Getting emotional with evolutionary simulations: the origin of affective processing in artificial neural networks
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Gamma Flicker Elicits Positive Affect Without Awareness

Abstract
High-frequency oscillations emerged from evolutionary simulations with artificial neural networks as a neural code for both positive affect and attentional processing. Visual 50 Hz flicker, which elicits neural oscillations in the gamma band, has been shown to foster attentional switching, but can it also elicit positive affect? Faces primed by subliminal 50 Hz flicker were explicitly evaluated more positively than when preceded by 25 Hz or 0 Hz. Subliminal 50 Hz flicker, moreover, implicitly facilitated approach reactions, and inhibited avoidance reactions relative to 25 Hz and 0 Hz flicker, when human participants had to select and judge either gender or subjective valence of neutral faces. Attentional switching was facilitated by the 50 Hz flicker. According to the Affect-Gamma hypothesis, also in biological neural networks, high-frequency gamma oscillations may code for positive affect.

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4 This chapter is a modified version of Heerebout, Tap, Rotteveel & Phaf (submitted).
6.1 Gamma Flicker Elicits Positive Affect Without Awareness

Watching television on a cathode ray tube (CRT) screen may influence your mood, regardless of the program that is on. Williams, Mechler, Gordon, Shapley, & Hawken (2004) demonstrated that the refresh rate of the screen could tune the frequency of firing of neurons in the visual cortex and speculated that: “… the synchronization of brain activity to the video refresh rate might be one of the factors that make television viewing addictive” (p. 8288). In the experiment reported here, we indeed found that participants’ affective evaluations of neutral targets were influenced by a, seemingly neutral, flicker that was not consciously detected. Previously, visual gamma flicker and neural gamma oscillations have primarily been implicated in attentional processing. According to the Attention-Gamma hypothesis (Bauer, Cheadle, Parton, Müller, & Usher, 2009; Womelsdorf & Fries, 2006, 2007), attentional processing of stimuli is modulated by synchronized oscillations in the gamma band (40-70 Hz). Bauer et al. (2009), for instance, observed that gamma flicker facilitated attentional shifting to the flicker position. We replicated these attentional results and, moreover, found that neutral stimuli gained a more positive valence as a consequence of a subliminal 50 Hz screen flicker on the position of the stimulus.

Neural oscillations have been hypothesized to be just an epiphenomenon without any function, but that stance has been contradicted by evolutionary computation in our group (Heerebout & Phaf, 2010a, Heerebout & Phaf, 2010b), which simulated the evolutionary development of simple nervous systems under biologically relevant environmental pressures. Oscillations serendipitously emerged in artificial neural networks that controlled agents navigating a virtual environment in search for food while avoiding predators. The emergence of oscillations coincided with a near doubling of the agents’ performance (i.e., the evolutionary fitness), indicating that, in these simulations at least, they had an important function. Further analyses revealed that the oscillations facilitated attentional switching. The simulated evolution implemented response selection in these networks by the resolution of competition (Desimone & Duncan, 1995; Duncan, 1996; Phaf, van der Heijden, & Hudson, 1990) between different response options. The troughs in the oscillations of the winning-node activations provide good opportunities to reset competition and to switch ‘winners’. The fittest agents were able to switch quickly from approach to avoidance when collecting
food. If a foraging agent suddenly detects a predator, fast switching contributes to a successful escape. However, if the agent is fleeing a predator, it should persist in its present mode of action and should not be distracted by food. In the simulations, higher oscillation frequencies, corresponding to higher switching speeds between winners, arose in response to positive stimuli (food) than to negative stimuli (predators). This evolutionary perspective directly linked affect to attentional processing, and gave rise to the novel hypothesis that also in biological brains high frequency (i.e., gamma) oscillations are associated with positive affect.

To test this Affect-Gamma hypothesis, we adapted Bauer et al.’s (2009) experiment, which supported the Attention-Gamma hypothesis. These authors demonstrated that a high-frequency subliminal flicker in the gamma band modulated attention. Our evolutionary simulations led us to predict that this flicker would also elicit positive affect, due to the intrinsic link between affect and attention. Bauer and colleagues presented three Gabor patches on a screen, located equidistantly on an invisible circle, with one Gabor patch showing a subtle change in spatial frequency. In a three alternative forced choice (3AFC) task, participants had to select the deviating (target) patch. A circle flickering at 50 Hz, 25 Hz, or 0 Hz (i.e., no flicker) on one of the three locations preceded one of the patches. The gradient of the flickering circle was set to such a low contrast relative to the background that participants would not consciously detect the flicker. Attentional switching was facilitated in these experiments when the 50 Hz flicker was on the same position as the target patch. The notion that gamma enhances switching is further supported by research in monkeys, which showed that high-frequency gamma band synchronization measured from local field potentials enhanced the speed of change detection (Herrmann, 2001).
To investigate affective priming in our experiment (see Figure 1 for the schematic representation of a 50 Hz trial), the Gabor patches were replaced by grey-scaled images of male and female, emotionally neutral, faces, which were also placed equidistantly on an invisible circle. The stimulus display consisted of either two male faces and one female face, or two female faces and one male face. Participants had to decide whether the deviating target represented a male or a female face (Block 1), while affect was measured implicitly, or whether it made a relatively positive or negative
impression on them (Block 2) in an explicit evaluation task. To check for awareness a flicker-detection task was performed in a third block.

**Figure 2.** The approach-avoidance button stand with the arm in resting position (angle between upper and lower arm 110º) pushing the rest button. Contraction of the biceps muscle leads to arm flexion which is consistently linked with approach actions for the participant. Contraction of the triceps leads to arm extension, which corresponds to avoidance. Due to the positioning of the arm with respect to the shoulder, arm flexion and extension are performed vertically, so that the participant will not explicitly interpret these movements as approach and avoidance.
The affective modulation of attentional switching by oscillations, which emerged in our evolutionary simulations, required only simple neural networks, with only a few levels of nodes, and recurrent connections between at least two levels. The processing capacities of these evolutionary early networks are limited and certainly do not involve conscious processing. We, therefore, expected that these effects could also be measured implicitly (i.e., without any explicit reference to affect or conscious processing of the affect-inducing stimulus). As in the simulations, also in human participants, positive affect has been found to be associated with approach tendencies, and negative affect with avoidance tendencies (Rotteveel & Phaf, 2004), even when these persons were not aware of the affect or its relation to these action tendencies (Phaf & Rotteveel, 2009). The implicit measurement in the first block consisted of a gender judgment task with a response button stand, which is well suited for the assessment of approach and avoidance tendencies (Rotteveel & Phaf, 2004; Phaf & Rotteveel, 2009). The explicit evaluation in the second block was also performed with this stand. It was expected that high-frequency gamma flicker would speed up approach and slow down avoidance in both blocks, and would result in more positive evaluations of the faces.

The stand (see Figure 2) has a resting button, on which the back of the hand should be placed between trials, and two response buttons, positioned at equal distances above and below the resting button, of which one should be pressed in the two-alternative-forced-choice (2AFC) task. The setup allows for the separation of response initiation times (i.e., the interval between the start of target presentation and resting button release) and movement times (i.e., the time between resting button release and response button pressing). Rotteveel and Phaf (2004) observed that only initiation times (i.e., reflecting action preparation), but not movement times (i.e., reflecting action execution), were influenced by the affective value of explicitly evaluated faces. Happy faces decreased approach initiation times (i.e., the start of an arm flexion movement) and increased avoidance initiation times (i.e., the start of arm extension), whereas angry faces did the reverse. To also measure explicit evaluation, participants judged in a 2AFC task with the approach-avoidance stand whether the target face (of deviating gender) made a more positive or a more negative impression. A subliminal 0, 25, or 50 Hz flicker preceded the stimuli always at the target position for 400 ms.
6.2 Method

Participants
Forty-six students from the University of Amsterdam (average age = 22.2 years, \(s.d. = 3.12\); 16 men and 30 women) participated for course credit. The experiment was approved by the institutional review board. Participants who indicated first or second degree epilepsy or migraine headaches were excluded from participation. All participants were right-handed, had normal or corrected-to-normal vision, and signed informed consent. One male participant and one female participant were excluded from further data analysis due to not following instructions. In the exit-interview they reported to have responded in a random fashion.

Design
The experiment consisted of three blocks, of which the first two blocks were performed with the button stand. In these blocks, three faces were presented and arranged on an invisible circle of 9.2°. Each block consisted of 81 trials with either two male faces and one female face (target), or two female faces and one male face (target). In the first block participants had to make a 2AFC decision with the button stand on the gender of the target face and no reference to emotion, affect, approach or avoidance was made. The second block consisted of the explicit affective evaluation of the emotionally neutral target face in a 2AFC fashion on the button stand. Finally, participants completed a flicker detection task, which served as a manipulation check. This third block consisted of thirty trials, in which a flicker (25 Hz or 50 Hz) was randomly presented on one of the three locations. Twelve additional trials (25 Hz or 50 Hz), with a larger contrast difference between flicker patch and background, served to encourage the participants to try to detect the visual flicker. After the flicker, three numbered circles appeared on the three target locations. Participants had to press the one, two, or three key on the numerical pad of the keyboard to indicate where they thought they saw the flicker. Participants were instructed to guess if they had not seen the flicker.

Procedure
The experiment was introduced as a study into attention, in which participants would have to detect and judge faces. The participants were warned that flickers would appear on the screen, but that these would probably not be visible. The experiment consisted of
Gamma Can Be Good

three blocks, which would be separated by short breaks. The first two blocks were performed with the button stand, of which the operation was demonstrated by the experimenter. In the first block no reference to emotion, affect, approach or avoidance was made. Participants were instructed to fixate at the fixation point at the start of the trial and subsequently indicate, as fast and accurately as possible, whether the deviating target face was male or female by pushing the upper or lower button of the button stand. They first practiced for twenty trials and then could choose to continue practicing or to get started with the first block.

After the first block, participants had a short break, in which they could relax their arm muscles. The second block was again practiced under the new instructions (affective evaluation of target faces) for at least twenty trials. Participants were asked to indicate whether the target face was positive or negative by pushing the upper or lower button on the stand. They were specifically instructed not to judge attractiveness of the target face, or any other quality, but to evaluate target faces based on a first impression in an impulsive manner. Finally, participants completed a flicker detection task, which served as a manipulation check.

The instructions in the first two blocks were counterbalanced over participants. In the first block, they either had to push the upper button to indicate a male target face or a female target face, and the lower one for the other gender. In the second block, they either pushed the upper button to indicate a positive target face or a negative target face, and to lower one for the other valence. The four levels of instruction in the two blocks (Block 1 instruction: male up vs. female up; Block 2 instruction: positive up vs. negative up) were randomly, but evenly, assigned to the forty-six participants.

Material en apparatus

In total 506 faces (visual angle of the height: 4.4°; average RGB value 102, 102, 102, corresponding to 19.71 cd/m² on the screen) were prepared with facial composition software (Faces™ 3.0, InterQuest Inc.). Sixteen types of hair, eyebrows, eyes, noses, and mouths for male and female faces were combined to ensure uniqueness of each face. Six types of head shapes, jaw shapes and chin lines also added to gender typicality of the faces. The authors selected the most affectively neutral facial elements for the facial composites. In both blocks, three faces were presented and arranged on an invisible circle of 9.2° (see Figure 3). Each block consisted of 81 trials with either two
male faces and one female face (target), or two female faces and one male face (target). In the experiment 243 unique male faces and 243 unique female faces were presented only once. The remaining twenty faces were repeated in the practice blocks.

All stimuli were presented on a 17" LG Flatron 795FT+ cathode-ray-tube (CRT) monitor set at a 100 Hz frame rate and resolution of 1024*768 pixels. Participants were seated 100 centimeters from the monitor. Because flicker from, for instance, fluorescence lighting might interfere with the gamma flicker on the monitor, all lights were turned off except for a small halogen lamp, which provided indirect lighting in the dimly lit room.

Figure 3. Target display which shows a target female face accompanied by two distracter male faces. The faces were located on the dotted circle (not visible during the experiment) with the midpoint between the eyes located equidistantly from the fixation point.
Figure 4. Screenshot of the oscilloscope when the luminance of the 100 Hz screen was scanned with a light cell for 50 Hz (Panel A), 25 Hz (Panel B) and 0 Hz (Panel C). The flicker was set at higher contrast levels for the screenshots than were used in the experiment.

Visual flicker, which in the experiment always preceded the target, was implemented by alternating background gray with a darker flicker patch (see Figure 4) for 400 ms. The background was set to a fifty percent grayscale. The flicker patch was a
circle (diameter 4.4°) that differed one shade of gray from the background (RGB value = 127, 127, 127 and 128, 128, 128 respectively). The 0 Hz no-flicker condition corresponded to a constant display of the background. A 25 Hz flicker cycle consisted of presenting the flicker patch for 10 ms, and the background for 30 ms. For the 50 Hz condition, flicker patch and background were alternated for 10 ms.

Reaction times were recorded with the Approach-Avoidance button stand (see Figure 2) positioned to the right of the chair of the participant, which was operated with the right hand. The stand consisted of one home button box and two response button boxes, which were positioned above and below the home button (at a distance of 10.3 cm). The home button had to be pushed with the back of the right hand when awaiting a trial (resting position), so that biceps and triceps muscles would exert equal strength (i.e., an isometric position with an angle of 110° between upper arm and lower arm). On this stand participants could easily flex or extend their arm without any need for precise aiming at the response buttons, and without tilting the hand.

The Approach-Avoidance stand allowed for the separation of two different reaction times: the initiation time (IT) from stimulus onset to the release of the home button and the movement time (MT) needed for moving to the response button from the home button. ITs and MTs that deviated more than 2.5 standard deviations from the participant’s average in that condition were considered outliers and removed from the averages. Incorrect responses were removed from the reaction times in Block 1. In Block 2 no incorrect responses could be given. For the ITs congruence indices were calculated. Because Flexion (Fl) and Extension (Ex) are influenced in different directions by affect, their difference represents the affective influences more clearly, and also eliminates attentional influences, which go in the same direction (see also main text). The difference (Fl – Ex) should be smaller in positive than in negative conditions. The 50 Hz condition is expected to be more positive than the 0 Hz and 25 Hz conditions, so that larger values of the congruence index
\[
\frac{(Fl_0 - Ex_0 + Fl_{25} - Ex_{25})}{2} - (Fl_{50} - Ex_{50})
\]
express more congruent affective priming of approach and avoidance.

An additional experimental block was included to investigate flicker detection rate. This manipulation check consisted of thirty trials, in which a flicker (25 Hz or 50 Hz) was randomly presented on one of the three locations. Twelve additional trials (25Hz or 50Hz), with a larger contrast difference between flicker patch (RGB value =
Gamma Can Be Good

124, 124, 124) and background, served to encourage the participants to try to detect the visual flicker. After the flicker, three numbered circles appeared on the three target locations. Participants had to press the one, two, or three key on the numerical pad of the keyboard to indicate where they thought they saw the flicker. Participants were instructed to guess if they had not seen the flicker.

6.3 Results

6.3.1 Affective Priming

Affective priming was most strongly expressed in the explicit evaluations of the target faces (F(2, 86) = 6.18, p < 0.005, ηp² = 0.125, see Figure 5A). Target faces primed by 50 Hz flicker (0.545 ± 0.070) were rated much more positively than when preceded by 0 Hz (0.485 ± 0.088) or 25 Hz (0.486 ± 0.063). Analyses of the initiation times (IT) and movement times (MT) revealed this was mirrored by similar effects in the implicit approach-avoidance task (see Table 1 and Table 2). No affective priming was found in the proportions of errors (F < 1).

Relative facilitation of flexion initiation and relative inhibition of extension occurred in Block 1 (F(2, 86) = 3.20, p < 0.05, ηp² = 0.068, see Figure 5B). In Block 2 this effect of the initiation times only reached marginal significance (F(2, 86) = 2.90, p = 0.06, ηp² = 0.063, see Figure 5C). Attentional facilitation and affective modulation are, however, confounded in these initiation times. With flexion, facilitation and modulation cooperate to decrease initiation times, whereas with extension they counteract. In the congruence index (CI), which opposes flexion and extension initiation times, attentional facilitation is eliminated and only affective modulation remains. CI increases with affectively congruent responding (i.e., positive affect speeds flexion and slows extension). The index differed from zero, both in Block 1 (CI = 23 ms; t(43) = 2.77, p < 0.005, Cohen’s d = 0.845) and in Block 2 (CI = 29 ms; t(43) = 2.26, p < 0.05, Cohen’s d = 0.689). So, even when there were no indications for awareness of the 50 Hz flicker, it modulated both implicit affective responding, and explicit affective evaluation.
Interestingly, only when participants explicitly rated affective value of target faces, a main effect of instruction was found in a 2 x 3 x 2 (Instruction x Frequency x Movement) ANOVA ($F(1, 84) = 5.183$, $p < 0.05$, $\eta_p^2 = 0.110$). Participants were overall faster to respond with an affectively congruent instruction (i.e., flexion-approach responses to positive impressions and extension-avoidance responses to negative impressions; $725 \pm 154$ ms) than with an incongruent instruction (i.e., flexion responses to negative impressions and extension responses to positive impressions; $842 \pm 191$ ms). No other significant effects with instruction were obtained in this study.

The MTs did not show any significant effects in Block 1 and in Block 2 only the main effect of movement reached marginal significance ($F(2, 86) = 3.48$, $p = 0.07$, $\eta_p^2 = 0.075$). With the button stand the execution of extension movements ($237 \pm 27$ ms) is accelerated by gravity, whereas flexion movements ($246 \pm 29$ ms) are slowed down.
Gamma Can Be Good

Table 1 Results (s.d.) in Block 1 as a function of flicker frequency and movement

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>0Hz</th>
<th>25Hz</th>
<th>50Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flexion</td>
<td>Extension</td>
<td>Flexion</td>
</tr>
<tr>
<td>IT (ms)</td>
<td>723 (44)</td>
<td>734 (33)</td>
<td>716 (31)</td>
</tr>
<tr>
<td>MT (ms)</td>
<td>236 (26)</td>
<td>237 (28)</td>
<td>237 (30)</td>
</tr>
<tr>
<td>Error (%)</td>
<td>14.0 (8.3)</td>
<td>18.2 (8.6)</td>
<td>14.3 (9.5)</td>
</tr>
</tbody>
</table>

Table 2 Results (s.d.) in Block 2 as a function of flicker frequency and movement

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>0Hz</th>
<th>25Hz</th>
<th>50Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flexion</td>
<td>Extension</td>
<td>Flexion</td>
</tr>
<tr>
<td>IT (ms)</td>
<td>801 (48)</td>
<td>777 (36)</td>
<td>798 (31)</td>
</tr>
<tr>
<td>MT (ms)</td>
<td>246 (38)</td>
<td>239 (22)</td>
<td>245 (24)</td>
</tr>
</tbody>
</table>

6.3.2 Attention

The Attention-Gamma hypothesis was supported by an attentional facilitation due to the 50 Hz flicker both in Block 1 and Block 2. In Block 1 the ITs averaged over flexion and extension were shorter \((F(2, 86) = 5.24, p < 0.01, \eta_p^2 > 0.109)\) with 50 Hz (710 ms) than with 25 Hz (718 ms), and with 0 Hz (729 ms). In Block 2 the attentional facilitation was again evidenced by shorter ITs \((F(2, 86) = 6.75, p < 0.005, \eta_p^2 = 0.136)\) with 50 Hz (773 ms) than with 25 Hz (791 ms), and with 0 Hz (789 ms). In addition, a similar trend occurred in the proportion errors in Block 1 (0 Hz: 16.1 %; 25 Hz: 15.0 %; 50 Hz: 13.2 %), but did not reach significance \((F(2, 86) = 1.27, \text{NS})\), but made a speed-accuracy trade-off less likely. Less errors were, moreover, made with flexion \((13.6 \pm 9.3 \%)\) than with extension \((15.9 \pm 9.8 \%); F(1, 43) = 4.76, p < 0.05, \eta_p^2 = 0.099)\).
6.3.3 Flicker Detection

Results from Block 3 confirmed that the 50 Hz flicker was not detected (34.2 ± 9.9 %; one-tailed \( t(43) = 0.598, \text{NS} \)) at low contrast levels. The 25 Hz flicker was, however, detected above chance (38.2 ± 11.5 %; one-tailed \( t(43) = 2.77, p < 0.005, \text{Cohen’s } d = 0.847 \)). The fact that the 50 Hz flicker is on average 0.4 % darker than the background, and the 25 Hz flicker 0.2 % darker, argues against the notion that conscious detection would depend on absolute brightness level. At higher contrast levels both 50 Hz (80.5 ± 28.9 %; one-tailed \( t(43) = 10.83, p < 0.001, \text{Cohen’s } d = 3.30 \)) and 25 Hz (85.2 ± 31.0 %; one-tailed \( t(43) = 11.11, p < 0.001, \text{Cohen’s } d = 3.39 \)) flickers could easily be detected (ps < 0.0001).

6.4 Discussion

Subliminal priming by visual gamma flicker, both implicitly and explicitly, raised positive affect towards neutral faces. Previous research has shown that gamma flicker facilitates attention shifting (Bauer et al., 2009), which was replicated in the present study, and that it elicits neural oscillations in the gamma band (Williams et al, 2009; Hermann, 2001). A role of neural oscillations in affective processing has, to our knowledge, never before been postulated. The emergence from the evolutionary simulations of the Affect-Gamma hypothesis, as well as the Attention-Gamma hypothesis, illustrates the productive capacity of this type of computational modeling, which is generally not shared by more traditional modeling methods. Nevertheless, the relationship between gamma oscillations and attentional selection has been researched extensively (Bauer et al, 2009; Womelsdorf & Fries, 2006, 2007), as has the increased attentional flexibility associated with positive affect (Fredrickson, 2004; Olivers & Nieuwenhuis, 2006; Tan, Jones, & Watson, 2009). In our view, the combination of these studies already suggests that fast oscillations enhance attentional flexibility, and may thus be associated with positive affect. A direct empirical link between the two domains has now been obtained in the present study.

6.4.1 Induced Gamma Serves as Unconditioned Reward.

Only one previous study obtained a causal relationship between gamma oscillations and positive affect. Tsai et al. (2009) found with their highly innovative ‘optogenetic’ method (Berridge, 2007) that selective stimulation of dopamine neurons using 50 Hz stimulus trains served as a strong reward signal in a place preference task performed by
Gamma Can Be Good
genetically modified mice. Tsai and collaborators could control the timing of dopamine release by neurons in the ventral tegmental area, because these neurons were genetically engineered to respond to light pulses. In one room the neurons were stimulated with high frequency light pulses (50 Hz) and in another with low frequency light pulses (1 Hz). Only the high-frequency stimulations induced a conditioned place preference, indicating that the stimulation served as a reward signal. The mice developed a strong preference for the room that had been reinforced by the gamma oscillations, even though the total number of light flashes was equal in both stimulation conditions. Gamma frequency stimulation, however, elicited dopamine transients (phasic increases in release) that were more than 50 times higher than after low frequency stimulation, which makes it likely that the rewarding effect was mediated by dopamine.

In our study, the gamma flicker may also have induced positive affect by frequency-dependent activation of dopamine release through projections from visual areas to midbrain dopamine neurons. In the evolutionary simulations (Heerebout & Phaf, 2010a, Heerebout & Phaf, 2010b), there was no capacity for developing neuromodulation, but an association between dopamine and approach behaviour has certainly been proposed before (e.g., Berridge, 2007). Dopaminergic function may thus further specify the processes linking gamma oscillations and affect, beyond the level that could be obtained in the simulations. In addition, a causal relationship between gamma and attentional flexibility, as suggested by the evolutionary simulations, was supported by another optogenetic study from the same group. Sohal and colleagues showed that gamma oscillations induced in the prefrontal cortices of these transgenic mice enhanced information transmission (2009). According to our hypothesis, synchronized gamma oscillations both signal positive affect and increase the flexibility of information transmission. Long-range synchronization (e.g., Gregoriou, Gotts, Zhou, & Desimone, 2009), moreover, may turn gamma oscillations into a more global gamma state modulating both attentional and affective processing.

6.4.2 Empirical Associations between Gamma and Positivity.
Implicit support for the affect-gamma hypothesis comes from two other studies that measured gamma oscillations, but presented alternative accounts not directly related to affect. Popescu et al. (2009) observed an increase in gamma synchronization between basolateral amygdala and striatum during multi-session reward learning, but attributed
this to an affect-independent learning process instead of to positive affect. Microelectrode recordings in cats revealed that the synchronization only developed after two conditioning sessions with the rewards. In our view, the gamma synchronization is not related to a general learning process, but constitutes the result of this process and signals the acquired positive value of the conditioned stimuli.

Jung-Beeman et al. (2004) found that insight solutions to a verbal remote-associates task were associated with a burst of gamma band activity over right anterior temporal positions, as measured with electroencephalography on the scalp of their human participants. These sudden insights, which are also called Aha! experiences, contrast with the results of analytic, conscious search strategies that work in a slower, more systematic fashion but rarely yield very innovative solutions. The insight often leads to strong emotional, particularly positive, reactions, as when, for instance, the punch line of a joke ‘breaks through’. We propose that the gamma burst in this study is not so much associated with the process of gaining insight, but with the positive affect coinciding with the insight.

6.4.3 A Neural Code for Positive Affect.

Affect is most commonly understood in terms of subjective feelings of good and bad, and is thus inextricably linked to conscious states. Alternatively, affect has been conceived in terms of unconditioned stimuli, which also seem to preclude further analysis. An evolutionary grounding of affect, which goes beyond such intuitive conceptions and allows for unconscious affective processes (Berridge & Winkielman, 2003), however, has been suggested by Johnston (2003). He proposed that positive affect constitutes the neural code of those conditions that enhance evolutionary fitness, whereas negative affect codes for fitness-reducing circumstances. Similar reasoning enabled Heerebout and Phaf (2010b) to conclude from their evolutionary simulations that food was affectively positive and a predator negative, and that positive affect is coded by high-frequency (gamma) oscillations. For the evolutionary development of oscillations relatively simple networks, in which there is no room for conscious processing, sufficed. The findings in the present experiment demonstrate that also in biological networks affect may be analyzed in component processes and need not be equated with conscious states.