Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Neuroscience Letters xxx (2005) xxx–xxx
Neuroscience Letters
www.elsevier.com/locate/neulet

Attention modulates the processing of emotional expression triggered by foveal faces

Amanda Holmes [a,*], Monika Kiss [b], Martin Eimer [b]

[a] *School of Human and Life Sciences, Roehampton University, Whitelands College, Holybourne Avenue, London SW15 4JD, UK*
[b] *School of Psychology, Birkbeck University of London, UK*

Received 2 August 2005; received in revised form 26 September 2005; accepted 2 October 2005

Abstract

To investigate whether the processing of emotional expression for faces presented within foveal vision is modulated by spatial attention, event-related potentials (ERPs) were recorded in response to stimulus arrays containing one fearful or neutral face at fixation, which was flanked by a pair of peripheral bilateral lines. When attention was focused on the central face, an enhanced positivity was elicited by fearful as compared to neutral faces. This effect started at 160 ms post-stimulus, and remained present for the remainder of the 700 ms analysis interval. When attention was directed away from the face towards the line pair, the initial phase of this emotional positivity remained present, but emotional expression effects beyond 220 ms post-stimulus were completely eliminated. These results demonstrate that when faces are presented foveally, the initial rapid stage of emotional expression processing is unaffected by attention. In contrast, attentional task instructions are effective in inhibiting later, more controlled stages of expression analysis.

Keywords: Emotional expression; Event-related potentials; Fearful faces; Foveal vision; Spatial attention

Emotional information is prioritized for processing: it is analyzed rapidly [3,6], and has the ability to engage preferential attention [1,9,10,19]. This preferential processing of emotionally significant events may reflect a variety of mechanisms, including modulatory influences from the amygdala on sensory processing [18], modulation of frontoparietal cortices by lateral orbitofrontal cortex [2], and cholinergic enhancement of these brain systems [4].

An important and controversial issue is whether the encoding and analysis of emotionally salient events can occur independently of attention [13,16]. Recent fMRI studies have provided conflicting results. In one study [17], amygdala responses to threat-related facial expressions were unaffected by spatial attention, and emotion-specific activity in some frontal and parietal regions was observed for unattended faces. This suggests that facial emotion can be discriminated pre-attentively, and that information concerning the affective value of irrelevant stimuli is still available even when attention is allocated to other events. Results from another study [15], however, contradict these findings. In this study, elevated neural activation levels in response to attended fearful versus neutral faces were found within a number of distinct brain regions, including the amygdala. In contrast, when spatial attention was diverted away from the faces, this differential activation was no longer apparent. These data clearly challenge the hypothesis that the detection and analysis of emotional events is independent of the current focus of attention.

Event-related potential (ERP) studies have also been used to examine interactions between attention and emotion processing [7,11]. In one study [11], stimulus arrays consisting of two faces and two houses positioned along horizontal and vertical axes were presented. Participants had to attend either to the two vertical or to the two horizontal locations (as indicated by a cue presented at the start of each trial), in order to detect occasional target events at these locations. On trials where faces were presented at cued (attended) locations, an enhanced positivity was triggered in response to arrays containing fearful as compared to neutral faces. This emotional expression effect started at anterior electrodes at about 120 ms after stimulus onset, had an initial frontal distribution, and was more broadly distributed beyond 200 ms post-stimulus (see also [6] for similar findings).

---

[*] Corresponding author. Tel.: +44 20 8392 3449.
E-mail address: a.holmes@roehampton.ac.uk (A. Holmes).

0304-3940/$ – see front matter © 2005 Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.neulet.2005.10.002

In marked contrast, when faces were presented at uncued locations, and attention was directed to the location of houses instead, these emotional expression effects were entirely eliminated. Similar findings were obtained in a second study [7]. In different blocks, participants directed their attention either towards a pair of peripheral faces in order to judge their emotional expression, or towards a centrally presented pair of vertical lines in order to judge their length, and ignored the other stimulus in the display (lines in the Faces task, and faces in the Lines task). Different facial expressions (anger, disgust, fear, happiness, sadness, surprise) were presented in separate blocks. When emotional faces were task-relevant, an enhanced positivity to emotional relative to neutral faces was elicited. Although starting slightly later (at about 160 ms post-stimulus), the distribution of this emotional positivity was similar to previous studies [6,11]. However, in blocks where participants directed their attention to the central lines while ignoring lateral faces, these emotional expression effects on ERP waveforms were no longer present.

These ERP results are largely consistent with the fMRI findings of Pessoa et al. [15] by revealing a strong interaction between emotion and attention. One possible explanation for the discrepancies between these findings and those of Vuilleumier et al. [17] is that the attentional filtering of task-irrelevant information may have been more efficient in the former studies, leading to the elimination of emotion-specific effects. By contrast, in the Vuilleumier et al. [17] study, the gating of information may have been incomplete, and thus emotional expression effects of task-irrelevant information remained present. Pessoa et al. [14] have suggested that the attentional task in the Vuilleumier et al. [17] study may have been less demanding than in their own experiments. It would therefore seem likely that to-be-ignored emotional information can still be processed, albeit in attenuated fashion, when the performance of an attentional task is relatively easy, and spare processing capacity remains available, thus resulting in incomplete attentional gating of task-irrelevant information (see [13,14]).

The aim of the present ERP study was to further investigate the role of spatial attention for the processing of emotional faces under conditions where these faces should be hard to ignore. More specifically, we investigated whether ERP emotional expression effects are still affected by attentional task instructions when fearful or neutral faces are presented at fixation. The design of the present experiment was similar to the task employed by Eimer et al. [7], in that participants were required to focus their attention either on faces while ignoring simultaneously presented pairs of vertical lines (Faces task), or to attend to these lines while ignoring faces (Lines task). The main difference was that faces were not presented peripherally, but at fixation, and were flanked by a pair of bilateral vertical lines that were either identical or different in length. In the Faces task, participants had to detect immediate repetitions of identical faces (which could be either fearful or neutral) across successive trials. In the Lines task, they had to detect immediate repetitions of identical line pairs across trials, and to ignore the central fearful or neutral faces.

ERPs triggered on trials containing a fearful face were compared to ERPs elicited on trials where a neutral face was present, separately for the Faces task and the Lines task. Since faces were always located at central fixation, they should be harder to ignore even when participants are instructed to monitor the line stimuli, as compared to our previous studies where faces were presented at peripheral locations [7,11]. The critical question was whether there would still be systematic differences in emotional expression effects on ERP waveforms between the Faces and the Lines task. If the emotional expression of faces at fixation was always processed fully regardless of attentional task instructions, emotional expression effects should be equivalent for both tasks. In contrast, if the instruction to direct attention away from these faces towards the laterally presented lines interfered with the processing of emotional expression, these effects should be attenuated or possibly even completely absent in the Lines task.

Twelve paid volunteers (four males, eight females), aged 18–41 years (mean age: 31 years) participated in the experiment. All subjects were right-handed and had normal or corrected-to-normal vision.

Subjects were seated in a dimly lit sound attenuated cabin, with response buttons under their left and right hands. All stimuli were presented on a computer screen in front of a black background at a viewing distance of 70 cm. Face stimuli were photographs of faces of 10 different individuals, all taken from a standard set of pictures of facial affect [8]. Facial expression was either fearful or neutral. Faces covered a visual angle of about $8.6^\circ \times 5.7^\circ$, and were presented at fixation together with a pair of grey vertical lines (0.2° width). These lines were presented to the left and right of the central face at an eccentricity of 4.0° (see Fig. 1). Two different line lengths were used. Short and long lines covered a visual angle of 1.3° and 2.8°, respectively. All four possible line arrangements (bilateral short lines, bilateral long lines, short left/long right, long left/short right) were presented with equal probability.

Two task conditions were run, each consisting of two successive experimental blocks. In the Faces task, participants were instructed to monitor the centrally presented faces, to respond with a right-hand button press whenever the face presented on the

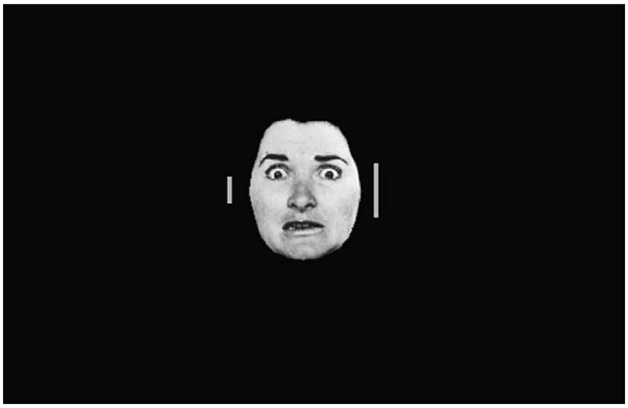

Fig. 1. Example of a stimulus array used in both tasks. In the Faces task, participants had to detect immediate repetitions of an identical face at fixation. In the Lines task, they had to detect immediate repetitions of an identical lateral line pair across trials.

preceding trial was shown again on the current trial, and to ignore the lateral lines. In the Lines task, participants were instructed to monitor these lines, to respond with a right button press when the line arrangement presented on the preceding trial reappeared on the current trial, and to ignore the centrally presented faces. Each block consisted of 92 trials. Stimuli were presented for 300 ms, and were separated by intertrial intervals of 1200 ms. Twelve trials per block were target trials, which contained an immediate repetition of an identical face in the Faces task, and an immediate repetition of an identical line pair in the Lines task. There were no immediate repetitions of task-irrelevant stimuli (faces in the Lines task, and line pairs in the Faces task) across trials. The remaining 80 trials were non-repetition trials (with a fearful or neutral face each presented in random order on 40 trials). Participants were instructed to respond as quickly as possible only to immediate repetitions of the task-relevant stimulus and to maintain central fixation. Short practice blocks were delivered for both task conditions.

Recordings were made from 23 Ag–AgCl electrodes, referenced to linked earlobes. Horizontal EOG (HEOG) was recorded bipolarly from electrodes at the outer canthi of both eyes. Electrode impedance was kept below 5 kΩ. EEG was d.c.-recorded with a sampling rate of 200 Hz and an upper cut-off frequency of 40 Hz. EEG was averaged relative to a 100 ms pre-stimulus baseline for all combinations of task (Faces task versus Lines task) and facial expression (fearful versus neutral). To avoid any contamination with movement-related artefacts, ERP analyses were restricted to non-repetition trials where no manual response was recorded. Trials with eyeblinks (Fpz exceeding ±60 μV) and lateral eye movements (HEOG exceeding ±30 μV) were also excluded prior to analysis. Artefact rejection led to the exclusion of 24.9% of all non-repetition trials in the Faces task, and of 21.3% of all non-repetition trials in the Lines task. Repeated measures analyses of variance (ANOVAs) were performed on ERP mean amplitudes obtained within successive latency windows (120–160, 160–220, 220–300, and 300–700 ms post-stimulus, respectively). These analyses were conducted separately for lateral electrode pairs F3/4, C3/4, and P3/4, and for midline electrodes Fz, Cz, and Pz, for the factors task, facial expression, electrode site (frontal versus central versus parietal) and hemisphere (left versus right, for lateral electrodes only).

Mean reaction times to immediate stimulus repetitions were faster in the Faces task than in the Lines task (666 ms versus 749 ms; $t(11) = 4.4$; $p < .001$). Reaction times in the Lines task were not significantly affected by the emotional expression of the task-irrelevant face. Participants missed more immediate stimulus repetitions in the Lines task than in the Faces task (22.2% versus 9.7%; $t(11) = 2.9$; $p < .02$). False Alarms on non-repetition trials occurred on less than 1% of these trials for both task conditions.

Fig. 2 shows ERPs in response to stimulus arrays containing a fearful face (dashed lines) or a neutral face (solid lines) at fixation, separately for the Faces task (top panel) and the Lines task (bottom panel). As predicted, a sustained positivity was elicited in response to arrays containing emotional faces in the Faces task. This emotional expression effect started at about 160 ms post-stimulus, overlapped with the P2 and N2 components, and remained present in a sustained fashion during the 700 ms interval shown in Fig. 2. When attention was directed away from the centrally presented faces in the Lines task, longer latency emotional expression effects were strongly attenuated, or entirely absent. In contrast, the early phase of this effect (an emotional positivity superimposed on the P2 component) appeared to remain present when faces were irrelevant.

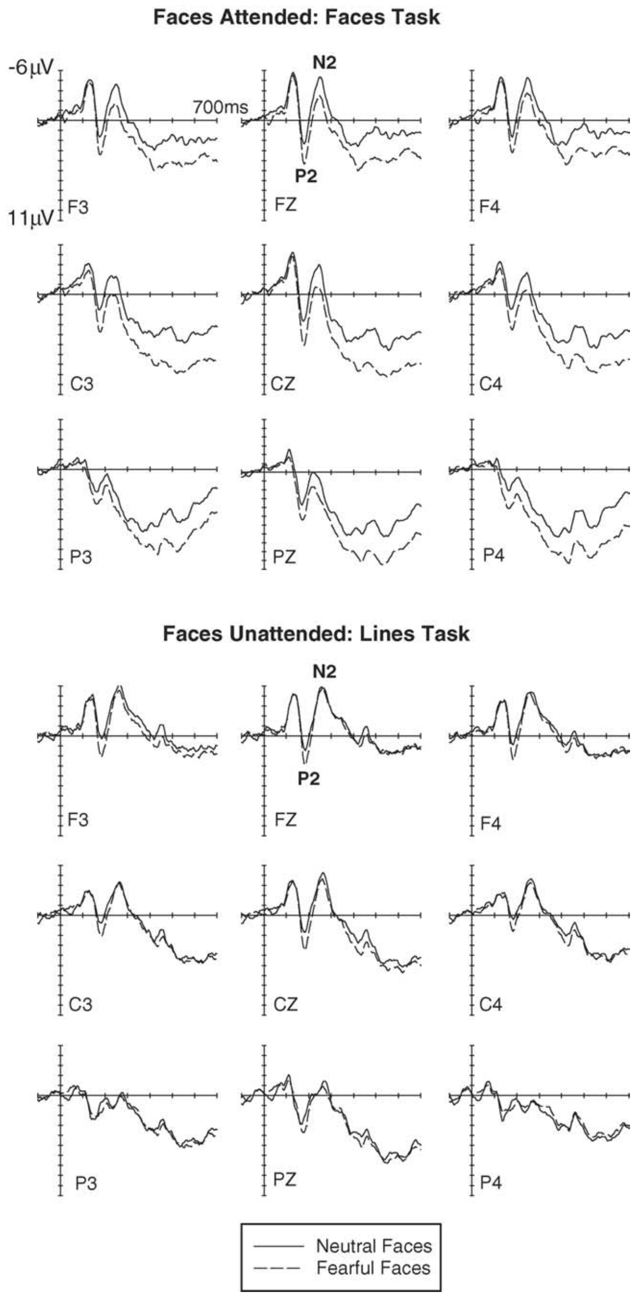

Fig. 2. Grand averaged ERPs elicited in the 700 ms after stimulus onset on non-repetition (non-target) trials in response to stimulus arrays containing a neutral face (solid lines) or a fearful face (dashed lines). Top: ERPs elicited in the Faces task where faces were task-relevant (attended). Bottom: ERPs elicited in the Lines task where faces were irrelevant (unattended).

This was confirmed by statistical analyses. No significant emotional expression effects were found in the earliest analysis window (120–160 ms post-stimulus). In the 160–220 ms post-stimulus interval, significant main effects of facial expression at lateral electrodes ($F(1,11) = 48.0$; $p < .001$) and at midline electrodes ($F(1,11) = 51.0$; $p < .001$) reflected the fact that ERPs to fearful faces were more positive than ERPs to neutral faces. Importantly, there was no indication of any task × facial expression interaction, and subsequent analyses confirmed that early emotional positivities were reliably present in the P2 time range not only in the Faces task ($F(1,11) = 22.8$ and 23.5; both $p < .001$, for lateral and midline sites), but also in the Lines task ($F(1,11) = 5.0$ and 6.4; both $p < .05$, for lateral and midline sites). At lateral posterior electrodes T5/6 (not shown in Fig. 2), where the face-specific N170 component is maximal, ERPs in response to fearful faces also tended to be more positive than ERPs triggered by neutral faces during the 160–220 ms measurement interval, although this difference failed to reach significance ($F(1,11) = 3.6$; $p < .09$).

A very different pattern of results emerged during the subsequent measurement interval (220–300 ms post-stimulus). Although main effects of facial expression were still observed at lateral and midline electrodes ($F(1,11) = 16.1$ and 13.3; both $p < .005$), these were now accompanied by significant task × facial expression interactions ($F(1,11) = 5.5$ and 6.0; both $p < .05$, for lateral and midline sites). Follow-up analyses revealed that significant emotional expression effects were present at both lateral and midline electrodes in the Faces task ($F(1,11) = 27.7$ and 23.3; both $p < .001$). In contrast, facial expression effects were completely eliminated in the Lines task (both $F < 1$). Essentially the same pattern of effects was also found for the longer latency analysis window (300–700 ms post-stimulus). Again, main effects of facial expression at lateral and midline electrodes ($F(1,11) = 26.1$ and 16.1; both $p < .002$) were accompanied by task × facial expression interactions ($F(1,11) = 11.7$ and 12.0; both $p < .01$). While highly significant facial expression effects were present in the Faces task ($F(1,11) = 31.3$ and 23.7; $p < .001$, for lateral and midline electrodes), no reliable ERP differences between arrays containing fearful and neutral faces were found for the Lines task (both $F < 1$).

Findings from previous studies [7,11,15] have shown that the processing of emotional faces is strongly dependent on focal attention. Effects of emotion, as reflected in haemodynamic responses [15] or ERPs [7,11], were found to be entirely eliminated when attention was focused away from critical emotional stimuli. The aim of the present study was to investigate the limits of this attentional gating of emotional information by studying whether attentional task instructions would even affect the processing of emotional faces when these faces are presented centrally within foveal vision, rather than in the periphery of the visual field, as in previous experiments. ERPs were recorded to stimulus arrays containing centrally presented fearful or neutral faces when these faces were either task-relevant and therefore attended (Faces task), or when they were task-irrelevant because attention was directed towards a pair of bilateral lines instead (Lines task).

When faces were attended (Faces task), emotional faces elicited an enhanced positivity relative to neutral faces, which started at about 160 ms after stimulus onset, and remained present throughout the 700 ms analysis interval. These ERP effects were very similar to the result obtained in the Faces task of our previous study [7], where analogous experimental procedures were used, except that faces were presented peripherally, while lines were located close to fixation. They are also in line with other previous findings [3,6,11]. The critical question was whether these effects would remain unchanged in the Lines task, where attention was directed away from the foveal faces. The early phase of the emotional expression effect observed between 160 and 220 ms post-stimulus was indeed preserved in the Lines task. During this time interval, an enhanced positivity was elicited for trials that contained a fearful face relative to trials where a neutral face was presented, even though participants' task was to monitor the lines. The absence of any task × facial expression interaction during this time interval suggests that the initial processing of the emotional expression of foveally presented faces is largely unaffected by attentional task instructions. In marked contrast, emotional expression effects at latencies beyond 220 ms post-stimulus were completely eliminated in the Lines task, suggesting that attentional task instructions had a strong impact on later stages of emotional face processing.

These findings contrast with previous results, which demonstrated an absence of emotional expression effects at early as well as late phases of facial expression processing when attention was directed away from the location of these faces [7,11]. The main difference between the present experiment and these earlier studies is that faces were now presented centrally within foveal vision, rather than in the periphery of the visual field. It would appear, therefore, that under conditions where emotional facial stimuli are presented foveally, and are consequently more difficult to exclude from attentional processing, early stages of facial expression analysis take place irrespective of current task demands, even when the encoding of these stimuli is irrelevant to the task at hand (i.e., judgments of line lengths). It is only at later, more controlled, stages of facial expression processing that attentional task instructions are effective in inhibiting the further analysis of foveally presented affective information.

In this context, it is interesting to note that Pessoa et al. [15] also presented faces in foveal locations, and yet still found strong effects of attention on emotional expression processing, as revealed by fMRI measures. The present findings suggest that these results by Pessoa et al. [15] are unlikely to reflect the attentional modulation of very early stages of facial expression processing, but rather attentional effects on longer latency, more sustained aspects of emotional processing, which are elicited in a controlled and task-dependent fashion after an initial rapid analysis of emotional information is completed. Results from another ERP study, which compared effects of attention on foveal versus peripheral non-emotional visual stimuli [12], also suggest that early stages in the processing of foveal information may remain unaffected by attention. In this experiment, attentional modulations of visual P1 components were only found in response to peripheral events, whereas effects of attention on the subsequent N1 component were present for both foveal and peripheral visual stimuli. These findings highlight the importance of recording electrophysiological responses in addition to haemodynamic activity, as ERPs can indicate the emergence of potentially subtle and transient effects that may not be evident from fMRI results. Neuroimaging measures, by contrast, have the capacity to reveal the precise spatial characteristics of longer lasting brain activations.

While current experimental evidence suggests that the processing of emotional stimuli is strongly dependent on the current focus of spatial attention, other aspects of a task such as the need to explicitly process emotional content seem to be much less important. For example, similar ERP effects of emotional expression processing have been elicited across a number of studies irrespective of whether processing of emotion was explicit, because observers had to judge emotional expressions [7], or incidental, because other non-emotional stimulus attributes were relevant [6,11]. Functional imaging data also reveal that the processing of signals associated with threat-related facial expressions may be independent of the explicit monitoring of emotional content ([5]; see [16]).

Taken together, these strands of evidence would seem to suggest that the allocation of selective spatial attention is critical for processing the emotional significance of attended information, and that other non-spatial aspects of selective attention are weaker modulators of emotional content. The importance of spatial attention is readily observed in situations where it can be successfully directed away from affective content, for example, when task-irrelevant emotional faces are presented eccentrically, and outside of focal attention [7,11]. In such circumstances, it is clear that affective value can be fully gated. In other cases, it may be more difficult to divert spatial attention away from affectively valenced information, as, for example, in the current study, where task-irrelevant expressive faces were presented inside foveal vision. Here, late stages of emotion analysis were directly influenced by manipulations of attention, revealing attention-dependent processing of motivationally relevant stimuli, similar to results in previous studies [7,11]. By contrast, early stages of emotion analysis were largely unaffected by instructions to attend away from the faces and towards competing peripheral stimuli, revealing attention-independent processing of affective information. These findings are consistent with the view that attentional load, spare processing capacity [13], and ease of excluding irrelevant information from the window of spatial attention, are important determinants of the extent to which the emotional significance of perceived information is encoded in the human brain. In conclusion, the present ERP results demonstrate that selective spatial attention gates the processing of emotional facial expression for foveal stimuli at latencies beyond 220 ms after stimulus onset. In contrast, earlier ERP effects of emotional expression appear to be largely immune to manipulations of spatial attention. These results provide new evidence for a special status of foveal stimuli in relation to their ability to trigger early stages of emotional processing irrespective of current task demands. However, they also underline the importance of attention for subsequent controlled stages of emotional expression analysis.

Acknowledgements

This research has been supported by a grant from the Biotechnology and Biological Sciences Research Council (BBSRC), UK. The authors thank Heijo Van de Werf for technical assistance. M.E. holds a Royal Society-Wolfson Research Merit Award.

References

[1] A.K. Anderson, E.A. Phelps, Lesions of the human amygdala impair enhanced perception of emotionally salient events, Nature 411 (2001) 305–309.
[2] J.L. Armony, R.J. Dolan, Modulation of spatial attention by fear-conditioned stimuli: an event-related fMRI study, Neuropsychologia 40 (2002) 817–826.
[3] V. Ashley, P. Vuilleumier, D. Swick, Time course and specificity of event-related potentials to emotional expressions, Neuroreport 15 (2003) 211–216.
[4] P. Bentley, P. Vuilleumier, C.M. Thiel, J. Driver, R.J. Dolan, Cholinergic enhancement modulates neural correlates of selective attention and emotional processing, NeuroImage 20 (2003) 58–70.
[5] H. Critchley, E. Daly, M. Phillips, T. Van Amelsvoort, D. Robertson, A. David, D.G.M. Murphy, Explicit and implicit neural mechanisms for processing of social information from facial expressions: a functional magnetic resonance imaging study, Hum. Brain Mapp. 9 (2000) 93–105.
[6] M. Eimer, A. Holmes, An ERP study on the time course of emotional face processing, Neuroreport 13 (2002) 427–431.
[7] M. Eimer, A. Holmes, F. McGlone, The role of spatial attention in the processing of facial expression: An ERP study of rapid brain responses to six basic emotions, Cogn. Affect. Behav. Neurosci. 3 (2003) 97–110.
[8] P. Ekman, W.V. Friesen, Pictures of Facial Affect, Consulting Psychologists Press, Palo Alto, CA, 1976.
[9] E. Fox, V. Lester, R. Russo, R.J. Bowles, A. Pichler, K. Dutton, Facial expressions of emotion: Are angry faces detected more efficiently? Cogn. Emo. 14 (2000) 61–92.
[10] A. Holmes, S. Green, P. Vuilleumier, The involvement of distinct visual channels in rapid attention towards fearful facial expressions, Cogn. Emo. 19 (2005) 899–922.
[11] A. Holmes, P. Vuilleumier, M. Eimer, The processing of emotional facial expression is gated by spatial attention: evidence from event-related brain potentials, Cogn. Brain Res. 16 (2003) 174–184.
[12] C. Miniussi, A. Rao, A.C. Nobre, Watching where you look: modulation of visual processing of foveal stimuli by spatial attention, Neuropsychologia 40 (2002) 2448–2460.
[13] L. Pessoa, To what extent are emotional visual stimuli processed without attention and awareness? Curr. Opin. Neurobiol. 15 (2005) 188–196.
[14] L. Pessoa, S. Kastner, L.G. Ungerleider, Attentional control of the processing of neutral and emotional stimuli, Cogn. Brain Res. 15 (2002) 31–45.
[15] L. Pessoa, M. McKenna, E. Gutierrez, L.G. Ungerleider, Neural processing of emotional faces requires attention, Proc. Natl. Acad. Sci. U.S.A. 99 (2002) 11458–11463.
[16] P. Vuilleumier, Facial expression and selective attention, Curr. Opin. Psyc. 15 (2002) 291–300.
[17] P. Vuilleumier, J.L. Armony, J. Driver, R.J. Dolan, Effects of attention and emotion on face processing in the human brain: An event-related fMRI study, Neuron 30 (2001) 829–841.
[18] P. Vuilleumier, M.P. Richardson, J.L. Armony, J. Driver, R.J. Dolan, Distant influences of amygdala lesion on visual cortical activation during emotional face processing, Nat. Neurosci. 11 (2004) 1271–1281.
[19] P. Vuilleumier, S. Schwartz, Emotional expressions capture attention, Neurology 56 (2001) 153–158.