VISUAL MISMATCH NEGATIVITY AND CATEGORIZATION

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Abstract

Visual mismatch negativity (vMMN) component of event-related potentials (ERPs) is elicited by stimuli violating the category rule of stimulus sequences, even if such stimuli are outside the focus of attention. Category-related vMMN emerges to colors, and color-related vMMN is sensitive to language-related effects. A higher-order perceptual category, bilateral symmetry is also represented in the memory processes underlying vMMN. As a relatively large body of research shows, violating the emotional category of human faces elicits vMMN. Another face-related category sensitive to the violation of regular presentation is gender. Finally, vMMN was elicited to the laterality of hands. As results on category-related vMMN show, stimulus representation in the non-conscious change detection system is fairly complex, and it is not restricted to the registration of elementary perceptual regularities.

Key words: visual mismatch negativity, categorization, color, emotion, gender, hand laterality

The majority of changes in an environment are irrelevant, unrelated to the ongoing behavior or have no survival value. Field studies and laboratory experiments show that in visual modality, individuals remain unaware of the majority of these changes, unless they are processed by a limited capacity system (see, e.g., the change blindness phenomenon; for a review see Simons and Levin, 1997). Thus, outside of the focus of attention, even large modifications of stimulation remain unnoticed. It is important to recognize that daily observations and the majority of laboratory experiments are both based on the reports or performance measures of the participants. The registration of event-related brain potentials (ERPs) provides an exceptional tool for investigating environmental changes without conscious representation or manifestation at the level of behavioral performance, i.e., the effects of automatic processes. Visual mismatch negativity (vMMN) fulfills this requirement.

VMMN is sensitive to a specific type of visual change, the effects of violated regularities of environmental stimulation. To investigate this type of change detection, it is necessary to establish the regularity, and it is important that both the representation and violation of regularity remain outside the focus of attention. In the auditory modality, these requirements were successfully solved, as demonstrated by 2933 items on (auditory) MMN in the Web of Science database during a period from 1975-2013 (May) (for reviews see Näätänen et al., 2007). In contrast, vMMN is represented with only 82 items because after some negative (Nyman et al., 1990) and apparently positive (Czigler and Csibra, 1990, 1992; Alho et al., 1992) results, vMMN studies were initiated only 10-15 years ago. In 2003, Pazo-Alvarez et al. published a comprehensive review on vMMN, i.e., earlier than the majority of vMMN research. More recent reviews on vMMN have focused on clinical studies (Maekawa et al., 2012) and specific issues, such as automaticity and memory-related characteristics (Czigler, 2007), vMMN and the predictive coding principle (Kimura, 2012; Kimura et al., 2011), and vMMN and object-related processing (Winkler and Czigler, 2012). Together, these reviews show that vMMN is sensitive to deviant stimulus features (color, orientation, movement direction, etc.), the deviant conjunction of features, object-related characteristics as well as sequential regularities.

VMMN studies have attempted to mimic the studies of (auditory) MMN to investigate similarities or differences in the two modalities (see, e.g., Winkler and Czigler, 2012). The almost exclusively used ‘passive oddball paradigm’ has also been imported from the field of auditory MMN. In this paradigm, a sequence of frequent, identical (or equivalent) stimuli (standards) is presented with infrequent stimuli which are different from the standards (deviants). The deviant-related activity is calculated as the difference between the ERPs associated with the deviant and the standard. The paradigm is ‘passive’, as no task-related attention is paid to the vMMN-related stimuli; participants attend to the stimuli of an ongoing task. In this respect, studies in the auditory and visual modality are different because the majority of auditory investigations involve visual tasks; however, in vMMN studies, task-related stimuli are also presented in the visual modality (Czigler, 2007).

In this paper category-related vMMN studies are reviewed. This set of studies provided evidence that the memory system underlying vMMN is capable of representing complex stimulus characteristics, well beyond individual stimulus features like color, orientation, spatial frequency, etc, the conjunction of features or object-related organizations of features.

Categorization is a basic process of visual perception, and this process goes beyond the physical characteristics of stimulation. There are hundreds of various “blue” colors, with the combination of different values of hue, saturation and brightness. We perceive dogs, even if there are considerable physical differences between a greyhound and a Scottish terrier (and even among different varieties of greyhounds). Bilateral symmetry is a common feature in the ‘animal kingdom’, even if other visual characteristics are highly different (for a review on visual categorization see Palmer, 1999, chapters 3.4 and 9). Categorization is a basic process of perception, therefore an increasing number of studies have investigated whether the processes underlying vMMN were sensitive to category-related deviancies. In these studies, either a set of standards acquired a category and the deviants were members of another category or the vMMN effects of category-member deviants and non-member deviants were compared. Currently, the effects of color categories (Athanasopoulos et al., 2010; Clifford et al., 2010; Fonteneau and Davidoff, 2007; Mo et al. 2011), symmetry (Kecskés-Kovács et al. 2013), facial emotions (Astikainen and Hietanen, 2009; Chang et al., 2010; Gayle et al., 2012; Li et al., 2012; Stefanics et al., 2012; Susac et al., 2010; Zhao and Li, 2006), left/right hand (Stefanics and Czigler, 2012) and gender (Kecskés-Kovács et al., 2013) have been investigated. In addition to the effects of language on color-related vMMN, the effects of word meaning (Wang et al., 2013) and phonological categorization (Files et al., 2013) were also investigated.

1. Language-related categorization and vMMN

The visible spectrum is continuous, but our perceptual experience is categorical (we see blue, green, yellow, red, etc.). Values on the basic dimensions of color (hue, lightness, saturation) and various colors can be characterized as points within the color space, and within this space, distances can be calculated between the various colors. Similar distances within the color space are perceived either as members of the same category (e.g., two different green colors) or members of different categories (a particular green and a particular blue color). First Fonteneau and Davidoff (2007) investigated whether deviant-related responses at identical distances were different for same-category and different-category deviants. Oddball series were constructed using color-patches with frequent and deviant colors as vMMN-related (task-irrelevant) stimuli and cartoon figures as targeted stimuli (participants reacted with button-press to the onset of the target stimuli). The deviant stimulus was a green patch, and it was presented within sequences of another *(standard)* green patch (same category, small distance), a standard blue patch (different category, small distance) or a standard red patch (different category, long distance). In the large distance (green *vs.* red) sequences, deviant-related activity emerged in the 120-160 ms range as anterior *negativity* and posterior *positivity.* In the small distance different category sequence (green vs. blue), the latency of the deviant-related ERP effect had longer latency, and the latency increased further in the within-color sequence. It is difficult to explain the unusual polarity of the difference potentials of this study. One explanation is that the posterior effect was an emergence of a “change positivity component” (e.g., Kimura et al., 2006). Even in this case, it is difficult to explain the lack of posterior negativity, but the results clearly show category differences. It is important to note that vMMN is considered as an index of automatic processes (i.e. processes without the obligatory involvement of the attentional system). In this study the task-relevant and irrelevant stimuli were the members of the same sequence in an otherwise empty screen. It is difficult to ignore such visual stimuli (the issue of attentional control is discussed in Czigler, 2007).

Clifford et al. (2010) conducted a related study. Task-irrelevant colored squares were presented either to the lower or to the upper part of the visual field. Participants were requested to fixate on the center of the screen and respond to the occasional changes of the fixation cross to a circle (this method provides a more effective control of attention). The standard and within-category deviants were two blue colors; the between-category deviant was green. Within the color space, the distances between the standard and the two deviants were identical. Lower half-field presentation elicited vMMNs in the 100-200 ms range, but the effect was reliable only in the case of between-category deviancies, showing the effect of categorization.

The possibility of language-related effects on perceptual processes is a controversial topic, and for years, language-related effects comprised a field of intensive research in psychology and linguistics. The results of the studies of Fonteneau and Davidoff (2007) and Clifford et al. (2010) can be interpreted as pure visual effects, i.e., colors were categorized within the visual system, and color naming was a consequence of perceptual categorization. As an opposite position, called *linguistic relativity* or the *Sapir-Whorf hypothesis*, categories developed within the language system, and perception was influenced through verbal categorization (for a review see Kay and Regier, 2006). A traditional test of the two possibilities involved the comparison of perceptual effects in languages with different color naming systems. Athanasopoulos et al. (2010) (reported also in Thierry et al., 2009) capitalized on the difference between the Greek and English languages. In Greek, there are two words for blue: 'ble' for dark blue and 'ghalazio' for light blue. In English, a single word is used for blue. Green has a unitary name in both languages. In some sequences, light and dark blue shapes were presented as standards and deviants, and *vice versa* in other sequences. In other sequences light and dark green stimuli were presented. The participants responded to the occasional square patterns in the sequence, but the vMMN-related patterns (both the standards and the deviants) were circles, i.e. color was an irrelevant stimulus feature. Three groups of participants were investigated: a group of native Greek speakers with short stay in Britain, a group of native Greek speakers with long stay in Britain and a group of native English speakers. In the green sequences, there was no vMMN difference between the groups; the deviant-related posterior negativities (in the 150-250 ms range) had identical amplitudes. However, in the blue sequences, the negativity was larger in the group of native Greek speakers with short stay in Britain. It seems that verbal categorization accentuated the perceptual effect; deviants belonging to different categories elicited larger vMMNs. This result supports the linguistic relativity principle; i.e., the effect of language on perceptual processes. Figure 1 shows the language-related vMMN differences in native Greek and English speakers.

Insert Figure 1 about here

Mo et al. (2011) applied a less direct method for investigating the language-related effects on vMMN. The starting point was the observation that language-related ERP effects concentrated over the left hemisphere. In this study, irrelevant colored squares were presented simultaneously to the right and left visual half fields (i.e., left and right hemisphere stimulation, respectively). These stimuli were irrelevant; participants had to detect the change of the fixation cross to circle. In the standard trials, the two squares were identical (two identical blue or two identical green squares in various sequences). Deviant stimuli, either on the left or the right side, were members of the same or different categories, but in both cases the standard-deviant distances were equal within the color space. Deviant colors elicited vMMNs in the 130-190 ms range, but the vMMN amplitude elicited through within-category deviants was smaller when the deviants appeared in the right visual field. No category-related effect appeared with left half-field stimulation. Because right half-field stimuli are processed in the left hemisphere, the authors argued that the lateral difference was a consequence of a language-related effect; i.e., the left hemisphere processing accentuated the effect of the category-related color difference.

Wang et al. (2013) conducted a category-related vMMN study, specific for the Chinese language. In logographic Chinese, different characters with different meanings are pronounced similarly, i.e., there is a many-to-one correspondence between orthography and phonology. The authors presented sequences consisting of various, visually different but phonologically identical characters as standard stimuli while characters with different phonology were presented as deviants. VMMN to the deviants was considered as indication of an automatic effect of phonemic coding on visual processing. VMMN-related stimuli were presented in white color, and within the sequences, black characters were presented as targets (requiring button press). VMMN (deviant-minus-standard difference) emerged in two ranges, in the 140-200 and 230-360 ms time windows. In both cases, vMMN was largest over the parieto-occipital regions, likely originated within the visual cortex.

A language-related effect at phonological level was investigated in a recent study (Filers et al., 2013). VMMN was recorded to visual speech stimuli with near /zha/ vs. /ta/ and far /zha/ vs. /fa/ articulatory movements (/ta/ and /fa/ were standard stimuli). Special care was taken for the onset of the averaging procedure (i.e. to the time of the movement onset). The same deviant /zha/ in the near context elicited vMMN over the right posterior temporal location, whereas the same syllable in the far context elicited bilateral vMMN. These authors suggest that language-related left-side structures are sensitive to larger differences, whereas the right structures, not specific for speech-related phonemic contrasts responded even to fine differences in facial movements. The vMMN in this study showed relatively long latency, and the variation of vMMN latency under different conditions was considerable within the 240-500 ms range. However, the results were consistent with the suggested language-related modulation of vMMN to articulatory movements.

2. Perceptual categories and vMMN

Bilateral symmetry is a characteristic of animals, and our perceptual system developed a specific sensitivity to this type of patterns (Tyler and Hardage, 1996). Kecskés-Kovács et al. (2012) presented various symmetric and random patterns comprising dark and light gray squares. These patterns appeared in the lower half-field. Participants played a video game that required continuous central fixation. Either the symmetric or the random patterns were deviants in various sequences. Deviant and standard symmetric patterns elicited identical ERPs. However, deviant random patterns elicited vMMNs in the 112-120 and 284-292 ms ranges. As the authors discussed, symmetry is a perceptual category, but there is no such perceptual category of ‘randomness’. Deviant random patterns violated a category rule, and accordingly, these deviants elicited vMMNs. However, deviant random patterns did not acquire regularity, and accordingly, no vMMN was elicited through symmetric deviants. Figure 2 shows vMMN to infrequent asymmetric patterns and the absence of vMMN to the infrequent symmetric patterns.

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Insert Figure 2 about here

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In a recent study, Kecskés-Kovács et al. (2013) obtained gender-related vMMN. In sequences of male or female photographs, as deviant stimuli, photographs of the other sex were inserted. These deviants elicited posterior negativity in the 140-300 ms latency range. Facial stimuli were irrelevant; participants had to detect changes in the fixation cross, and this change was independent of sequence of facial stimuli.

The violation of the sequential presentation of left or right hands as perceptual categories also elicits vMMN. Stefanics and Czigler (2012) presented either four left or four right hands as standard stimuli. The hands appeared in four corners of the display. The orientation of the hands varied within and between the displays. When the standard stimuli contained right hands, the deviants contained left hands and *vice versa*. The task was to detect infrequent changes in the fixation cross. All participants were right-handed. As the deviant-minus-standard difference potentials showed, both the right- and the left-handed deviants elicited vMMNs over parietal locations within the 170-200 ms range, with larger difference over the right side.

It is necessary to remember that perceptual categories like symmetry, handedness and even gender have common visual attributes that are absent in stimuli outside the category. However, in the studies of this section the within-category stimuli were highly different, and the within-category attributes were higher-order characteristics. In case of bilateral symmetry the attribute of the category is well-defined in visual terms, but in other cases, like photographs of cropped male and female faces visual description is rather difficult. This difficulty is also obvious at the most frequently investigated facial emotion category.

3. Emotional expression and vMMN

The expression of emotion on the face has immense importance in everyday life. Facial emotions have a well-established categorical system (Ekman and Friesen, 1967; for a review see Adolphs, 2002); therefore, there is an increasing interest concerning whether changes of facial emotions are detected automatically. In other words, these studies investigated the possibility of vMMN to the appearance of infrequent (deviant) emotions within the sequence of frequent (standard) emotions. Consecutive studies have attempted to impose more stringent control on the contribution of low-level visual differences and on the on the involvement of attentional processing.

Zhao and Li (2006) used the 'cross-modal delayed response paradigm' (Wei et al., 2002). In this paradigm, vMMN-related stimuli are presented between task-relevant auditory stimuli. In this particular study, a tone was presented first, followed by one or two pictures or blank intervals between the tones. The last stimulus of the trial was an imperative click, and participants had to respond according to the pitch of initial tone. The visual stimuli were photographs of a single person. As the standard, the person had a neutral expression. The deviants were photos with either happy or sad expressions. Deviant-related negativity started at 110 ms (happy deviant) or at 120 ms (sad deviant) and terminated at 360 ms (happy) or 430 ms (sad deviant). The negativities were distributed over the parieto-occipital and parieto-temporal areas, and these values were larger over the right side (especially for happy faces). While the results exhibited the characteristics of vMMN, this method has two shortcomings. First, it is impossible to isolate the effect of obvious physical (low level) differences from the effects of emotion. Second, without a concurrent task, it is difficult to withdraw attention from the centrally presented faces.

Astikainen and Hietanen (2009) attempted to avoid the confounding effects of low-level visual features. Instead of a single person, photographs of four persons were presented. The faces had neutral (standard) or fearful (deviants) expressions. Participants attended to a radio-play and counted particular target words. An emotion-related negativity started at 150 ms after the stimulus (the latency was somewhat shorter in response to the happy deviant) and terminated at 180 ms. The negativity was largest over the occipital locations. Furthermore, an anterior positivity emerged in the 130-170 ms range, and there was a later posterior negativity in the 280-320 ms range. The latency range of the earlier negativity was similar to the latency of the face-related N170 component (for a review see Eimer, 2011); therefore, it is possible that the negativity in the 150-180 ms range was associated with the amplitude change of the N170 component. Presenting the faces of four persons reduced the effects of low-level differences. However, in the case of salient stimuli (faces), and particularly in the case of emotional expression, the method of attentional control of the study was not particularly strong.

In 2010, Chang et al. (Experiment 1) conducted a related study with a schematic face with various emotional expressions. Neutral faces were standard stimuli, and happy and sad faces were deviants. The participants had to count faces presented in an infrequent color. In various sequences, either upright or inverted faces were presented. (Presentation of inverted faces is a frequent control in face-related research. Specificity of face-related processing, including identification of emotion, is rather difficult at inverted faces.) Emotional faces elicited vMMNs in the 140-350 ms range, and larger vMMNs were reported in response to upright faces than for inverted faces. Furthermore, for the upright faces, the vMMNs were larger over the right hemisphere. The different amplitude and scalp distribution between the vMMNs to upright and inverted faces is an indication that the results reflected a face-specific effect. However, even the authors observed that these methods did not control low-level (physical) differences. Therefore, in Experiment 2, six different schematic faces were introduced to control for the physical effects, and the results were fairly similar. The authors proposed that the first part of the negative difference reflected the refractoriness of the face-related N170 component[1], but the deviant-related negativity of the later latency range cannot be explained by the amplitude change of exogenous activity. However**,** the results shown in Figures 2 and 3 did not support the refractoriness interpretation of the early deviant-related negativity. The onset of the VMMN was earlier than the onset of the N170 component, and the hemisphere-related amplitude difference in the N170 was much smaller than the right-side dominance of the vMMN. In a study using this method, Tang et al. (in press) obtained deviant-related negativity in similar ranges. Notably, the issue of automaticity *vs.* the involvement of attentional processes is not well controlled in a study where single facial stimuli are presented at the center of an otherwise empty screen, since it is impossible to ignore these stimuli (Czigler, 2007).

The early onset of deviant-related activity in response to emotional faces was reported in an MEG study (Susac et al., 2010). In this study, a single photograph of a neutral face was presented as a deviant, and in various sequences, the standard was the happy expression of the same person or the neutral face of a different person. The faces were presented in upright or inverted positions. In the target stimuli, the model wore glasses. As it was previously described, the presentation of a single face without simultaneously presented task-related stimuli cannot prevent attentional processing. The results of this study showed that electromagnetic (MEG) responses to deviant faces in the upright position were larger than the responses to standard faces. The difference emerged as early as 90-120 ms. The upright versus inverted difference in the deviant effect suggests a face-specific effect. A deviant identity (face of another person) elicited similar negativity, showing that the emotion-specificity of the deviant-difference is not unequivocal.

Gayle et al. (2012) presented neutral faces as standard, and happy, sad and colored neutral faces as deviants. In various micro sequences, the personal identities were different. To minimize the effect of low-level differences in emotional faces, all faces had closed mouths. During the presentation, participants attended to an auditory task. All deviants elicited vMMNs, but the largest negativity appeared in response to sad faces. The vMMN was larger over the right side (at PO8), and the lateralization was stronger for the emotional faces than for the color deviants. Based on these results, it is possible that emotion-related vMMN is differently sensitive to various emotional deviancies, but it is obvious that in such comparisons a stronger control of physical differences is needed.

Stefanics et al. (2012) attempted to control both attention and possible low-level differences. In this study, the facial expressions of eight persons were used. As in the previously mentioned study using hands as stimuli (Stefanics and Czigler, 2012), the faces were presented at the four edges of an imaginary square. Within a stimulus, the emotions were identical, but the personal identities were different; i.e., the same person was not presented more than once within a stimulus. Furthermore, the identities were varied among the stimuli. The task was to react to changes in the central fixation cross. In various sequences, either the fearful or the happy faces were standard stimuli, and the other emotions served as the deviants. ERPs to the same emotion in deviant and standard roles were compared. For both emotional deviants, the elicited posterior negativities (with temporal maxima) emerged in the 170-220 ms and 250-360 ms ranges. These posterior negativities were accompanied by central positivities. Furthermore, fearful deviants elicited early (90-120 ms) negativity with right side dominance. This early effect may reflect the specific sensitivity to negative emotions. Figure 3 shows emotion-related vMMN from the Stefanics et al. (2012) study.

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Insert Figure 3 about here

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Although there are methodical shortcomings in some of the studies discussed here and it is difficult to compare the details of the results of the various studies (due to the methodological variability), the findings unequivocally show that facial emotions are registered in the system underlying vMMN. This system is responsive to deviant emotions i.e., to the violation of regularity: The same facial emotion is presented within a stimulus sequence. However, two issues require further (and systematic) investigation: 1) Is the system differently sensitive to various emotions? 2) How early are the onset latencies in emotion-related deviance detection, and how such processes are related to the ERP activity attributed to facial processing?

Summarizing the studies on categorical vMMN, the results show that the memory system underlying vMMN is obviously sensitive to higher order structures, such as facial characteristics (emotional expression, and gender), and not only to elementary visual features of simple combinations of these features. The sensitivity is associated with the ecological importance of the environmental events, such as symmetry, gender, and emotion. Moreover, the effects of language show that the processes underlying vMMN are not restricted to the functions of 'encapsulated modules'. Long-term learning is capable of modulating the processes of automatic change detection.

Like in other topics of vMMN, the methodical variability is considerable. While this variability prevents the comparison of the results, on the bright side, emergence of posterior negativities is almost equivocal in the studies with different methods. However, latencies of vMMN in the category-related studies were variable, and in many studies, mainly with facial stimuli, multiple components emerged. Hierarchical architecture and strong feedback connections are basic characteristics of the visual system. Emergence of multiple negativities may indicate the activity of structures on different levels of the hierarchy, or the activity of the same structure after the feedback from a different level of the hierarchy (reentrant processing). In the future localization studies may help to clarify this issue.

Another question is the sensitivity limit of the memory system underlying vMMN. As some behavioral and ERP studies show, detection of category membership is a rapid process in case of living creature vs. objects (e.g. Delorme et al., 2000; Fize et al., 2005; VanRullen and Thorpe, 2001). As these results show, differences of obvious visual features cannot explain the categorization process. The automaticity of this rapid process can be investigated by using vMMN methods.

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Footnote

[1]In the oddball sequences the interval between two standards is shorter than the interval between two deviants. As a function of inter-stimulus interval the amplitude of some ERP components increase. Therefore standard stimuli may elicit smaller negative components than the deviant, i.e., deviant-minus-standard difference potential would be negative. The relationship between the mismatch components and the refractoriness of ERP components (particularly N1 refractoriness) is discussed in detail in the auditory modality (May and Tiitinen, 200, Näätänen et al., 2005), and in some visual studies (e.g. Kenemans et al., 2003; Kimura et al., 2009). The refractoriness issue is a central topic of vMMN research, but it is outside the scope of the present review. In a recent paper Li et al. (2012) attempted to control the N170 refractoriness as a contributing factor of the deviant-minus-standard ERP difference in emotion-related vMMN. As the results showed, the contribution of selective N170 refractoriness cannot be ruled out; however, the emotion-related vMMN might have started in the early (~ 110 ms) latency range.

Legends of figures

Figure 1. ERPs elicited by circles with standard and deviant color (linear derivation of IZ, O1, O2, Oz. PO7, PO8, PO9 and PO10 locations). ERPs were significantly more negative for deviants than standards in the 162-323 ms range (shaded intervals). VMMN of Greek participants with short stay in Britain was larger in the sequences with blue stimuli than in sequences of green stimuli, whereas vMMN of Greek participants with longer stay in Britain was similar to the vMMN of native English speaking participants. From Athanasopoulos et al., (2010). With the kind permission of Elsevier B.V.

Figure 2. A. Illustration of sequences with symmetric and random standards, an a stimulus display. VMMN-related stimuli appeared on the lower half field; to the upper half field stimuli of a video-game were presented. B. Upper row: Group averages ERPs elicited by standard and deviant stimuli, and the deviant-*minus*-standard difference potentials to symmetric and random patterns. Lower row: Surface distribution in latency ranges with significant deviant-related negativities From Kecskés-Kovács et al. (2013). With the kind permission of Wiley-Blackwell.

Figure 3. ERP responses to standard and deviant stimuli and deviant-*minus*-standard difference (vMMN) waveforms. Upper panel: responses to fearful deviant and standard facial emotions. Lower panel: responses to happy deviant and standard facial emotions. Shaded areas mark the intervals selected for statistical analyses (70-120 ms for fearful stimuli; 170-220 ms and 250-360 ms for both fearful and happy faces). From Stefanics et al., 2012. With the kind permission of Elsevier B.V.