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PLASTICITY CHANGES IN THE BRAIN IN HYPNOSIS AND MEDITATION

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Abstract

Neuroscientific evidence interprets both hypnotic trance induction and different meditation traditions as modified states of consciousness that emphasize attention, concentration and the letting go of thoughts, but they differ in terms of sensory input, processing, memory, and the sense of time. Furthermore, hypnosis is based on the suggestibility of a person and meditation on mindfulness; therefore it is not surprising to find differential brain plasticity changes. We analysed shared and non-shared neural substrates using electroencephalography (EEG), positron emission tomography (PET), and functional magnetic resonance imaging (fMRI). Most pronounced EEG changes were in deep as compared to light hypnosis (step-by-step induction) and in arm levitation where suggested movement was perceived as external. In a within-subject-design changes in brain activity during hypnosis and Tibetan Buddhist meditation were compared. High amplitudes in alpha frequency bands were most pronounced with meditation at frontal positions and with hypnosis in central and temporal locations. Significantly greater activity in theta 2 band was observed only with hypnosis in both hemispheres. PET cerebral activation patterns of imagery-mediated learning were analysed in hypnosis in a within-subject-design. Compared with baseline the learning of high-imagery words was associated with (i) more pronounced bilateral activation in the occipital cortex and prefrontal areas and (ii) improved memory performance. Visual illusion in hypnosis was studied with fMRI, analysed with Granger Causality Mapping, showing changes in the effective connectivity relations of fusiform gyrus, anterior cingulate cortex and intraparietal sulcus. Little is known about the neurobiological basis of the *process* of enhancing cognitive and emotional traits in meditation. In a longitudinal fMRI study attention abilities through intensive Soto-Zen meditation were investigated before (baseline), after training (6 months) and at follow-up (9 months). After six months differences were observed in the left inferior and left superior frontal gyrus; after 9 months activations in the left precuneus. Taken together, the findings advance understanding of the neural mechanisms that underlie hypnosis and meditation. Further studies with a greater sample size are needed to explore the differences and commonalities of hypnosis and different meditation techniques.

Key words: brain plasticity, EEG, fMRI, hypnosis, meditation, PET

Introduction: What is essential in hypnosis and meditation? A neurobiological perspective

A major problem in defining hypnosis and meditation is the ambiguity of the terms. 'Hypnosis' was derived from the Greek word 'hypnos' meaning sleep[1] and is characterized by focused attention, a heightened compliance with suggestion, an awareness of internal images and a reduced ability to think critically. Hypnosis extends to different aspects of the subject's personal awareness and may turn their experience into a different form of reality (Revenstorf, 1996; Peter, 2009).

The term 'meditation' comes from the Latin 'meditatio' which originally indicated every type of physical or intellectual exercise. Meditation generically refers to an extremely wide range of practices including Buddhist, Christian, Islamic, Hindu and Jewish traditions. Thus, defining meditation involves the need for a precise understanding of meditation as a scientific explanandum taking into account the importance of various traditions (Lutz et al., 2007). Furthermore, certain aspects that have been described as 'self-hypnosis' by one scientist might well be described as 'meditation' by another scientist and vice versa (Tart, 2001).

It is important to take the problem of terminology into consideration when the impact of meditation and hypnosis on brain function, attentional and emotional states is investigated. The word 'meditation' refers to a broad variety of practices, and failure to make distinctions would be akin to the use of the term 'sport' to refer to all sport disciplines as if they were essentially the same (Lutz et al., 2008). Hence, descriptions of various meditation practices imply that there are differences in brain function associated with different types of meditation (Lutz et al., 2004). Lutz et al. (2008) suggested a useful framework in which meditation techniques are grouped into two main categories:

1) focused attention; directing and sustaining attention on a selected object, such as breathing, scriptural passage, mantra, religious pictures, etc. A typical example is Shamatha[2], a single pointed, focusing, pacifying and calming meditation technique. The key concept is the concentration of mind. If the mind is wandering meditators show a disengagement of attention from distraction and a shift of attention back to the selected object.
2) open monitoring: no explicit focus on objects. This meditation technique is characterized by meta-attention. Vipassana is an example of a form of meditation that includes any meditation technique that cultivates *insight* including contemplation, introspection, analytic meditation and observations about experience.

Common aspects and differences between hypnosis and meditation techniques

The search for the neural correlates that characterize hypnosis and different forms of meditation is a topic of great interest in neuroscience. From a neurobiological point of view, both hypnotic trance induction (e.g. Rainville et al., 2002; Halsband, 2006) and meditation (e.g. Holroyd, 2003; Lutz et al., 2007) can be interpreted as a *modified state of consciousness* which reflects a dynamic change of brain activity. The experiencer feels a qualitative alteration in the overall pattern of mental functioning such that their consciousness is radically different from the way it functions ordinarily (Tart, 1972); this is linked to plasticity chances in the brain. Consciousness is a multifaceted concept. According to Laureys (2005) it can be viewed as having two major components: i) awareness

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of the environment and of the self (i.e. the content of consciousness); and ii) the level of vigilance or arousal. Hypnosis and different kinds of meditation traditions emphasize attentional focus, concentration and letting go of thoughts. So, at a first glance hypnosis and meditation seem to have lots in common.

However, there are also crucial behavioural differences between hypnosis and meditation. A main difference is that hypnosis is based on the suggestibility of a person and meditation is focused on mindfulness (Holroyd, 2003). Table 1 directly compares hypnosis and two kinds of meditation techniques: focused attention, Shamatha; and open monitoring, Vipassana. The table was modified and extended after Tart (2000, 2001) and it shows differences and commonalities in terms of interactions, sensory input and processing, concentration, memory, sense of time and stress coping.

In hypnosis a special rapport with the hypnotist is of crucial importance, whereas in the meditation context independence from needing social relationships is expected. The special rapport between the hypnotist and the hypnotized person as well as the absorption of the voice of the hypnotist takes a key role, whereas such interpersonal interactions are not of relevance for meditation techniques. Meditation, however, interacts with independence, empathy for all living beings and bliss.

In hypnosis sensory processing is limited and determined by suggestions. Sensory processing is focused and deliberately controlled in Shamatha meditation. In Vipassana the input/processing is mainly aware-controlled.

Hypnotic trance is accompanied by a heightened suggestibility, in which suppressed memories may be experienced. In hypnotic trance age-regression or age-progression can be used therapeutically to allow the subjects to experience or re-experience all forms of inner sensory, perceptual or emotional events. Concerning memory processing, results

Table 1. Comparison of hypnosis with Shamatha and Vipassana meditation

		Meditation	
	Hypnosis	***Shamatha*** *focused attention*	***Vipassana*** *open monitoring*
Interactions	special rapport	independence, empathy for all living beings, bliss	
Input/Processing	limited and determined by the suggestion	focused, deliberately controlled	meta-attention, aware-controlled
Concentration	⟶	increased concentration	⟵
Memory	*explicit learning*: increased memory for high-imagery material, reduced memory for abstract material improved *implicit learning*	inactive, focus on the present	
Sense of Time	time distortion, progression/regression	focus on the here and now	
Stress Coping	⟶	reduction of stress	⟵

showed an improved recall of high-imagery word pairs under hypnosis, but a decrease in the ability to learn abstract word pairs (Halsband, 2004, 2006). Furthermore, the use of implicit knowledge and implicit information processing play a key function in hypnosis. In contrast, memory does not play a major role in meditation: the meditator is asked to remain in the 'here and now'; the main focus of meditation is the present.

Both, hypnosis and different forms of meditation practices show beneficial effects for coping with stress. It is possible to relax one's mind, soul and body. The techniques can also be used as prevention methods to avoid harmful effects of stress induction. People suffering from stress are often exhausted, lack concentration and have a weakened immune system. Using meditation and hypnosis people have a powerful tool to calm down and to disentangle themselves from their stressful environment.

From a neurobiological point of view a critical question to be addressed is as follows: what are the shared and non-shared neural substrates in hypnosis and in different forms of meditation?

Neurophysiology: EEG studies

Hypnosis

Attentional control, concentration, imagination, mental relaxation, altered perception of the environment, disengagement of the discursive, and critical analytical reasoning are all characteristic elements of hypnosis (Halsband, 2008). Numerous EEG studies showed changes in neuroelectrical activity. There is evidence for a higher proportion of occipital alpha waves in high suggestibles as compared to lows (e.g. London et al., 1968; Bakan and Svorad, 1969; Engstrom et al., 1970; Ulett et al., 1972; Morgan et al., 1974; Edmonston and Grotevant, 1975), but this finding was not replicated by some other studies (Barabasz, 1983; Perlini and Spanos, 1991).

Significantly greater activity in high alpha (11.5–13.45 Hz), beta (16.5–25 Hz) and high theta (5.5–7.5 Hz) band was reported in highs in the right parietal cortex (Crawford et al., 1996). Several authors reported an increase of the power in the theta frequency band (Tebecis et al., 1975; Crawford, 1990; Sabourin et al., 1990; Graffin et al., 1995; De Pascalis et al., 1998). In contrast to meditation, increased beta activity in the right occipital cortex was measured (Ulett et al., 1972) and a significant power increase in the right parietal region (Crawford et al., 1996). In addition, there is evidence for an increase in the gamma band power around 40 Hz – more pronounced over the right than the left hemisphere (De Pascalis et al., 1998) and in the parieto-midline-to-right temporal areas (Schnyer and Allen, 1995).

High-hypnotizables – as compared to lows – also produced a higher theta 1 amplitude (4–6 Hz) in bilateral frontal and right posterior areas (De Pascalis et al., 1998). In the bilateral frontal cortex the same subjects showed a smaller alpha 1 (8.25–10 Hz) amplitude. High and low hypnotizables were also distinguished by means of changes in mismatch negativity across hypnosis and pre- and post-hypnosis conditions (Jamieson et al., 2005). Isotani et al. (2001) made an important point: already before hypnosis was induced, high and low susceptible subjects were in different brain electric states. In high-hypnotizables posterior brain activations were most pronounced whereas lows presented with anterior weighted brain activation patterns.

Fingelkurts et al. (2007) published a single case study of a highly susceptible subject (virtuoso). During hypnosis there were alterations in all studied frequency bands (delta, theta, alpha, beta, and gamma) which were stable after one year. Results gave evidence for local and remote cortex functional connectivity changes. Interestingly, the authors reported a disruption in the functional synchrony among neural assemblies within the left frontal cortex which is consistent with Gruzelier′s findings (2000) of hypofrontality and left-hemisphere inhibition.

Taken together the results are very heterogeneous. This may be partly caused by the great variability in intracerebral source location, EEG dimensionality, the technology and methods of analysis used as well as by the different ways (e.g. direct/indirect suggestions, confusion techniques) and various stages of trance induction (e.g. auto-focusing, arm levitation, deep trance experience). Most studies failed to disentangle the different state patterns of the brain during specific periods of the trance induction (see next chapter).

Arm levitation and deep trance induction

We present a single case EEG-study on a highly susceptible person (male/aged 25)[3] who was guided through a hypnotic trance induction. The experimental setting comprised the measurement of 64 channel EEG plus peripheral physiological measures. The participant was seated on a chair approximately one meter in front of the hypnotist. A 15 min baseline session was recorded consisting of 5 min sitting relaxed with eyes open, 5 min with eyes closed, and 5 min of reading a text from a book. Subsequently a hypnotic induction (26 min) was recorded, subdivided into the following phases: i) auto-focussing and introduction, ii) fostering mental and physical relaxation, iii) arm levitation, iv) step-by-step instructions to allow the subject to enter a deeper state of trance (counting from 1 to 10), v) metaphoric story, trance anchoring, and vi) termination, when the hypnotic trance was brought to an end.

For statistical analysis, the EEG data were first corrected for eye movements. Phases with large amplitude movement artefacts were removed from the analysis. A Fast Fourier Transform (FFT) was applied using a window size of 2 seconds. The resulting Fourier amplitudes were converted into spectral power by squaring. The power spectral density (PSD) in the bands of interest was defined as the mean of the Fourier coefficients of 4 to 7.5 Hz (theta band), 8 to 12 Hz (alpha band), and 25.5 to 70 Hz (gamma band). The region from 47 to 53 Hz was ignored due to the possible 50 Hz humming artefact. In the following, the results of the two phases with the most profound changes in brain activations are reported: stepwise trance induction and arm levitation phase. These two phases led to distinct changes in theta, alpha and gamma frequency bands. Full details will appear later (Hinterberger and Halsband, to be submitted).

Hypnotic suggestions may dissociate physical movements from normal conscious volition (Kirsch and Lynn, 1997; Weitzenhoffer, 2000; Heap and Aravind, 2002). A typical example is arm levitation, which is an important sign for verifying a trance induction. It is a frequently demonstrated hypnotic phenomenon in which self-induced movements are attributed to an external source (Oakley, 1999; Heap and Aravind, 2002; Raz and Shapiro, 2002; Blakemore et al., 2003;). The experience of such an anomalous control is different from the normal conscious experience of a similar movement produced intentionally (Haggard et al., 2004). We gave the hypnotized subject the suggestion that his arm is being raised upwards by a helium balloon. This suggestion resulted in the appropriate movement. The left arm of our subject started to rise on itself after the suggestion and remained upraised.

During the arm levitation phase changes in the global PSD could not be clearly observed on the time series graph. However, a brain mapping statistical analysis

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uncovered interesting results, comparing the time after the arm began to levitate (min 12 to 13) with the time before (min 11 to 12) (see Figure 1a). At minute 12 the left arm started to raise and remained uplifted until the termination phase of the session. During arm levitation global significant decreases were found in the theta band. Most pronounced decreases were measured in central areas ($t < -5$, $p < 0.001$). Alpha power revealed a more significant increase in the occipital and parietal cortex as compared to frontal areas (occipital $t > 4$, $p < 0.001$). In contrast, central areas including sensory motor regions showed a trend towards a decrease. This decrease of activity becomes clearly significant over the right and left hemispheric arm and hand area when looking at the sensory motor rhythm (SMR) in the range from 12–16 Hz ($t < -3$, $p < 0.001$). Gamma power increased significantly in the occipital and temporal cortex ($t > 4$, $p < 0.001$). In contrast, a strong decrease was found in central areas ($t > -3$, $p < 0.002$) (Fig. 1a).

Our findings are in agreement with the PET-study by Blakemore et al. (2003) who reported differential brain activity in a deluded passive movement condition where subjects attributed the movements to an external source as compared to an identical active movement. The authors concluded that as a result of hypnotic suggestion, the functioning of a cerebellar-parietal network is altered so that self-produced actions are experienced as being external.

In a separate analysis, the step-by-step deep trance induction was systematically examined. The step-by-step-induction is a technique in which the hypnotized person goes deeper and deeper into hypnotic trance. In our study the subject was instructed to

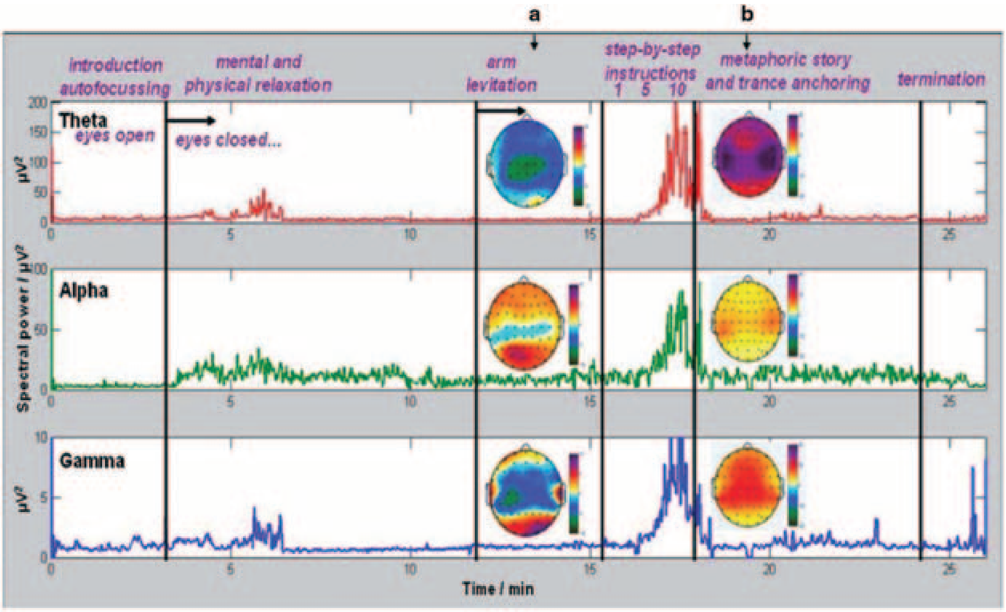

Figure 1. Time series graphs of the global power spectrum density (PSD) in the theta, alpha and gamma bands. The colour maps in the arm levitation phase (Fig. 1a) indicate an increase (yellow/red) or decrease (blue/green) of the spectral power. The arm levitation phase was compared with the activity before the levitation started. The maps on the right (Fig. 1b) show the spatial distribution of the activity in the last half of the stepwise induction (counting from 6 to 10) compared to the time before (counting from 1 to 5). The colour maps show significance values (t-test) in the range from –10 (blue) to 10 (red) for the arm levitation and from –20 to 20 for the stepwise instruction. (This figure is available in colour online)

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go on an imaginary journey in hypnosis. The further the participant had to walk in imagination downstairs the deeper was the level of experienced hypnotic trance.

In the deep hypnotic condition (stepwise induction 6–10) differential brain activity changes occurred that were not present in light hypnotic conditions. During the last half of the stepwise trance induction phase a highly significant increase in all frequency bands was observed. The participant was sitting completely motionless. For a more detailed examination a statistical comparison (t-test) was calculated for each electrode separately between the time interval counting from six to ten (44 seconds) and counting from one to five (50 seconds). The colour maps in Figure 1b show highly significant increases in all frequency bands. In the theta band ($t > 10.0$, $p < 0.001$) a strong global increase was measured with a special emphasis on sensory motor areas bilaterally. In the alpha band the increases were less pronounced ($t > 3$, $p < 0.002$ over sensory motor areas) but significant – again with a higher activation rate bilaterally in sensory motor areas. In addition, within the gamma band strongest activations were recorded in parietal, central, and frontal brain regions ($t > 4$, $p < 0.001$ over central areas) (Fig. 1b).

Our findings are in agreement with the results by Katayama et al. (2007) who reported differences in brain activity in deep and light hypnosis. Furthermore, our most pronounced increases in activity within the sensory-motor areas in alpha-, gamma- and theta frequency bands should be interpreted in the context of motor imagery. Interestingly, other findings confirm a relationship between motor imagery and hypnotic responding (Konradt et al., 2005).

Meditation

During meditation sensory input is diminished (Carrington, 1998; Dietrich, 2003). In meditation sustained concentration and heightened awareness can be achieved by focusing attention on mantra, breathing rhythm, or a number of other internal or external events (Herzog et al., 1990; Lou et al., 1999; Lazar et al., 2000; Newberg et al., 2001; Dietrich, 2003). This is accompanied by changes in neuroelectrical activity and indicated by increases in alpha, gamma and theta waves (e.g. Anand et al., 1961; Banquet, 1972; Corby et al., 1978; Benson et al., 1990). Under meditation – as compared to relaxation – an increase in alpha amplitudes was observed (Wallace, 1970; Wallace and Benson, 1972; Banquet, 1973; Glueck and Stroebel, 1975) which appeared to be most pronounced in the frontal cortex (Kesterson, 1989; Sudsuang et al., 1991; Jevning et al., 1992). An increase in theta power was reported by several authors in different types of meditation (e.g. Pan et al., 1994 for Qi Gong; Kubota et al., 2001 for Zen breath counting; Aftanas and Golocheikine, 2002 for Sahaja yoga; Kjaer et al., 2002 for yoga nidra). Lutz et al. (2004) found in eight long-term practitioners of the Kagyüpa- and Nyingmapa- schools (compared to 10 non-practising students) a high amplitude activity and a marked phase synchronization in the gamma-band (between 25 and 42 Hz), especially in lateral fronto-parietal locations (see also Banquet, 1973).

Coromaldi et al. (2004) investigated the EEG-activity in a Zen-master – a highly experienced subject – during deep meditation. The results of the deepest meditation stage showed an increase in the alpha band (8–13 Hz) and theta-power (4–7 Hz) at all locations and most prominent in the left parietal cortex. In contrast, there was a reduction of beta-activity (15–28 Hz) over the right hemisphere. Aftanas and Golosheikine (2005) made an important point: in long-term meditators (Sahaja yoga tradition) changes in EEG activity were dynamical and dependent on the arousal level. Increasing the arousal level (viewing aversive video clips) desynchronized activities in theta and alpha frequency bands.

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Taken together the results are controversial. There are different kinds of meditation techniques and therefore the findings are heterogeneous. The heterogeneity is additionally caused by the great variability in the degree of experience in meditation (Halsband, 2008). It is also difficult to compare recent and older studies because technology and analytical procedures have changed.

Intersection: hypnosis and meditation

There is an increasing interest in plasticity changes in the brain in hypnosis compared to different types of meditation (Holroyd, 2003; Otani, 2003; Grant and Rainville, 2005). In the present study a within-subject design was used to allow for a direct comparison of brain changes in hypnosis and a Tibetan form of meditation (Vajrayana-Buddhism).

EEG activity was recorded under hypnosis and meditation in a high-suggestible (according to the German version of the Harvard Scale of Hypnotic Suggestibility) male subject (43 years) who practised meditation for 18 years and has started every day with meditation exercises. 32 channel EEG was recorded with an electrode cap at standard positions of the extended international 10/20 system. Data were analyzed with the Fast-Fourier-Transformation for the following frequency bands: theta 1 (3.71–5.57 Hz), theta 2 (5.57–7.42 Hz), alpha 1 (7.42–9.28 Hz), alpha 2 (9.28–11.13 Hz), beta (13–30 Hz) and gamma (30–49 Hz). The frequency windows were defined individually as suggested by Klimesch (1999) and Aftanas and Golocheikine (2001) using alpha-peak-frequency of the subject as a reference point.

Most striking differences were found in alpha 1 and theta 2 frequency bands. As a common characteristic for both hypnosis and meditation – in comparison to control conditions – significant increases in the power of the alpha 1-band became apparent. However, in the meditation condition, a highly significant increase in alpha 1 power was predominantly observed in the frontal cortex. In contrast, under hypnosis significant increases were most pronounced in central and temporal locations (see Fig. 2a).

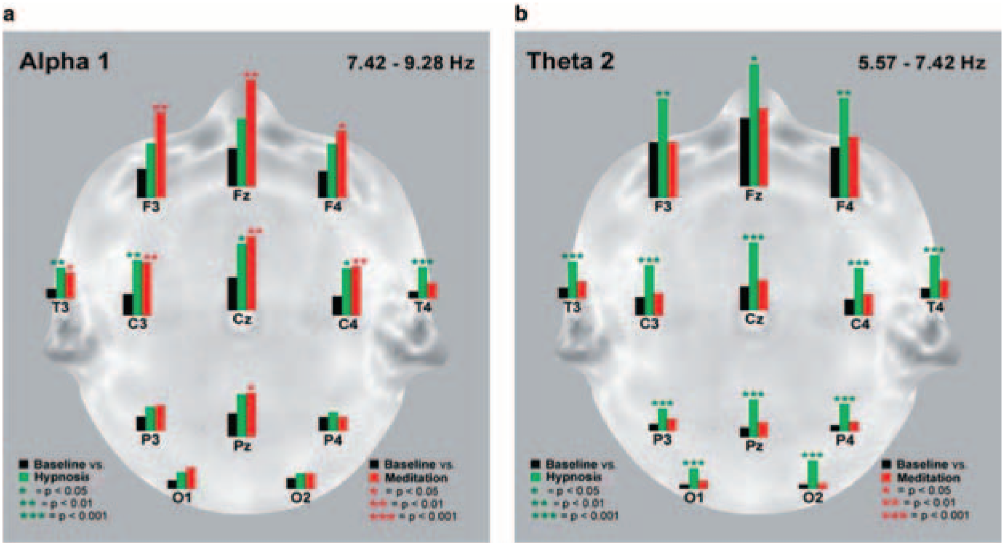

Figure 2. Power spectra of the alpha 1 (Fig. 2a) and theta 2 (Fig. 2b) frequency bands for hypnosis and meditation compared to baseline. The respective significance level is marked by stars: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$ (Halsband, 2008). (This figure is available in colour online)

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Interestingly, significantly greater activity in theta 2 band was observed only under hypnosis, but not under Tibetan meditation. Theta band activity changes in hypnosis were observable in both hemispheres (see Fig. 2b).

Taken together brain plasticity changes in hypnosis can be clearly differentiated from neurophysiological changes in meditation. Further research is needed to systematically compare shared and non-shared neuronal substrates in different kinds of meditation traditions and different levels of hypnotic trance.

Brain imaging tools in neuroscience

Functional magnetic resonance imaging (fMRI) and positron emission tomography (PET)

A major breakthrough in the study of the cortical plasticity during hypnosis and meditation was the use of modern brain imaging techniques. In this fascinating world of neuroscience, efforts for an improved understanding of the brain mechanisms involved were made by the use of positron emission tomography (PET) and functional magnetic resonance imaging (fMRI). The PET tomograph is an external detection system that maps the distribution of an injected radiotracer in three-dimensional space. The masses of the positron and electron are converted into two photons emitted in directly opposite directions (180°) with the same energy. By contrast, fMRI is a non-invasive method based on the increase in blood flow to the local vasculature that accompanies neural activity in the brain. Changes in the oxygenation level of the blood, the so-called BOLD (Blood Oxygenation Level Dependent) effect, occurs as a consequence of neuronal activity. The magnitude of change in signal intensity can be used as an indirect measure of excitary input to neurons (Logothetis et al., 2001). A detailed description of brain imaging tools was given by Otte and Halsband (2006). Earlier, we reported a preponderance of commonalities in the activation patterns yielded with fMRI and PET (e.g. Halsband et al., 1998, 2002; Krause et al., 1999a, b; Mottaghy et al., 1999, 2000; Schmidt et al., 2002); these findings were confirmed by other studies (e.g. Schall et al., 2003).

The decision to choose one or another neuroimaging modality depends on the task of interest. Major advantages of fMRI are 1) that this technique does not need radioactive tracers which is of value especially in studies with repetitive measurements and follow-up investigations; and 2) a better spatial and time resolution. However, special skills are needed by the experimenter to ensure that subjects would relax with their heads restrained in the noisy MRI scanner environment. Although it is possible to reduce the noise level to about 70 decibels with the help of a special fMRI-compatible headset, this background noise remains an inadequate interference. In fMRI-studies on hypnotic trance induction we found it useful to keep the noise level stable in order not to interrupt the state of deep relaxation (Halsband, 2009).

There is hope for an introduction of a ‘silent fMRI’. This promising new approach was introduced by Schmitter et al. (2008). The authors reported about a new low-noise echo-planar imaging (EPI) that is optimized for auditory fMRI measurements. The sequence produces a narrow-band acoustic frequency spectrum by using a sinusoidal readout echo train and a constant phase encoding gradient. This could be a most useful tool for future studies on hypnosis and meditation.

Hypnosis

Several authors have shown that plastic changes in neuronal activity occur after hypnotic trance induction (e.g. Grond et al., 1995; Crawford et al., 1998; Szechtman et al., 1998; Maquet et al., 1999; Rainville et al., 1999, 2002; Faymonville et al., 2000; Kosslyn, et al., 2000; Halsband, 2004; 2006; Spiegel and Kosslyn, 2004; Egner et al., 2005).

In a PET-study by Maquet et al. (1999) subjects were allowed to listen to pleasant autobiographical memories. During hypnosis significant activations were observed in a complex neural network including occipital, parietal, precentral, prefrontal and cingulate cortices. Using PET, Rainville et al. (2002) reported that hypnotic relaxation involved an increase in occipital regional Cerebral Blood Flow (rCBF), a decrease in cortical arousal and a reduction in cross-modality suppression (disinhibition). In contrast, increases in mental absorption during hypnosis were associated with rCBF increases in a distributed network of cortical and subcortical structures previously described as the brain's attentional system.

Using event-related fMRI and EEG coherence measures, Egner et al. (2005) were able to show that individual differences in hypnotic susceptibility are linked with the efficiency of the frontal attention system, and that the hypnotized condition is characterized by a functional dissociation of conflict monitoring and cognitive control processes. Muzur et al. (2006) concluded that hypnosis and suggestion are methods of external manipulation with frontal-lobe functions. The effectiveness of hypnosis in producing analgesia has been well documented (e.g. Faymonville et al., 1997, 2000, 2006; Rainville et al., 1999). Faymonville and co-workers came to the conclusion that the midcingulate cortex (Brodman area 24) mediates the hypnosis-induced analgesia. They reported that the reduced nociception under hypnosis is mediated by an increased functional connectivity between the midcingulate cortex and insular, pregenual, frontal and pre-SMA regions as well as brainstem, thalamus and basal ganglia.

Hypnotic visual illusion

In hypnosis, perceptual changes may occur. This is accompanied by changes in brain activation. Using PET, Kosslyn et al. (2000) reported that hypnotic illusion of colour induced blood flow changes consistent with actually observing colour. It was found that colour areas were activated under hypnosis when subjects were asked to perceive colour, whether they were actually shown the colour or a grey-scale stimulus. It was concluded that among highly hypnotizable subjects, observed changes in subjective experience in hypnosis were reflected by changes in brain function.

But, critically speaking, in the study by Kosslyn et al. (2000) colour change suggestions were only given in hypnosis, whereas imagination instructions were given outside hypnosis. Hence it remains unclear whether differences between the two conditions reflect the effects of suggestion or hypnotic trance or a combination of the two. In other words, it is not possible to conclude from the data that hypnotic trance was the factor that created the differences in brain activity. In cooperation with the University of Maastricht we used fMRI and an experimental design in which the same suggestions were given in and outside hypnosis (Otto, 2007). RCBF changes were measured using fMRI with short time repetition to obtain high temporal resolution data. Granger Causality Mapping (Roebroeck et al., 2005) was used to identify voxel time courses for inferring directions of neural interactions and information flow.

Three subjects were asked to see a grey-scale in colour or a colour pattern in a grey scale (visual illusion) or to see a colour pattern in colour and a grey scale as a grey scale (natural suggestion). The same instructions were given in hypnosis and without hypnosis.

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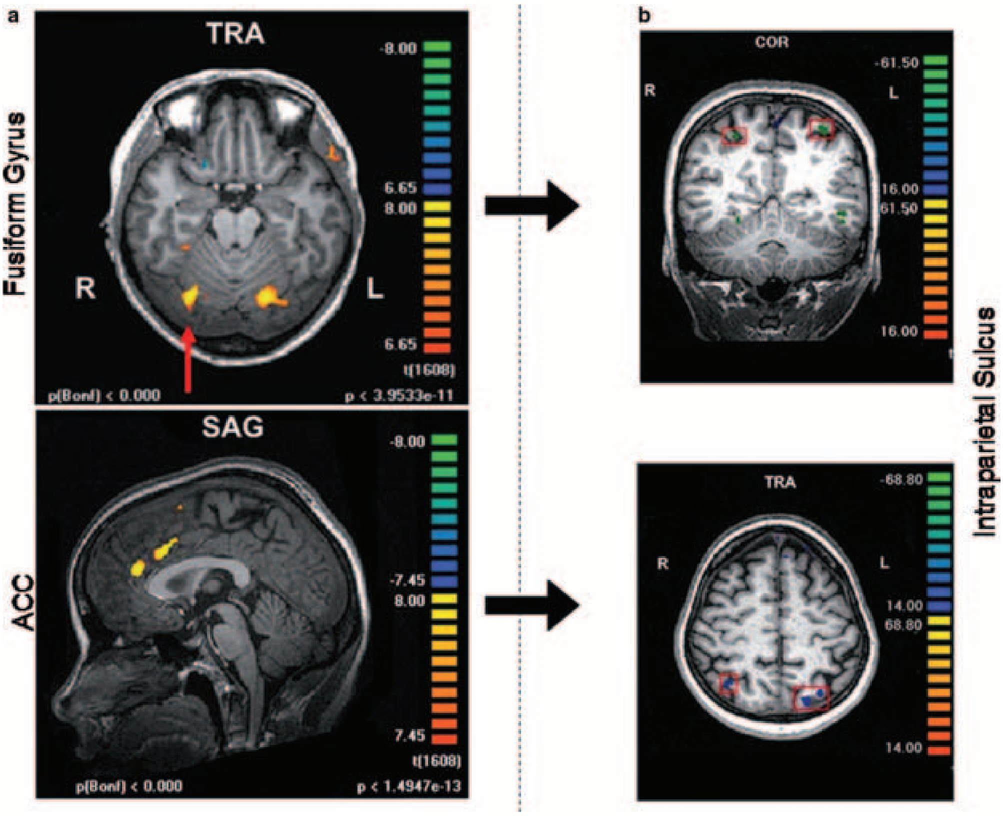

Figure 3. Hypnotic suggestions to perceive a grey chart in colours resulted in a significant bilateral increase in activity in the fusiform gyrus (Fig. 3 a, top) and in two foci in the anterior cingulate cortex (ACC, Fig. 3a, bottom). Both regions were found to receive bilateral input from the intraparietal sulcus (Fig. 3b) (Otto, 2007). (This figure is available in colour online)

A contrast analysis between the individual hypnotic illusions and perceptual conditions revealed a significant increase in activity bilaterally in the fusiform gyrus (Fig. 3 a, left) and in two foci in the anterior cingulate cortex (ACC, Fig. 3b, left).

When a grey chart was presented in hypnosis and subjects were asked to perceive it in colours, both the right fusiform gyrus (Fig. 3a, right) and the ACC (Fig. 3b, right) were found to receive bilateral input from intraparietal sulcus. Taken together, results indicate in the visual illusion condition in hypnosis changes in effective connectivity relations of fusiform gyrus, anterior cingulate cortex and parietal areas (Otto, 2007).

Learning under hypnosis

A key question to be addressed is whether an enhanced utilization of high-imagery associations positively affects learning under hypnosis (Bongartz, 1985; Crawford and Allen, 1996; Halsband, 2004, 2006). Crawford and Allen (1996) systematically investigated the relationships between the recall of low- and high-imagery word-pair associations and hypnotic susceptibility. Recall was significantly better for high-imagery compared to low-imagery words. In a more sensitive within-subjects design, high-hypnotizables recalled more paired association words during hypnosis than waking. In contrast, lows did not differ. However, in a between-subjects design, hypnotic level was not a moderator of performance during hypnosis. Taken together, the findings by Crawford and Allen (1996) are controversial and do not allow a general conclusion that the use of imagery strategies in high-hypnotizables increases their learning ability. Furthermore, the neural correlates of learning under hypnosis remained unclear.

Using O–15 water PET in a within-subject design the neural mechanisms of encoding and retrieval of high-imagery words in high-hypnotizables were systematically investigated under hypnosis and in the waking state (Halsband, 2006). Subjects were assessed on the German version of the Harvard Group Scale of Hypnotic Susceptibility (HGSHS Form A). Seven highly hypnotizable subjects with a susceptibility score >7 were assigned to the PET study. Their mean age was 25.4 years (sd 3.1).

A verbal episodic memory task was used. During encoding subjects were visually presented 12 word pairs. Words implemented in the study were two-syllable German high-imagery nouns that were of high frequency (Meier, 1964). Afterwards, the subjects were asked to retrieve the corresponding word-pair associate after having been randomly presented the first of the two words of each word pair (retrieval). Two reference conditions were used, either containing 12 single nonsense words (two-syllable pseudo words that obey German spelling rules) or 12 nonsense word pairs.

The word pairs were semantically unrelated and therefore difficult to associate (e.g. monkey-candle). Word pairs were of high-imagery according to a German linguistic database of 800 nouns on a scale between 6 and 7 (Baschek et al., 1977).

Results indicate during the encoding phase in hypnosis a most pronounced occipital activation and an increased prefrontal activity When word pairs were retrieved previously learned under hypnosis, a stronger activation in the prefrontal cortex and cerebellum, as well as an additional bilateral activation in the occipital lobe were reported (Halsband, 2006).

Highly hypnotizables benefit from hypnosis when they have to acquire word pairs with high-imagery content. Halsband and Herfort (2007) found that highly hypnotizable subjects show a better learning performance of high-imagery word-pair associations than do low-hypnotizable subjects. However, the ability to retrieve abstract word-pair associations (e.g. wisdom-moral) strongly decreased when encoding took place in trance.

Meditation

Attentional regulation is a common cognitive function associated with divergent meditation methods (Cahn and Polich, 2006). Several authors have demonstrated that meditation practice alters brain activity in areas important for sensory, cognitive and emotional processing (e.g. Newberg and Iversen, 2003; Lazar et al., 2005; Doraiswami and Xiong, 2007; Jha et al., 2007; Srinivasan and Baijal, 2007) concluded that an increased activity in the bilateral prefrontal cortex and the cingulate gyrus already appears at an early stage of meditation. Using fMRI, Baron et al. (2007) tested subjects with at least four years of regular meditative practices from different meditative traditions (Tibetan Buddhists, Zen Buddhists, Yoga practitioners) and different experiences in meditation practices and durations. Results indicate that brain activities in the dorsal lateral prefrontal cortex and anterior cingulate cortex varied over the time of a meditation session and differed between long- and short-term practitioners. In the more practiced subjects regional brain activations correlated with better sustained attention and attentional error monitoring.

With regard to *focused attention* meditation (example: Shamatha) neural activations associated with selective attention including the temporal-parietal junction, intraparietal sulcus, ventro-lateral prefrontal cortex and frontal eye-fields are of crucial importance

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(Corbetta and Shulman, 2002). Furthermore, brain areas engaged in sustaining attention, such as right frontal and parietal cortex and the thalamic structures, are involved (Kastner et al., 1999). Long term meditators showed less amygdala activation during meditation compared to novices (Slagter et al., 2007). Interestingly neural networks associated with conflict monitoring, i.e. the dorsal anterior cingulate cortex and dorsolateral prefrontal cortex seem to play an important role in both focused meditation and hypnosis (Coull, 1998; Raz et al., 2006).

In open monitoring, meta-attention meditation (for example, Vipassana), the awareness of the subjective features of a given moment and its emotional tone are of crucial importance. One may therefore argue that brain regions involved in focusing or sustaining attention onto a specific object are of less importance. But instead processes that rely on meta-representation in the brain are critically involved including the anterior insula, somatosensory cortex and anterior cingulate cortex (Damasio, 2000; Craig, 2000). Recently, 15 Vipassana meditators were compared with 15 non-meditators. Results indicate stronger activation in the rostral anterior cingulate cortex and bilaterally in the dorsal medial prefrontal cortex (Hoelzel et al., 2007).

So far only a few studies are available that specifically compared aspects of anatomical correlates between meditators and non-meditators (Lazar et al., 2005; Hoelzel et al., 2008; Luders et al., 2009; Vestergaard-Poulsen et al., 2009). Lazar et al. (2005) reported that brain regions associated with attention, interoception and sensory processing were thicker in long-term meditators (Vipassana) as compared to a non-meditating control group including the prefrontal cortex and anterior insula. Differences in prefrontal cortex thickness were most pronounced in the most experienced and older subjects.

Hoelzel et al. (2008) found differences in grey matter concentration associated with long-term meditation (Vipassana). These findings are consistent with the results by Vestergaard-Poulsen et al. (2009) who reported increased grey matter density in meditators in the left superior and inferior frontal gyri, the left fusiform gyrus, the lower brain stem and the bilateral anterior lobes of the cerebellum. Most recently Luders et al. (2009) found larger hippocampal and frontal volumes of grey matter in long-term meditators (range of meditation: 5–46 years) using different meditation techniques (Zazen, Samatha, Vipassana, etc.). Taken together the results suggest that long-term meditation can induce changes in brain structure. However, it remains an open question whether alterations in brain functions like enhanced attentional capacities are caused by long-term meditation training itself or by individual personality differences. Therefore longitudinal studies are needed to follow individuals over time in response to mental training.

Zen meditation and attention: a longitudinal study

Taken together, there have been two major approaches in meditation research: 1) studies on advanced and highly skilled meditators, and 2) studies on novices who usually started meditation training in a clinical setting as adjuvant therapy. However, as yet little is known about the neurobiological basis of the *process* of enhancing cognitive and emotional traits. Therefore we tried to bridge the gap between the two before mentioned experimental designs by conducting a longitudinal study on meditation training with different types of assessment strategies including fMRI.

We conducted an fMRI study to examine longitudinal meditation effects in a within-subject design. Seven persons without previous meditative experience but the motivation to take part in an intensive Zen meditation training (Soto) during 6 months were systematically evaluated. Assessments (psychological, neurophysiological) were conducted before (baseline), after the training (6 months) and in a follow-up (9 months). Our main

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focus was on the process of enhancing attention abilities through meditation. By studying the neural mechanisms underlying attention we also analyzed their relation to changes of emotional and socio-behavioural traits. Full details will appear in Mueller and Halsband (to be submitted).

A useful experimental paradigm in studying the neural correlates of (focused) attention and conscious perception – as described in the study of Carter et al. (2005) – is binocular rivalry. Binocular rivalry involves perceptual alternations between competing monocular images. Because transitions between each monocular view occur without any change of the physical stimulus, perceptual processes can be clearly distinguished from those due to stimulus characteristics. While this paradigm has traditionally been of interest to visual scientists, it has recently gained wider prominence as a tool for studying visual consciousness and focused attention. It could be shown in previous studies that observers were able to voluntarily control the alternation rate of the competing images. We used face and house images as stimuli which were adopted with friendly permission from previous fMRI work (Tong et al., 1998; Meng and Tong, 2004).[4] Based on the biased competition model of selective attention we expected our participants to enhance the attended percept while suppressing the unattended one. Moreover we expected an improvement in the ability to voluntarily control the duration of the attended percept during the course of the six months intensive meditation training.

The subtraction method was applied to highlight regions where the activity is maximally different in the active (selective attendance to house resp. face) vs. passive ('look passively') conditions. At baseline (see figure 4a) these differences were clearly marked by activations in the right and left middle frontal gyrus (BA 8, 11), in the right and left precentral gyrus (BA 4, 6) and in the right inferior frontal gyrus (BA 47). After 6 months of Zen meditation training (see figure 4b) smaller differences were observed and characterized by activations in the left inferior (BA 45) and left superior frontal gyrus (BA 22). After 9 months (see figure 4c) only activations in the left precuneus (BA 31) were found, a structure which was shown earlier to play an important role in mental imagery and memory processes (e.g. Halsband et al., 2002, Lundstrom et al., 2003). Our data suggest an enhanced capacity for selective attention after intensive meditation training. Behavioural measurements indicate that the ability to focus on the desired percept while suppressing the undesired one improved during the course of the meditation training. Full details will appear later (Mueller and Halsband, to be submitted).

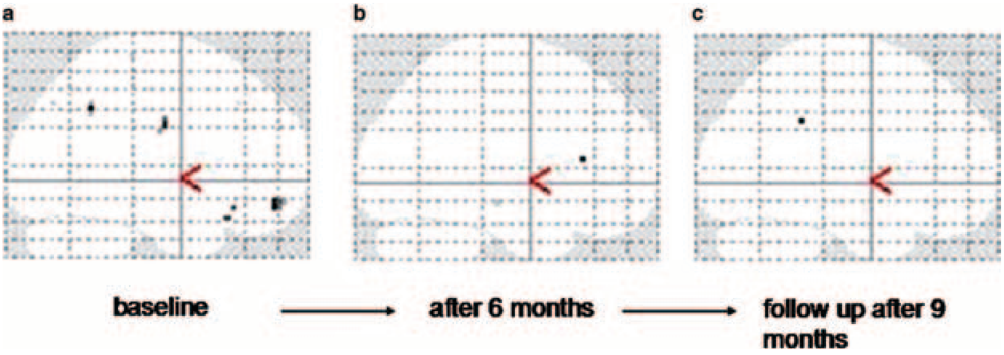

Figure 4. Contrasts active condition – passive condition for a single subject at baseline (4a), after 6 months Zen meditation training (4b) and after 9 months follow up (4c). (This figure is available in colour online)

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Conclusions and future perspectives

This study examined the brain mechanism of hypnosis and meditation. We analysed shared and non-shared neural substrates and studied brain plasticity changes using functional magnetic resonance imaging (fMRI) and positron emission tomography (PET). We also used electroencephalography (EEG). The decision to choose one or the other brain imaging technique depended on the task of interest.

Hypnosis

Hypnosis is a state of focused attention, concentration and inner absorption (Laureys et al., 2004). It is generally established by an induction procedure. Under hypnosis the imagery content is polymodal and perceptual changes may occur. As yet, the neural mechanisms underlying hypnosis remain poorly understood.

Using fMRI visual illusion effects in hypnosis were systematically investigated and analysed with Granger Causality Mapping. Perceptual illusions were accompanied by changes in brain activations in fusiform gyrus, anterior cingulate cortex and parietal areas. In a separate study, EEG was used to analyse the mechanisms of a hypnotic trance induction.

Meditation

Meditation is a very heterogeneous term and it refers to a broad variety of different practices. Therefore it is not surprising that there are differences in brain function associated with different types of meditation techniques. We adopted the framework by Lutz et al. (2008) and compared brain activation patterns in meditation techniques with focused attention (example: Shamatha) and open monitoring, meta-attention (example: Vipassana).

We conducted a longitudinal study on Zen meditation training with different types of assessment strategies including fMRI. Our main focus was on the process of enhanced sustained attention abilities through meditation as well as developing a mindful attitude. The experimental paradigm used in combination with fMRI was ‘binocular rivalry’ which has recently gained wider prominence as a tool for studying (visual) consciousness and focused attention. Our findings suggest an enhanced capacity for selective attention after a 6-month meditation training.

Comparison of hypnosis and meditation techniques

Common aspects and differences between hypnosis and meditation techniques were critically discussed. As a common denominator, both hypnosis and different kinds of meditation traditions emphasize attention, concentration and letting go of thoughts. One of the main purposes of both hypnosis and meditation techniques are to understand and gain control of our emotions. Both methods show beneficial effects for stress reduction and help us to improve our immune system. But this common goal is achieved by different means. Whereas in hypnosis a special rapport with the hypnotist and suggestions play a central role, it is independence from needing social relationships that plays a key role in meditation exercises. In addition, it was argued that hypnosis and meditation show differences in terms of sensory input, processing, memory, and sense of time. Therefore it is not surprising to find brain plasticity changes in hypnosis that can be clearly differentiated from neurophysiological changes in meditation.

Using EEG changes in brain activity in hypnosis and Vipassana meditation these were directly compared in a within-subject design. Striking differences were found in

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alpha and theta frequency bands. Further research is needed to disentangle plasticity changes in hypnosis and different types of meditation and to systematically compare shared and non-shard neuronal substrates in different stages of hypnotic trance induction.

One main purpose of our current studies was to try to understand different states of consciousness in terms of the subjective meanings individual subjects bring to them. Some of the findings are based on single-case studies. Single case studies are a challenging approach, e.g. to analyze in detail the progression of a hypnotic trance or to directly compare within the same subject the different brain activations in hypnosis and meditation. The principles of evidence based practise in single case studies are well established (Crombie, 1996) and accepted as a legitimate and useful method research (Klein and Myers, 1999). However, we are well aware of the fact that these findings are limited and difficult to generalize. There are individual differences in the experience of a hypnotic trance and meditation skills which are not taken into account. Thus, further studies with a greater sample size are needed to explore the differences and commonalities of hypnosis and different meditation techniques.

In an integrative working programme, PET and/or fMRI could be used to measure regional activation effects in combination with neurophysiological recordings of the brain (EEG, magnetoencephalography, MEG). This ensures simultaneously a high spatial (fMRI, PET) and a high temporal resolution (EEG, MEG) in the range of milliseconds.

Another interesting future perspective is the integration of the analysis of neurochemical changes, e.g. stress hormones (cortisol, β-endorphin) and neurotransmitters with functional brain imaging techniques. Recently a new system was introduced (Siemens MR-PET) which is capable of performing simultaneously measurements of anatomy, functionality and biochemistry. MR-PET holds great promises for differentiating the functional and biochemical basis of hypnosis and meditation.

Notes

1 Nowadays it has been well established that distinct differences exist between hypnosis, sleep and normal waking consciousness.

2 The semantic meaning of shama is ‘pacification’, ‘the slowing or cooling down’, or ‘rest’ (Ray, 2004).

3 The recordings were carried out using a 72 channel QuickAmp EEG amplifier system (Brainproducts GmbH, Munich, Germany) and a 64 channel electrode cap with actively shielded Ag/AgCl electrodes (ANT, Netherlands). EEG was recorded from DC to 70 Hz at a sampling rate of 250 S/s and a resolution of 0.07 microvolt. Additionally, ECG, vertical and horizontal eye movements, respiration and skin conductance from the non-dominant hand were recorded.

4 Perception of face and house images is associated with the activation of two specific regions. One of them, the fusiform face area (FFA) responds at least twice as strongly to faces as to other non-face stimuli. In contrast, perception of houses and places is strongly associated with a bilateral activation in the parahippocampal area (PPA).

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