, effect sizes may vary due to participant characteristics and paradigm differences, allowing generalization to broader populations, whereas fixed-effect models do not permit such generalization. Given that included EMMN studies varied in participants, paradigms, and stimulus types, and because we aimed for generalizable results, we selected the random-effects model. Additionally, heterogeneity test results were used to evaluate the appropriateness of this model choice.

Effect size heterogeneity was assessed using Q tests and I^2 statistics. In Q tests, significant Q values indicate significant heterogeneity. I^2 reflects the proportion of total variance explained by actual effect size differences, with larger values indicating greater heterogeneity [57]. Q tests and I^2 statistics were used to evaluate the appropriateness of random-effects models, with $I^2 > 25\%$ considered necessary for selecting random-effects models, consistent with most meta-analytic research.

Publication bias was assessed through Egger' s regression test of funnel plot asymmetry, Duval and Tweedie' s trim-and-fill method, and Rosenberg' s fail-safe N (Nfs). In Egger' s regression test, a significantly positive intercept and 95% confidence interval indicates significant funnel plot asymmetry [58], suggesting potential publication bias in overall effect sizes. The trim-and-fill method evaluates whether trimmed effect sizes significantly impact overall effects [59].

Nfs estimates how many non-significant studies would be required to render the current overall effect size non-significant. If Nfs > 5K + 10 (where K is the number of effect sizes) [60], the significant effect is considered stable.

Overall effect sizes, heterogeneity analyses, moderator analyses, and publication bias assessments were all conducted using R software (version 3.6.3) with the metafor package (version 2.1-0).

Results

Data from 36 studies meeting the aforementioned criteria were included (see Figure 1 [Figure 1: see original paper]), comprising 733 participants. EMMN effects and moderator effects are reported for both early and late intervals. Results showed that most early EMMN effects fell within 130–200 ms, while most late EMMN effects fell within 200–350 ms. Twenty-nine studies (K = 49) were used to calculate early EMMN effects, and 32 studies (K = 54) for late EMMN effects. Twenty-two studies (K = 24) were used to calculate early EMMN negative bias, and 24 studies (K = 25) for late EMMN negative bias. Forest plots in Figure 2 [Figure 2: see original paper] and Figure 3 [Figure 3: see original paper] display effect sizes and time windows for EMMN and EMMN negative bias across both intervals.

4.1.1 EMMN Effects

The overall effect size for early EMMN was significant, d = -0.63, CI: -0.75 to -0.51, $p < 0.001$. The overall effect size for late EMMN was also significant, d = -0.63, CI: -0.76 to -0.51, $p < 0.001$, indicating that facial emotions elicited significant early and late EMMN effects. Heterogeneity analysis revealed significant heterogeneity for both early EMMN studies, Q(48) = 132, $p < 0.001$, I^2 = 64%, and late EMMN studies, Q(53) = 189, $p < 0.001$, I^2 = 72%, justifying the use of random-effects models.

4.1.2 Negative Bias in EMMN

EMMN negative bias, calculated by subtracting positive EMMN from negative EMMN, showed a significant overall effect size in the early interval, d = -0.28, CI: -0.48 to -0.09, p = 0.004. Similar to early EMMN, late EMMN also exhibited significant negative bias, d = -0.32, CI: -0.54 to -0.10, p = 0.004, indicating negative bias in both early and late MMN. Heterogeneity analysis revealed moderate heterogeneity for both datasets: early effects Q(23) = 49, $p < 0.01$, I^2 = 53%; late effects Q(25) = 78, $p < 0.01$, I^2 = 68%, both exceeding the 25% criterion and supporting random-effects models.

4.2.1 Influence of Deviant-Standard Stimulus Pairs on EMMN

D-S pair type significantly moderated early MMN effects, Q(1) = 7.3, $p < 0.01$, but not late MMN effects, Q(1) = 1.51, p = 0.21, indicating that physical property differences significantly affect early but not late MMN effects.

4.2.2 Influence of Probability on EMMN

In same D-S pair studies, probability showed no significant effect on EMMN in either the 0–200 ms interval, $Q(1) = 0.28$, $p = 0.60$, or the 200–400 ms interval, $Q(1) = 0.02$, $p = 0.89$, suggesting that probability does not influence early or late EMMN effects in same D-S pair research.

4.2.3 Influence of Deviant-Standard Stimulus Pairs on EMMN Negative Bias

D-S pair type did not significantly moderate early MMN negative bias, $Q(1) = 0.12$, $p = 0.73$, nor late MMN negative bias, $Q(1) = 1.25$, $p = 0.26$, indicating that physical property differences do not affect EMMN negative bias in either interval.

4.3 Publication Bias

Publication bias was assessed and corrected using Egger’ s regression test, Nfs, and Duval and Tweedie’ s trim-and-fill method. Egger’ s regression test revealed significant funnel plot asymmetry for early EMMN effects, $t(48) = -6.71$, $p < 0.001$, suggesting probable publication bias. Nfs was 2705 ($> 5K + 10 = 255$), requiring numerous non-significant or opposite-effect studies to nullify the results. Using the trim-and-fill method, 10 studies with large effect sizes but small samples were imputed, yielding a corrected early MMN effect that remained significant, $d = -0.51$, CI: -0.63 to -0.39, with no significant difference from the pre-correction effect size ($p = 0.11$). Late EMMN effects showed similar publication bias patterns: Egger’s test indicated significant asymmetry, $t(53) = -6.54$, $p < 0.001$, requiring 2912 ($> 5K + 10 = 280$) null or opposite-effect studies to render results non-significant. After imputing 13 studies with large effects but small samples, the corrected late MMN effect remained significant, $d = -0.44$, CI: -0.57 to -0.30, though significantly different from the pre-correction effect size ($p = 0.03$).

The same tests were applied to EMMN negative bias studies. Egger’ s regression test revealed symmetric funnel plots for early effects, $t(23) = 0.05$, $p = 0.96$, and late effects, $t(26) = -1.6$, $p = 0.13$. Nfs values were 87 for early studies and 109 for late studies, both below $5K + 10$. Trim-and-fill analysis indicated no imputation was needed for either early or late data, suggesting absence of publication bias. Across three tests, one indicated potential publication bias while two showed no bias.

Discussion

We systematically reviewed facial emotion automatic processing studies using EMMN through meta-analysis. Consistent with most vMMN research, we focused on the 0–400 ms difference wave component over posterior cortical regions. Results showed that D-S pair type (same/different) significantly affected early but not late EMMN effects, while both early and late EMMN were influenced by emotion type (negative/positive). In same D-S pair studies, probability type (equiprobable/non-equiprobable) did not affect EMMN in either interval.

5.1 MMN Reflects Probability Effects of ERP Components

This study examined EMMN effects in 0–200 ms and 200–400 ms intervals, finding significant effects in both. In the 0–200 ms interval, the median EMMN time window was 165 ms, closely matching the time window of the face-specific N170 component over posterior-lateral scalp regions. A meta-analysis of emotion-elicited N170 found that task relevance significantly modulated N170 emotion effects, with larger effects under task-irrelevant conditions, similar to our different D-S pair results since deviant stimuli were typically emotional faces and standards were neutral faces. However, our meta-analysis also indicated that probability affected N170 amplitude, as same D-S pair EMMN was significant in the 0–200 ms interval. In the 200–400 ms interval, the median EMMN time window was 275 ms, approaching the N250/P3 time window. Research shows ERP components vary with facial emotion, with emotional faces eliciting larger N250/P250 than neutral faces. Our meta-analysis found similar results: in task-irrelevant EMMN studies, infrequently presented emotional faces elicited larger negative waves than frequently presented neutral faces (different D-S pair EMMN). Additionally, same D-S pair results showed that infrequently presented faces elicited more negative late ERP components than frequently presented faces despite identical physical properties, indicating that probability influences late emotion-related ERP components.

Indeed, most included studies showed negative-going late EMMN regardless of whether corresponding ERP subcomponents were N250, P250, or other components. This suggests that low-probability emotional faces caused negative shifts in ERP waveforms across both 0–200 ms and 200–400 ms intervals, demonstrating that EMMN reflects probability effects of emotion-related ERP components.

5.2 Influence of Deviant-Standard Stimulus Pairs on EMMN Effects

As described above, D-S pair type moderated EMMN effects in the 0–200 ms interval, with different D-S pairs eliciting significantly larger EMMN than same D-S pairs, while no significant difference emerged in the 200–400 ms interval. These conclusions align with Li et al. [19] but contradict Kovarski et al. [35] and Kreegipuu et al. [22], which examined both same and different D-S pair EMMN within the same participants. Previous research suggests that when D-S pairs differ, N1 or N170 effects in occipito-temporal regions reflect visual refractoriness, while effects after 200 ms reflect genuine automatic processing of visual changes [38, 65]. Our study synthesizes existing EMMN research and finds similar conclusions for automatic processing of high-level visual information. However, comparing same and different D-S pair EMMN revealed that same D-

S pairs also elicited significant EMMN in the 0–200 ms interval, suggesting that even excluding physical property differences, facial emotion information can be automatically processed in early intervals. This implies that unlike automatic processing of low-level visual stimuli, automatic processing of high-level visual stimuli with social information may be more extensive.

These results differ from EMMN studies using equiprobable paradigms [19, 38], possibly because equiprobable paradigm EMMN represents ERP differences between equiprobable same D-S pairs, potentially confounding physical property and probability differences. In included studies, same D-S pair probabilities were likely complementary (i.e., deviant and standard probabilities summed to 100% in reverse block paradigms), meaning standards and deviants differed in probability despite identical physical properties. To test whether probability also influences EMMN effects, we compared equiprobable and non-equiprobable EMMN effect sizes under same D-S conditions, finding no significant differences in either 0–200 ms or 200–400 ms intervals. This indicates that probability does not affect EMMN effects, suggesting that automatic processing of facial emotion changes in both intervals is not a probability effect. However, since only 2 included studies used equiprobable paradigms compared to 11 using non-equiprobable paradigms, future research with more targeted studies is needed to verify this conclusion.

5.3 Negative Bias in EMMN

By aggregating effect sizes from studies comparing two EMMN types within the same participant sample, we obtained negative bias results for both early and late intervals, specifically showing that negative emotional faces (angry, fearful, sad) elicited more negative EMMN amplitudes than positive emotional faces.

A key difference between negative and positive emotions is that negative emotions reflect affective states such as anger, fear, or sadness that may be associated with danger signals. Recent research indicates that negative emotions can be automatically processed without awareness, more easily break through unconscious thresholds, and are transmitted to the amygdala faster than positive emotions. A meta-analysis of P3 found that picture stimuli more readily elicit negative bias than word stimuli. Combined with our findings, this suggests that negative bias is widespread, including in automatic processing of facial emotions. The incidental appearance of negative emotions elicits stronger brain activity than positive emotions because negative emotional signals may be associated with survival-threatening events in the environment.

5.4 Publication Bias

In this study, Nfs for EMMN effects far exceeded 5K + 10, requiring numerous unpublished studies to nullify the results—an unlikely scenario—suggesting that significant EMMN results are valid and stable. However, Egger’ s regression test for funnel plot symmetry revealed significant publication bias for EMMN effects, indicating potential unpublished studies that could make the funnel plot symmetrical. This may not affect our overall EMMN conclusions, as funnel plots should be symmetric around the true effect estimate rather than zero, and asymmetry may also stem from high heterogeneity among included studies. In vMMN studies using low-level visual information, visual refractoriness exists in early intervals, with different D-S pair MMN effects significantly larger than same D-S pair effects—similar to our EMMN meta-analytic moderator effects. We speculate that unpublished EMMN studies likely show similar patterns, suggesting that publication bias probably does not affect our moderator analysis conclusions.

This meta-analytic study examined several factors influencing EMMN effects. First, we established significant EMMN effects in both early and late time windows (0–200 ms and 200–400 ms), indicating that EMMN reflects probability effects of emotion-related ERP components. Second, D-S pair type rather than probability influenced EMMN effects: specifically, different D-S pairs produced significantly larger EMMN than same D-S pairs in the early window, suggesting that EMMN effects may be overestimated in different D-S pair studies. In same D-S pair studies, probability showed no significant effect on EMMN in either interval. Finally, EMMN exhibited negative bias, with angry, sad, and fearful faces eliciting significantly larger EMMN than happy faces. These results demonstrate that EMMN effects are influenced by experimental variables such as D-S pair type and emotion type. Future research should employ same D-S pair paradigms to study automatic facial emotion processing. Additionally, since probability is closely related to automatic processing of visual information changes, future studies should further examine whether visual refractoriness in EMMN research is influenced by probability in addition to physical property differences.

Table 1 : Study characteristics including author and year, sample (male/female), mean age (SD), deviant-standard stimulus pair type, standard-deviant ratio, images per trial, electrode/ROI, and calculation method.

Figure 1 [Figure 1: see original paper]: Literature screening flowchart.

Figure 2 [Figure 2: see original paper]: Forest plots showing effect sizes and time windows for early and late MMN. Emotion types: Angry (A), Fearful (F), Happy (H), Sad (S), Neutral (N), Negative (Ne), Positive (Po).

Figure 3 [Figure 3: see original paper]: Forest plots showing effect sizes and time windows for early and late EMMN negative bias. Emotion types: Angry (A), Fearful (F), Happy (H), Sad (S), Negative (Ne), Positive (Po).

Figure 4 [Figure 4: see original paper]: Funnel plots showing early and late EMMN effects (top panels) and early and late EMMN negative bias effects (bottom panels).

References: [The reference list is preserved exactly as provided in the original text.]

Author Contributions Statement:

ZENG Xianqing: Proposed the meta-analysis topic and literature search strategy; ZENG Xianqing, XU Bing, SUN Bo, YE Jiantong: Reviewed article abstracts and full texts, confirmed included studies, extracted data, and verified extracted data; ZENG Xianqing: Analyzed data and drafted the manuscript; XU Bing, SUN Bo, YE Jiantong, FU Shimin: Revised the initial manuscript; ZENG Xianqing: Revised the final version.

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Note: Figure translations are in progress. See original paper for figures.