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Self-generated happy and sad emotions in low and highly hypnotizable persons during waking and hypnosis: laterality and regional EEG activity differences

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Self-generated happy and sad emotions in low and highly hypnotizable persons during waking and hypnosis: laterality and regional EEG activity differences

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Abstract

EEG correlates of self-generated happy and sad emotions during counterbalanced conditions of waking and hypnosis were investigated in 16 low ('lows') and 15 highly ('highs') hypnotizable men, as assessed by the Harvard Group Scale of Hypnotic Susceptibility and the Stanford Hypnotic Susceptibility Scale, Form C. Using log mean spectral magnitude, 11 frequency bands (3.5–42 Hz) were evaluated at frontal (F3, F4), central (C3, C4), and parietal (P3, P4) regions. As anticipated, only parietal hemispheric differences in low alpha activity (7.5–9.45 Hz) differentiated between emotions, whereas mid and high alpha activity (9.5–13.45 Hz) did not. There was significantly less low alpha activity in right parietal (P4) in sad than happy emotions, supportive of prior research showing relatively greater right hemispheric involvement in negative than positive emotions. Yet, overall there was more low alpha activity in the left parietal (P3) region. During sadness only in waking, low beta (13.5–15.45 Hz) activity was greater in the right than left frontal region, greater in the left than right central region, and similar in both hemispheres in the parietal region. As anticipated, in comparison to lows, highs showed significantly greater hemispheric asymmetries (right greater than left) in the parietal region in high theta (5.5–7.45 Hz), high alpha (11.5–13.45 Hz), and beta activity between 16.5 and 25 Hz – all frequency bands that are associated with sustained attentional processing. Results support prior research (for reviews, see Crawford, 1994a; Crawford and Gruzelier, 1992) that highs have greater sustained attentional abilities than do lows, which is reflected in different regional brain dynamics. Future EEG research needs to address narrower EEG frequency bands, as well as consider the moderating effects of hypnotic susceptibility level in observed hemispheric asymmetries.

Keywords: Emotion; EEG; Electroencephalography; Laterality; Hypnosis; Hypnotic susceptibility

1. Introduction

Basic emotions utilize specific cortical and subcortical brain systems, and have been differentiated by regional brain electrical activity and cerebral metabolism activity (e.g., Davidson, 1992a,b; Derryberry and Tucker, 1992; LeDoux, 1989; Pribram, 1967, 1981, 1991; Simonov, 1986; Tucker, 1981). Anterior-posterior regional differences as well as hemispheric differences in EEG activity have been noted. Emotionally-laden thoughts associated with approach-related and withdrawal-related stimuli that

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are environmentally generated (e.g., watching film clips) are more likely associated with distinct patterns of left and right frontal and anterior temporal EEG alpha activity (e.g., for reviews, see Davidson, 1992a,b; Fox, 1994), while recall of past positive and negative personal emotional events may produce different patterns of frontal, temporal and parietal EEG activity (e.g., Harmon and Ray, 1977; Kukiken and Mathews, 1986–87; Stenberg, 1992; Tucker and Dawson, 1984). Furthermore, the attentional demand of external or internal attention focus on emotional stimuli has led to different brain activation patterns (Aftanas et al., 1994; Cole and Ray, 1985; Ray and Cole, 1985; Valentino and Dufresne, 1993).

The importance of the functional asymmetry of the brain for the organization of emotions is commonly accepted, although the relative contribution of the left and right hemispheres is still under dispute (e.g., Tucker and Williamson, 1984). Observed EEG asymmetries associated with emotional states may be moderated by enduring personal traits or states of affect intensity (Davidson et al., 1990; Tomarken et al., 1990), repressive and defensive coping styles (Kline et al., 1994; Lorig et al., 1994–95; Wexler et al., 1992), and depression (Davidson et al., 1985; Dawson et al., 1992; Henriques and Davidson, 1990, 1991; Tucker et al., 1981). Not yet addressed systematically is the proposal by Levy et al. (1983) that the large variability in hemispheric activity may be due, in part, to individual variation in patterns of asymmetric parietotemporal hemispheric activity.

To investigate further the differential involvement of the two hemispheres as well as anterior and posterior regions of the brain during emotion, the present study examined EEG correlates of self-generated happy and sad emotional states in both waking and hypnosis conditions. A wider range of EEG activity, ranging from 3.5 to 42 Hz, than is typically addressed in emotion research was evaluated. Finally, to evaluate how enduring trait differences may moderate observed EEG activity, subjects were healthy young adults who differed in levels of hypnotic susceptibility – a stable cognitive/personality trait that has a high test-retest reliability over 25 years (Piccione et al., 1989) and correlates with imaginal, absorptive and sustained attentional abilities (e.g., Crawford, 1982; Crawford et al., 1993a; Tellegen and Atkinson, 1974).

1.1. EEG correlates of emotion

Within electrophysiological studies of emotion, much emphasis has been placed upon the evaluation of frontal, temporal and/or parietal regions within the broad alpha frequency range of 8 to 13 Hz with little consideration of functionally different components within the alpha range or of other EEG frequency bands that may be of importance. In this section, we review prior EEG findings and argue for the evaluation of narrower EEG frequency bands that may help elucidate emotional processing.

1.1.1. Alpha activity (8–13 Hz)

An underlying assumption in emotion EEG research is that increased 8–13 Hz alpha activity is associated with decreased cortical activity in that cortical region (Shagass, 1972), and that the relative contribution of the two hemispheres, and regions within the hemispheres, to different emotional states can be inferred by evaluating the relative power of alpha activity (Davidson, 1992a,b). Thus, as the alpha rhythm becomes desynchronized (reduces in amplitude as evidenced by decreased magnitude or power), greater cognitive and emotional processing is commonly inferred to occur in that region (for an excellent discussion of the evolving views of EEG synchronization and desynchronization, see Barlow, 1993). Less relative alpha power in the right than left frontal region, and sometimes anterior temporal area, is correlated with greater dysphoric affect when processing film clips, while an opposite relation is observed in happy affect (Davidson et al., 1990, 1979; Ekman et al., 1990; Jones and Fox, 1992; Sobotka et al., 1992; Tomarken et al., 1990). These findings also suggest that the right hemisphere is more involved in negative than positive emotions. Other research points toward parietal involvement during the recall of personal positive and negative past emotional experiences or sexual arousal (Collet and Duclaux, 1987; Tucker and Dawson, 1984; but see Tucker et al., 1981).

The present study introduces the discrimination between low, medium and high alpha activity to emotion research. Within the standard 8–13 Hz alpha band there are functionally different rhythmic components (e.g., Barlow, 1993). Factor analytic work indicates two (Hermann and Schaerer, 1986) or three (Andresen et al., 1984; Iznack, pers. comm.) discrete alpha frequency band factors. Coppola (1986, Coppola and Chassey (1986) found a parietal maximum for a 7–10 Hz band and an occipital maximum for a 10–13 Hz band. Research also indicates that individuals who self-reported poor sustained attentional abilities generated significantly more low alpha spectral magnitude than did high sustained attention subjects while performing tracking or decision-making tasks, while mid and high alpha bands did not discriminate between them (Crawford et al., 1995b; Crawford and Vasilescu, 1995c). At higher alpha (above 10.5 Hz) general mental workload, not just attention, may lead to desynchronization (Mecklinger and Bosel, 1989, as in Sterman et al., 1994; Pfurtscheller and Klimesch, 1991). Klimesch and his associates (e.g., Klimesch et al., 1993; for a review, see Klimesch, 1995) found good memory performers have a significantly higher mean alpha frequency than those with bad memory performance. Fluctuations in alertness have a greater effect on lower than higher alpha frequencies (Gale and Edwards, 1983), and increased lower alpha activity is associated with poorer cognitive performance (e.g., Bosel, 1992; Klimesch et al., 1990). Given these findings, we anticipated that low alpha activity would be more likely to discriminate between positive and negative emotional states than either mid or high alpha activity.

1.1.2. Theta activity (3–7.5 Hz)

The theta rhythm has been implicated in emotional and cognitive processes (for reviews, see Schacter, 1977; Simonov, 1986). Increased theta activity has been linked with 'visceral pleasure' (Walter, 1959, cited in Stenberg, 1992), and found during sexual arousal (Cohen et al., 1976), laboratory-induced stress (Schwarz et al., 1982), and recall of pleasant and unpleasant personal memories (Stenberg, 1992; for a review, see Simonov, 1986). Stenberg (1992) found the right lateral frontal (F7) site, most close to the limbic system of those sites recorded at the scalp, showed the greatest theta activity increase during induced emotions. Furthermore, right-lateralized frontal theta was stronger in high-anxious than low-anxious subjects during recalled emotional memories (Stenberg, 1992). Intracranial stimulations of the cingulate gyrus led to reports of euphoria that were accompanied by increased theta rhythm activity at the scalp (Talairach et al., 1973).

Low and high theta frequency bands may be associated with, respectively, drowsiness/inactivity and efficient/attentive performance (for a review, see Schacter, 1977). Within the broad theta band, two types of theta were differentiated by Vogel et al. (1968): (1) 'Class I inhibition', which is associated with general inactivity and drowsiness, and is more desynchronized; and (2) 'Class II inhibition' which is more regular and higher in amplitude, and is associated with cognitive activity (for review, see Schacter, 1977), and represents "a selective inactivation of particular responses so that a continuing excitatory state becomes directed or patterned" (Vogel et al., 1968, p. 172). Distinct theta oscillatory activity at 6–7 Hz, most predominant at the frontal midline (Fz) site, has been reported to be associated with focused cognitive activities (e.g., Katayama et al., 1992; Laukka et al., 1995; Nakagawa, 1988). Theta synchronization is related to the encoding of episodic information, with amplitude increasing with increasing task demands (for a review, see Klimesch, 1995).

A robust finding is that highly hypnotizable persons generate more theta power than do low hypnotizables during rest, cognitive performance, and cold pressor pain dips (e.g., Graffin et al., 1995; Sabourin et al., 1990; for reviews, see Crawford, 1994a,b; Crawford and Gruzelier, 1992), and show increases in theta production during hypnosis (e.g., Sabourin et al., 1990). The enhanced theta activity among highs has been proposed to reflect their greater focused attentional abilities (for a review, see Crawford, 1994a). In a study of cold pressor pain, Crawford (1990) found highly hypnotizable persons generated significantly more high theta (5.5–7.5 Hz) than did lows at frontal, temporal, parietal and occipital regions. Additionally, theta power shifted hemispheric dominance in the anterior temporal (T3, T4) region for the highs only when they concentrated on the pain (left greater than right) and successfully eliminated the perception of pain with hypnotic analgesia suggestions (right greater than left); lows showed no significant asymmetries or shifts.

In the present study we anticipated anterior and posterior hemispheric differences in low and high theta activity during induced emotional conditions. Furthermore, we anticipated that highly hypnotizable subjects would generate more high theta magnitude activity than lows. Given the hemispheric differences observed during pain and hypnotic analgesia (Crawford, 1990), we also anticipated greater high theta hemispheric asymmetries favoring the right hemisphere for the highs than lows, particularly in the parietal region (Levy et al., 1983).

1.1.3. Beta activity

Higher frequency EEG activity appears in many cortical areas and may be indicative of different types of emotional, cognitive and attentional processes. Certain beta frequency oscillations found within specific beta frequency bands are thought to reflect states of neuronal networking of specific cortical and subcortical cell assemblies during which cognitive and sensory inputs are being processed and acted upon (e.g., Basar, 1990; Lopes da Silva, 1991).

Beta activity, particularly in the temporal region, has been implicated in emotional processing. Ray and Cole (1985; Cole and Ray, 1985) found temporal beta (16–24 Hz) activity to be more abundant in negative than positive emotion, possibly because of a deeper involvement in the negative emotion. Schellberg et al. (1990) reported a trend towards greater right temporal beta activity (26–45 Hz) in positive than negative emotion. Stenberg (1992) found higher right temporal beta activity in positive than negative emotion conditions. Temporal beta has also been correlated with ratings of pleasure (Matousek et al., 1983). This data supports the model of Heller (1993) which proposes that the right parietotemporal region is essential in the overall modulation of emotional states. Given this, in the present study, we anticipated greater right parietal activation in the beta frequencies, particularly those within the 16 to 25 Hz range.

Further support for this proposal is found in several studies that found that higher activity levels of 16–20 Hz is associated with vigilance in dogs (Lopes da Silva, 1991; Lopes da Silva et al., 1970), baboon and squirrel monkeys (Rougeul et al., 1979), and humans (Makeig and Inlow, 1993). In the alert cat, focusing of attention is associated with increased activity in the 35–45 Hz range in motor and parietal association areas (Bouyer et al., 1987). While these studies did not address individual differences, it may be that those individuals with excellent focused attentional abilities or those who are focusing more strongly on a task, may show regional enhancements of beta activity reflective of task activity. Levy et al. (1983) proposed that the large variability in hemispheric activity may be due, in part, to individual variation in patterns of asymmetric parietotemporal hemispheric activity. Since highly hypnotizable individuals have greater absorptive and focused attentional abilities (see below), one would anticipate greater hemispheric asymmetries – among those EEG frequencies associated with focused attention – favoring the right hemisphere during emotional processing, particularly in the parietal region (Heller, 1993), among high than low hypnotizables.

A high frequency, low amplitude EEG rhythm centered around 40 Hz within a narrow band (36–44 Hz) has been found by Sheer and his associates (for reviews, see Sheer, 1976, 1989) to be a covariate of focused cognitive activity and uncorrelated with other beta bands or muscle activity. When the 40-Hz rhythm synchronizes, alpha desynchronizes and vice versa (Pfurtscheller et al., 1994). This 40-Hz rhythm appears to be from localized cortical neurons that receive thalamic afferents (Steriade et al., 1990) and has "been taken to be indicative of a mechanism linking or temporally coordinating the distributed cortical representation of stimuli" (Barlow, 1993, p. 165). Highly hypnotizable subjects showed greater 40-Hz EEG density (that was not correlated with muscle activity) at both left and right parieto-occipito-temporal cortex junctions during induced emotional states compared to rest, whereas low hypnotizables did not, in both nonhypnotic (De Pascalis et al., 1987) and hypnotic (De Pascalis et al., 1989) conditions. Highs showed bilateral hemispheric 40-Hz density increases during the recollection of positive emotions, and a reduction of density in the left and an increase in the region during negative emotions. We anticipated similar findings in the present study.

The low beta activity within a 13 to 16 Hz frequency band has not previously been associated with emotional processing in the literature. A distinctive 11–15 Hz sensorimotor EEG rhythm, termed the SMR, is seen in cats during alert quiescence and presentation of visual or auditory stimuli, with accompanying reduction during movements (for review, see Sterman, 1996; Sterman and Bowersox, 1981). This SMR is localized to the sensorimotor cortex and found within the ventrobasal thalamic nuclei of cats. It is analogous to the mu rhythm observed in humans in the central region (Kuhlman, 1978). A suppression of rhythmic activity in the 11–15 Hz range occurred during visual tracking in the temporal-parietal area and during driving performance in the central cortex (Mann et al., 1996). In the present study, we evaluated whether there was a differential impact of focused internally generated positive and negative emotional states, during quiescence without motoric movement, on beta activity within the 13 to 16 Hz frequency band.

Given these prior findings, we evaluated EEG activity during induced emotional conditions in six beta frequency bands: Beta 13 (13.5–16.45 Hz), Beta 16 (16.5–19.45 Hz), Beta 19 (19.5–25.45 Hz), Beta 31 (31.5–37.45 Hz), and the so-called 40-Hz band (37.4–41.7 Hz).

2. Hypnotic level and hypnosis: possible moderators of emotional asymmetries or intensity

Hypnosis is conceptualized as a condition of amplified attention towards and deeper absorption in attended-to emotional and cognitive phenomena and events (e.g., Crawford, 1982, 1994a,b; Hilgard, 1965; Krippner and Bindler, 1974). Hypnotically responsive individuals possess more efficient controlled attention and inhibitory systems (for reviews, see Crawford, 1994a, Crawford and Gruzelier, 1992). In comparison to low hypnotizable persons ('lows'), highly hypnotizable persons ('highs') often report and demonstrate greater absorption in everyday events (e.g., Crawford, 1982; Crawford et al., 1993a; Tellegen and Atkinson, 1974; for a review, see Roche and McConkey, 1990), greater emotional involvement (Crawford, 1989; Crawford et al., 1995a; Crowson et al., 1991), greater imaginal involvement (e.g., Crawford, 1982; Sheehan, 1982, Wallace, 1990; for reviews, see Crawford, 1986, 1996; Crawford and MacLeod-Morgan, 1986), and greater sustained attentional and disattentional abilities (Atkinson and Crawford, 1992; Crawford, 1981; Crawford et al., 1993a; Priebe and Wallace, 1986; Wallace, 1986, 1988; Wallace et al., 1994). These findings have been interpreted as providing support for the hypothesis that highs possess greater cognitive flexibility and greater willful sustained and focused attention that is less vulnerable to distraction (Crawford, 1994a). Furthermore, it has been proposed that such findings are reflections of differences in underlying neurophysiological processes, particularly those associated with the anterior attentional system (e.g., Crawford, 1989, 1994a,b; Crawford and Gruzelier, 1992; Crawford et al., 1993a).

During hypnosis, highs show enhanced imaginal and holistic processing of untransformed information (e.g., Crawford, 1986, 1996; Crawford and Allen, 1983; Crawford et al., 1983, 1986; Dywan and Bowers, 1983; Walker et al., 1976; Wallace, 1978). Based upon the assertion that emotional states induced during hypnosis are accompanied by physiological and phenomenological changes consistent with the type of suggested emotion, studies have investigated the effect of hypnotically induced emotions on perceived intensity (e.g., Bryant and McConkey, 1989), personality tests (e.g., Hodge and Wagner, 1964; Howell and Carlisle, 1971), learning and recall (e.g., Bower, 1981; Bower et al., 1981; for a review, see McConkey, 1989), reaction times (Gaunitz et al., 1980), and physiological functioning (e.g., Damaser et al., 1963; Harris et al., 1993) with mixed results (for a review, see Friswell and McConkey, 1989). In a well-designed study comparing low (simulators) and highly hypnotizable subjects, Damaser et al. (1963) demonstrated consistent changes in heart rate, skin potential and muscle activity in conjunction with induced emotions of fear, calmness, happiness, and depression. Most importantly, both highs and simulating lows demonstrated similar physiological reactivity in both waking and hypnosis. As previously discussed, De Pascalis et al. (1987, De Pascalis et al., 1989) found hypnotic level differences associated with induced emotions in 40-Hz activity. Otherwise, no research has examined EEG correlates of induced emotions in hypnosis as moderated by hypnotic level.

During hypnosis, there are observed shifts in brain dynamics, dependent upon the task at hand (for reviews, see Crawford, 1989, 1990, 1994a; Crawford and Gruzelier, 1992; Gruzelier, 1988), with a possible inhibition of analytical processing so that there is an increase of holistic and imaginal processing of information that is reflected in hemispheric and anterior-posterior regional shifts (e.g., Gruzelier, 1988). Greater cognitive flexibility in highs may be correlated with observed greater EEG hemispheric specificity in certain EEG frequency bands, in nonhypnosis and hypnosis conditions (e.g., Crawford, 1989; De Pascalis and Palumbo, 1986; MacLeod-Morgan and Lack, 1982; Mészáros and Bányai, 1978; Mészáros et al., 1989; Sabourin et al., 1990). Highs commonly generate more theta activity that may be indicative of more focused attentional abilities (for reviews, see Crawford, 1994a; Crawford and Gruzelier, 1992). Inhibitory processing of painful stimuli during hypnotically suggested analgesia resulted in increases in regional cerebral blood flow particularly in the orbito-frontal region (Crawford et al., 1993b), shifts in EEG theta frequency band hemispheric dominance particularly in the anterior temporal region (Crawford, 1990), and amplitude changes in somatosensory pain-related potential in anterior and posterior regions (e.g., Crawford, 1994b; Spiegel et al., 1989; for a review, see Crawford and Gruzelier, 1992) and in the anterior cingulate cortex and temporal cortex (Kropotov et al., in press).

Intensity of affect processing has been associated with hypnotic susceptibility. Highs report more intense affect when viewing violent films (Crowson et al., 1991) and when experiencing positive and negative emotions (Crawford, 1989; Crawford et al., 1995a). Effects of hypnotic level, affect valence and cerebral asymmetry on reaction time in the discrimination of stimuli of angry and happy faces of Ekman and Friesen (1978) were studied in waking and hypnosis by Crawford et al. (1995a). Highs were significantly faster than lows in angry and happy affect recognition in both waking and hypnosis conditions. For highs only, faces with angry emotional valence were identified faster when presented to the right (left visual field) than left (right visual field) hemispheres, while there were no significant hemispheric effects for happy faces. Lows exhibited no significant asymmetries. Since the right anterior cingulate and bilateral prefrontal and frontal cortex have been associated with external visual sensory emotion recognition (George et al., 1993), these differences may reflect underlying neurophysiological differences in low and highly hypnotizable persons in the anterior attentional system that is suggestive of greater attentional efficiency (faster reaction times) and hemispheric specificity differences. Since the right parietal region is associated with reaction time responses (Heller, 1993), these data also suggest that the highs may have been more aroused in the right parietal region (Heller, 1993).

2.1. Aims of present study

In this study, self-induced imagery of past personal experiences was used to elicit emotional states because there is much evidence that imagery evokes quite similar patterns of physiology and self-report as found in actual situations (Cuthbert et al., 1991; Damaser et al., 1963; Lang, 1979). Happiness and sadness were chosen as they appear on most lists of discrete emotions (e.g., Ekman, 1992; Ekman and Friesen, 1975; Watson and Tellegen, 1985) and have been shown, as reviewed above, to produce specific and reproducible EEG patterns. Whereas earlier research has often evaluated a broad alpha frequency band alone or a small range of EEG frequencies, this study included 11 frequency bands, covering a range of 3.5 to 42 Hz, recorded at frontal (F3, F4), central (C3, C4) and parietal (P3, P4) regions. To evaluate how enduring traits may moderate observed EEG activity, subjects were healthy young university students who differed in hypnotic susceptibility level. We anticipated that highs would report more intense and vivid emotional experiences, even more so in hypnosis than waking, than lows.

It was hypothesized that hemispheric differences in low alpha activity (7.5–9.45 Hz) would differentiate between self-generated happy and sad emotional states, but that the higher alpha band activity (9.5–13.45 Hz) would not. In addition, since they were self-generated internal images rather than externally viewed emotional scenes, we anticipated these effects would occur in the parietal region rather than in the frontal region. It was hypothesized that there would be significantly less low alpha in the right parietal region during sadness than happiness, due to the right hemisphere's greater involvement in negative emotions. Since both theta and beta activity have been associated with emotional processing, as explicated previously, we anticipated possible anterior and posterior hemispheric differences during the two induced emotional states.

Based upon prior hypnosis research, we anticipated greater hemispheric asymmetries during the induced emotional conditions in the highly hypnotizable subjects in comparison to low hypnotizable subjects. Highs were expected to show greater EEG asymmetries in those bands shown to be associated with focused attention (high theta, high alpha, Beta 16, and Beta 19). If Levy et al. (1983) are correct, then these asymmetries should be most apparent in the parietal region. Based upon the work of De Pascalis et al. (1987, De Pascalis et al., 1989 work, we anticipated greater 40-Hz activity among the highs than the lows during the emotional conditions. Given past research, we anticipated highs would generate more theta than lows. We also evaluated whether highs would produce more high alpha and beta activity between 16 and 25 Hz, since activity in these frequency bands has been associated with focused and vigilant processing.

3. Method

3.1. Subjects

Subjects were 31 university undergraduate men who were in self-reported excellent health with no known neurological or psychiatric history, not tobacco users, not depressed, and under no medication. They were strongly right-handed, as assessed by the Annett (1970) Handedness Scale, with no left-handed or ambidextrous close relatives. Previously all subjects were administered the 12-item Harvard Group Scale of Hypnotic Susceptibility (Shor and Orne, 1962), and the small group version (Crawford and Allen, 1982) of the 12-item Stanford Hypnotic Susceptibility Scale, Form C (SHSS:C; Weitzenhoffer and Hilgard, 1962). Only those subjects who consistently scored low (0–4) or high (10–12) in hypnotizability on the two measures participated in the present study. Lows did not differ significantly from highs on either the Beck Depression Inventory (lows: $M = 6.53$; highs: $M = 5.79$) or the State Anxiety Scale of Spielberger et al. (1970) (lows: $M = 33.81$; highs: $M = 35.79$). The subjects received extra credit in their psychology courses or $8 for their participation. Subjects refrained from caffeine use for at least 4 h prior to the experiment. They were medication-free.

3.2. Procedure

Subjects were informed that the study involved an evaluation of brain wave activity, in waking and following a hypnotic induction, while (1) remaining rather neutral, (2) re-experiencing a past event that made them feel very happy, and (3) re-experiencing a past event that made them feel very sad. Care was taken to develop rapport with the subjects and put them at ease. The EEG recording procedures were described clearly to the subjects and all questions were answered before the session. After signing the consent form, subjects filled out the Beck Depression Inventory and the Spielberger State Anxiety Scale. Subjects were seated comfortably in a chair in a sound-attenuated room, with the experimenter observing through a one-way mirror from an adjoining room.

Subjects participated in the waking and hypnosis conditions on the same day, counterbalanced across subjects. Within waking and hypnosis states, there were three eyes-closed conditions: (a) neutral relaxation, (b) induced happiness, and (b) induced sadness. First, subjects were asked to remain relaxed, let their thoughts come and go, and be neutral (no intense emotion). Following this, imagining a very happy or very sad past event in their lives were counterbalanced across subjects. After each induced emotion, subjects were asked to return to a neutral state and sit quietly, letting their thoughts come and go in a neutral manner. Subjects were given a 10-min break between waking and hypnosis conditions.

The tape-recorded hypnotic induction used a shortened version of the SHSS:C instructions with all mention of sleep and drowsiness removed. During waking, subjects listened to an equivalently-timed tape-recorded passage from a college text that discussed child development, also used in Crawford et al. (1993b). Tape-recorded instructions for the neutral, happy and sad conditions were presented to ensure consistency across subjects. The instructions for happy and sad emotions are provided in Appendix A. After each set of instructions, there was silence for 60 s while subjects were told to continue experiencing the condition. During this 60-s silence, 40 s of EEG was recorded (see below). Subsequently, subjects were asked the following: (a) What was your hypnotic depth during this emotion, where

Table 1
Summary of significant effects and follow-up analyses of Hypnotic Level (HypL) × Condition (Cond) × Emotion (Emot) × Hemisphere (Hemi) analyses of variance of mean log μV magnitude for each frequency band

Hz band	Region	Significant effects	Simple effects analysis	Follow-up analyses		
			Level (effect)	Level	Significance	Explanation
Low theta	Parietal	Cond × Hemi × Emot	Waking (Hemi × Emot)	Happiness	$t(30) = 3.36^{b}$	Right > left
3.5–5.45 Hz		$F(1,29) = 4.57^{a}$	$F(1,30) = 6.66^{a}$	Sadness	n.s.	Right ≅ left
			Hypnosis (Hemi × Emot)			
			n.s.			
High theta	Parietal	HypL × Cond × Emot	Lows (Cond × Emot)	Hypnosis	$t(30) = 3.36^{b}$	Sad > happy
5.5–7.45 Hz		$F(1,29) = 4.79^{a}$	$F(1,15) = 5.43^{a}$	Waking	n.s.	Sad ≅ happy
			Highs (Cond × Emot)			
			n.s.			
		HypL × Hemi		Highs	$t(14) = 5.67^{c}$	Right > left
		$F(1,29) = 6.34^{a}$		Lows	$t(15) = 2.58^{a}$	Right > left
Low alpha	Parietal	Emot × Hemi		Happiness	$t(30) = 4.48^{c}$	Right > left
7.5–9.45 Hz		$F(1,29) = 5.87^{a}$		Sadness	$t(30) = 2.15^{a}$	Right > left
Mid alpha	Frontal	HypL × Emot		Happiness	$t(29) = 28.94^{b}$	Highs > lows
9.5–11.45 Hz		$F(1,29) = 5.49^{a}$		Sadness	n.s.	Highs ≅ lows
				Lows	$t(15) = 2.61^{a}$	Sadness > happiness
				Highs	n.s.	Sadness ≅ happiness
	Parietal	Hemi				Right > left
		$F(1,29) = 13.70^{c}$				
High alpha	Parietal	HypL × Hemi		Highs	$t(14) = 5.61^{c}$	Right > left
11.5–13.45 Hz		$F(1,29) = 4.12^{a}$		Lows	n.s.	Right ≅ left
Beta 13	Frontal	Emot × Hemi × Cond	Wake (Emot × Hemi)	Happiness	$t(30) = 3.29^{b}$	Right > left
13.5–16.45 Hz		$F(1,29) = 83.89^{c}$	$F(1,30) = 112.06^{c}$	Sadness	$t(30) = 13.95^{c}$	Right > left
				Right	$t(30) = 10.76^{c}$	Sadness > happiness
				Left	n.s.	Sadness ≅ happiness
			Hypnosis (Emot × Hemi)			
			n.s.			
	Central	Emot × Hemi × Cond	Wake (Emot × Hemi)	Happiness	n.s.	Left ≅ right
		$F(1,29) = 137.38^{c}$	$F(1,29) = 165.46^{c}$	Sadness	$t(30) = 12.16^{c}$	Left > right
				Right	$t(30) = 2.89^{b}$	Happiness > sadness
				Left	$t(30) = 11.27^{c}$	Sadness > happiness
			Hypnosis (Emot × Hemi)			
			n.s.			
Beta 16	Frontal	HypL × Emot		Highs	$t(14) = 2.71^{a}$	Happiness > sadness
16.5–19.45 Hz	Frontal	$F(1,29) = 8.09^{b}$		Lows	n.s.	Happiness ≅ sadness
	Parietal	HypL × Hemi		Highs	$t(14) = 5.14^{c}$	Right > left
		$F(1,29) = 5.98^{a}$		Lows	n.s.	Right ≅ left
Beta 19	Frontal	Emot				Happiness > sadness
19.5–25.45 Hz		$F(1,29) = 4.88^{a}$				
	Central	Emot				Sadness > happiness
		$F(1,29) = 15.77^{c}$				
	Parietal	HypL × Hemi		Highs	$t(14) = 5.26^{c}$	Right > left
		$F(1,29) = 5.69^{a}$		Lows	n.s.	Right ≅ left
Beta 25	Frontal	HypL × Emot		Highs	$t(14) = 4.19^{c}$	Happiness > sadness
25.5–31.45 Hz		$F(1,29) = 8.56^{b}$		Lows	n.s.	Happiness ≅ sadness
	Central	HypL × Emot		Highs	$t(14) = 4.19^{c}$	Happiness > sadness
		$F(1,29) = 10.26^{b}$		Lows	n.s.	Happiness ≅ sadness
	Parietal	Emot × Hemi		Happiness	$t(30) = 4.89^{c}$	Right > left
		$F(1,29) = 6.35^{a}$		Sadness	$t(30) = 5.16^{c}$	Right > left
				Right	$t(30) = 5.61^{c}$	Happy > sad
				Left	$t(30) = 5.18^{c}$	Happy > sad

Table 1 (continued)

Hz band	Region	Significant effects	Simple effects analysis	Follow-up analyses		
			Level (effect)	Level	Significance	Explanation
Beta 31 31.5–37.45 Hz	Frontal	Emot	$F(1,29) = 15.49$ ^{c}			Happiness > sadness
	Central	Emot $F(1,29) = 20.67$ ^{c}				Happiness > sadness
	Parietal	Emot $F(1,29) = 33.42$ ^{c}				Happiness > sadness
		Hemi $F(1,29) = 36.75$ ^{c}				Right > left
Beta 40 37.5–41.70 Hz	Frontal	Emot $F(1,29) = 10.95$ ^{c}				Happiness > sadness
		HypL × Emot $F(1,29) = 7.91$ ^{b}		Highs	$t(14) = 4.65$ ^{c}	Happiness > sadness
				Lows	n.s.	Happiness ≅ sadness
	Central	Emot $F(1,29) = 12.23$ ^{b}				Happiness > sadness
		Hemi $F(1,29) = 7.07$ ^{b}				Right > left
	Parietal	Emot $F(1,29) = 26.46$ ^{b}				Happiness > sadness
		Hemi $F(1,29) = 27.67$ ^{b}				Right > left

[a] $p < 0.05$; [b] $p < 0.01$; [c] $p < 0.001$.

0 is not at all hypnotized, 5 is moderately hypnotized, and 10 is deeply hypnotized? (b) For the emotion you just experienced, please rate how intense it was on a scale of 1 to 10, where 1 is being a neutral mood, 5 being a moderately happy (sad) emotion, and 10 being an extremely happy (sad) emotion. How intense would you rate it? (c) For the emotion you just experienced, please rate how vivid it was on a scale of 1 to 10, where 1 is just thinking about the emotion with no images, 5 is moderately vivid, and 10 is extremely vivid. How vivid would you rate it? (d) How much effort, from 1 (very effortful) to 10 (extremely effortless, just happened), did it take on your part to experience the emotion?

Immediately after removal of the electrodes, a short postexperimental interview was given to collect the different reactions to the experienced emotions and states. Subjects described their thoughts and images during each induced emotional condition in waking and hypnosis. Subjects were reminded that these were just memories and thoughts of real or imagined events. Subjects also rated how they felt overall in the waking and hypnosis conditions on the Spielberger et al. (1970) State Anxiety Scale. Great care was taken to ensure they were in positive moods before leaving the experimental setting, with an encouragement to return if they had any questions. No difficulties were reported.

3.2.1. EEG recording

Six monopolar EEG recordings were made with silver-silver chloride electrodes according to the international 10-20 EEG System (Jasper, 1958) at left and right hemisphere locations in the frontal (F3, F4), central (C3, C4), and parietal (P3, P4) regions. All scalp leads were referred to linked ear lobes (A1-A2), and the ground was attached 3 cm above the nasion. Resistance of electrodes were always below 5 kOhm and kept as equal as possible across electrodes. A bipolar EOG record was also taken, with electrodes at the outer canthus and sub-orbital to the right eye. The brain wave activity signals were passed through bioamplifiers in a Beckman Accutrace polygraph and amplified peak to peak 7.5 μV/mm with a filter rate of 0.3 TC.). The sampling rate was 250 samples/s. A 60-Hz notch filter was used to reduce electrical noise. EEG signal was recorded on paper and simultaneously collected and stored on a hard disk for subsequent off-line analysis, using the Computerscope ISC-16 system (R.C. Electronics, Santa Barbara, CA).

Subsequent EEG editing included rejecting EEG segments that contained eye movement contamination and muscle artifact. EEG was visually scanned by two independent observers to identify artifact contamination; any differences of interpretation were discussed and an agreement come to.

3.2.2. Data analysis

Using the Computerscope-PHY (R.C. Electronics) Fast-Fourier spectral analysis program, with data demeaning and the Hanning window to normalize the spectrum analysis, two segments of data (each 12.28 s in length) were analyzed for each channel from 0.08 to 42.00 Hz. Mean magnitude was calculated for the following frequency bands: low theta (3.5–5.45 Hz), high theta (5.5–7.45 Hz), low alpha (7.5–9.45 Hz), mid alpha (9.5–11.45 Hz), high alpha (11.5–13.45 Hz), Beta 13 (13.5–16.45 Hz), Beta 16 (16.5–19.45 Hz), Beta 19 (19.5–25.45 Hz), Beta 25 (25.5–31.45 Hz), Beta 31 (31.5–37.45 Hz) and 40-Hz (37.5–41.7 Hz). The mean of the spectral magnitudes within each frequency band for the two time segments (total 25.56 s) was submitted to statistical analyses. Hemisphere was used as a factor in the ANOVAs to determine the absolute contribution of the left and right hemispheres, as laterality ratio scores have been criticized for their lack of being able to present the absolute contribution of each hemisphere (Beaumont et al., 1984; Gevins and Schaffer, 1980).

Due to a commonly observed negatively skewed frequency distribution of EEG with high kurtosis, a natural log transform of spectral magnitude was used in all data analyses (e.g., see Sterman et al., 1994). Log mean spectral magnitudes in the above spectral frequency bands were subjected to a mixed design repeated measures analysis of variance (ANOVA) with conditions and emotions being within-subjects factors and hypnotic level a between-subjects factor. When necessary, the F-values were those obtained after Greenhouse–Geisser corrections.

Subjects' reports of thoughts during the neutral condition indicated a consistent bias towards thoughts of positive affect. Therefore, the neutral condition was not used as a baseline measure by which to compare sad vs. happy emotions. Results for neutral condition are reported elsewhere (Crawford and Clarke, in prep.).

4. Results

4.1. Emotion manipulation check

All subjects reported experiencing the appropriately induced happy and sad emotions. Typical ruminations for sadness included re-experiencing death of a parent or grandparent, death of a pet, or parents getting a divorce. Some subjects were tearful. Typical ruminations for happiness included re-experiencing very joyful times with friends, winning something or getting an award, or getting an unexpected inheritance.

To verify that the happy and sad emotional manipulations were successful, comparisons were made for intensity self-reports between the neutral and two emotion conditions. During waking, in comparison to the neutral condition, happiness [$F(1,24) = 22.99$, $p < 0.001$] and sadness [$F(1,24) = 12.43$, $p < 0.002$] were significantly more emotionally intense. During hypnosis, happiness [$F(1,24) = 22.32$, $p < 0.001$] and sadness [$F(1,24) = 28.16$, $p < 0.001$] were also significantly more emotionally intense than in the neutral condition. Thus, we concluded that the sad and happy emotions were successfully induced. Further comparisons will be made in a subsequent section (see Table 3).

The following result sections address (a) conditions of sadness and happiness in waking and hypnosis as moderated by hypnotic level, (b) possible relationships between intensity ratings and EEG activity, and (c) phenomenological ratings during each of the emotion conditions.

4.2. Happiness and sadness during waking and hypnosis conditions

The 11 frequency bands are presented sequentially. Within each frequency band, the frontal, central and parietal regions are addressed. All means are reported as the mean log μV magnitude. Table 1 presents a summary of all significant ANOVAs and a breakdown of the complex interactions with follow-up analyses. Since these *F*s and *t*s are not redundantly presented in the text, the reader is refered to Table 1.

4.2.1. Low theta (3.5–5.45 Hz)

At both the frontal and central regions, there were no significant main effects or interactions. At the parietal region, during waking, there was significantly more low theta activity in the right ($M = 3.58$) than left ($M = 3.37$) hemisphere for happiness ($p < 0.002$), whereas there was no significant difference between the left ($M = 3.29$) and right ($M = 3.35$) hemisphere for sadness. In addition, during hypnosis, these parietal asymmetries were in the same direction but were not significant (happiness: right = 3.55, left = 3.42; sadness: right = 3.51, left = 3.39).

4.2.2. High theta (5.5–7.45 Hz)

At the frontal and central regions, there were no significant main effects or interactions. At the parietal region, there was significantly more high theta activity in the right than left parietal regions. This asymmetry was moderated by hypnotic susceptibility level. As shown in Fig. 1, this asymmetry was substantially greater for highs (right = 3.63, left = 3.33; $p < 0.001$) than lows (right = 3.43, left = 3.33; $p < 0.02$). There was a nonsignificant trend for highs to generate more high theta activity in the right parietal region than lows.

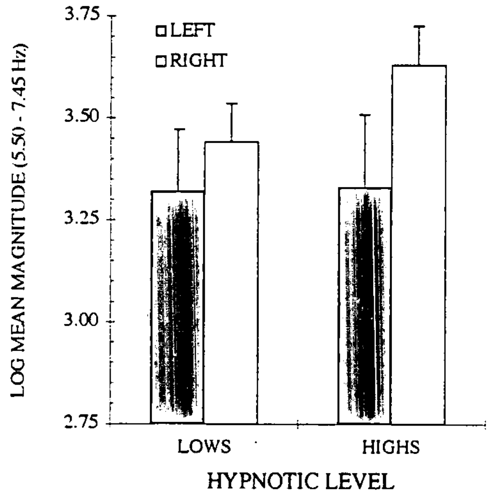

Fig. 1. High theta (5.50–7.45 Hz) activity at left and right parietal regions for low and highly hypnotizable subjects: spectral magnitude means ± S.E..

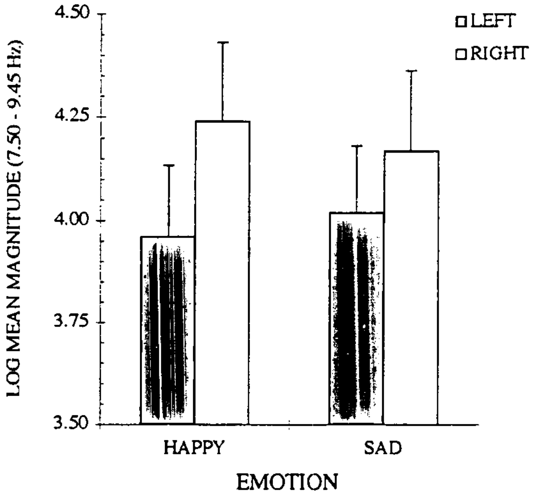

Fig. 2. Low alpha (7.50–9.45 Hz) activity at left and right parietal regions for happy and sad emotions: spectral magnitude means ± S.E..

At the parietal region, the subsequent analysis of the Hypnotic Level × Condition × Emotion interaction ($p < 0.02$) showed the effect to occur for lows but not highs. The lows had significantly ($p < 0.05$) more high theta during sad ($M = 3.53$) than happy ($M = 3.32$) emotions in hypnosis, with no significant difference between happy ($M = 3.38$) and sad emotions ($M = 3.30$) in waking.

4.2.3. Low alpha (7.5–9.45 Hz)

As expected, a significant Emotion × Hemisphere interaction occurred in low alpha and was found only in the parietal region. At the frontal and central regions, there were no significant main effects or interactions.

As predicted and shown in Fig. 2, at the parietal region, there was a significantly greater hemispheric asymmetry during happy (right = 4.24, left = 3.96; $p < 0.001$) than sad (right = 4.17, left = 4.02; $p < 0.05$) emotions regardless of condition or hypnotic level. This consistent finding may be interpreted as indicating greater relative right hemispheric involvement during sadness than happiness.

It should be noted that at frontal, central and parietal regions there were no significant main effects or interactions involving either hypnotic level or condition.

4.2.4. *Mid alpha (9.5–11.45 Hz)*

As anticipated, unlike low alpha activity, there were no significant mid alpha hemispheric differences between the two emotions at frontal, central and parietal regions. In addition, there were no significant effects involving condition.

Hypnotic Level played a significant moderating role in the frontal region during the two emotions. During happiness, highs generated significantly ($p < 0.02$) more mid alpha activity ($M = 4.00$) than lows ($M = 3.36$), whereas there was no significant difference between highs ($M = 3.91$) and lows ($M = 3.54$) for sadness. In addition, lows generated significantly ($p < 0.03$) more mid alpha activity in sadness than in happiness, whereas there was no significant difference for highs.

At the central region, there were no significant main effects or interactions. There was significantly ($p < 0.001$) more mid alpha activity in the right ($M = 4.68$) than left ($M = 4.42$) parietal region.

4.2.5. *High alpha (11.5–13.45 Hz)*

As anticipated, unlike low alpha activity, there were no significant high alpha hemispheric asymmetry differences between the two emotions at frontal, central and parietal regions. In addition, there were no significant effects involving condition.

At the parietal region, as shown in Fig. 3, highs showed a significant ($p < 0.001$) right hemispheric dominance (right = 3.26, left = 2.94), whereas the lows had no significant asymmetry (right = 3.31, left = 3.21).

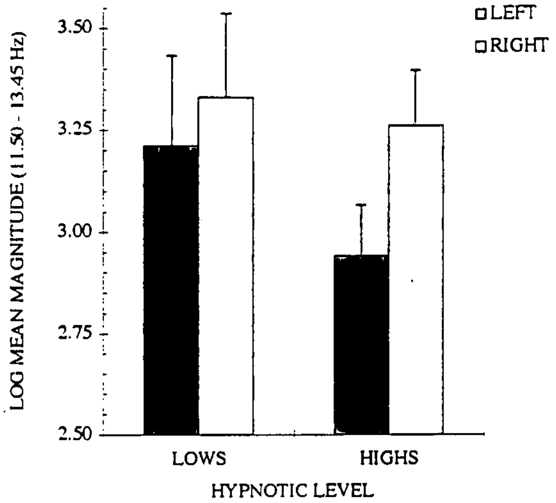

Fig. 3. High alpha (11.5–13.45 Hz) activity at left and right parietal regions for low and highly hypnotizable subjects: spectral magnitude means ± S.E..

4.2.6. *Beta 13 (13.5–16.45 Hz)*

As shown in Fig. 4, there were complex interactions involving emotion, hemisphere and condition at both the frontal and central regions ($p < 0.001$). The hemispheric asymmetries differed both for emotion and region, and were greater in waking than hypnosis conditions. A further examination of this figure shows that during sadness – in waking but not hypnosis – there are dramatic hemispheric asymmetry differences in the three regions: in the frontal region, there is greater Beta 13 activity in the right hemisphere relative to the left; in the central region, there is greater Beta 13 activity in the left hemisphere relative to the right; and in the parietal region, there is similar Beta 13 activity in both hemispheres.

At the frontal region, as shown in Fig. 4, there was a significant Emotion × Hemisphere interaction during waking ($p < 0.001$) but not during hypnosis. In waking, significantly more Beta 13 activity occurred in the right than left frontal regions during both sadness (right = 3.44, left = 2.15; $p < 0.001$) and happiness (right = 2.35; left = 2.21; $p < 0.01$). In addition, there was significantly ($p < 0.001$) more right frontal Beta 13 activity during sadness than happiness, with no significant difference in left frontal Beta 13 activity during sadness and happiness.

At the central region, as shown in Fig. 4, a significant Emotion × Hemisphere interaction occurred during waking ($p < 0.001$) but not during hypnosis. In waking, there was significantly ($p < 0.001$) greater Beta 13 activity in the left ($M = 3.41$) than right ($M = 2.18$) hemisphere during sadness, while there was no significant hemispheric asymmetry during happiness (right = 2.35, left = 2.29). There was significantly ($p < 0.01$) greater Beta 13 activity in the left central region during sadness than during happiness, whereas there was significantly ($p < 0.01$) greater Beta 13 activity in the right central region during happiness than during sadness.

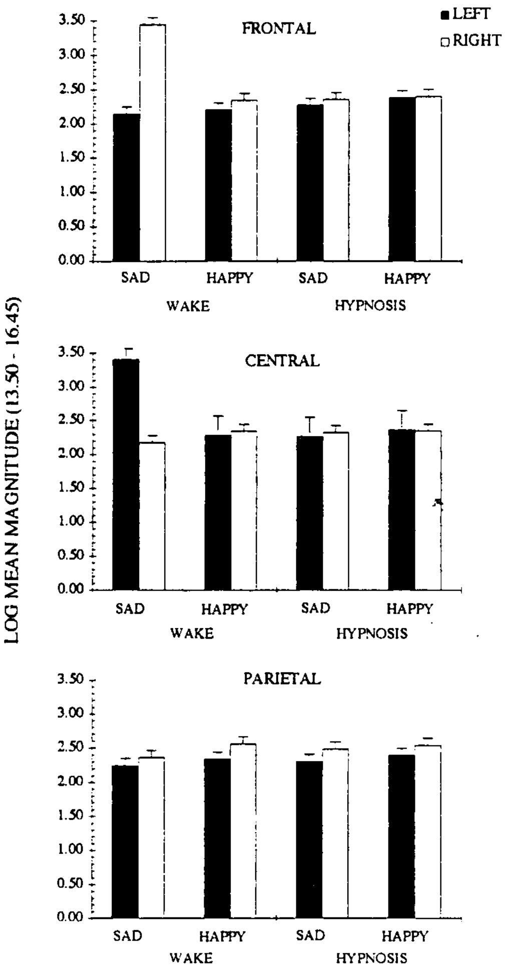

Fig. 4. Beta 13 (13.5–16.45 Hz) activity at left and right frontal, central and parietal regions for happy and sad emotions within waking and hypnosis conditions: spectral magnitude means ± S.E..

At the parietal region, as shown in Fig. 4, the Emotion × Hemisphere interaction was not significant during waking. Beta 13 activity was similar for happiness (right = 2.36, left = 2.25) and sadness (right = 2.56, left = 2.34).

4.2.7. Beta 16 (16.5–19.45 Hz)

At the frontal region, highs had significantly ($p < 0.02$) more Beta 16 activity during happiness ($M = 2.32$) than sadness ($M = 2.14$), whereas lows did not significantly differ during happiness ($M = 2.14$) and sadness ($M = 2.19$).

As anticipated, at the parietal region (Fig. 5, upper), highs had a significant hemispheric asymmetry in Beta 16 activity, whereas lows did not. Highs had significantly ($p < 0.001$) more Beta 16 activity in the right ($M = 2.41$) than left ($M = 2.16$) parietal region, whereas lows did not (right = 2.24, left = 2.18). There was a nonsignificant trend for highs to have more right parietal Beta 16 activity than lows.

4.2.8. Beta 19 (19.5–25.45 Hz)

At the frontal region, there was significantly ($p < 0.04$) more Beta 19 activity during happiness than sadness. By contrast, at the central region, there was significantly more Beta 19 during sadness than happiness ($p < 0.001$).

As anticipated, at the parietal region (Fig. 5, lower), highs had a significant Beta 19 hemispheric asymmetry, whereas lows did not. Highs had significantly ($p < 0.001$) more Beta 19 activity in the right ($M = 2.00$) than left ($M = 1.75$) parietal regions,

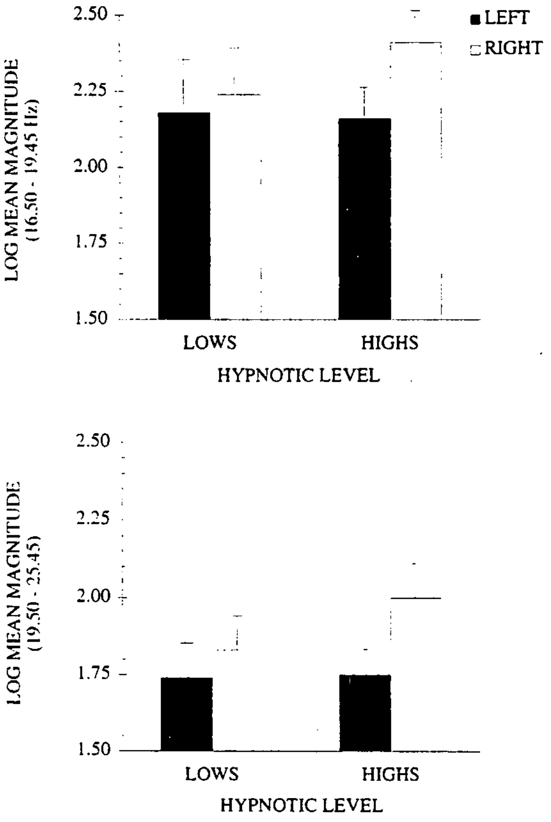

Fig. 5. Beta 16 (16.50–19.45 Hz) and Beta 19 (19.5–25.45 Hz) activity at left and right parietal regions for low and highly hypnotizable subjects: spectral magnitude means ± S.E..

whereas lows did not (right = 1.83, left = 1.74). There was a nonsignificant trend for highs to have more right parietal Beta 19 activity than lows.

4.2.9. Beta 25 (25.5–31.45 Hz)

At the frontal and central regions, highs showed differential activity during the two emotions, whereas lows did not. At the frontal region, highs had significantly ($p < 0.001$) more Beta 25 activity during happiness ($M = 1.50$) than sadness ($M = 1.19$), whereas lows had the same Beta 13 activity during happiness ($M = 1.31$) and sadness ($M = 1.31$). At the central region, highs had significantly ($p < 0.001$) more Beta 25 activity during happiness ($M = 1.44$) than sadness ($M = 1.08$), $t(14) = 4.19$, $p < 0.001$, whereas lows had very similar Beta 13 activity during happiness ($M = 1.30$) and sadness ($M = 1.31$).

It should be noted that unlike the two lower beta frequency bands (Beta 13, Beta 16), at the parietal region the low and highly hypnotizable subjects did not show differential hemispheric asymmetries in Beta 24 activity. At the parietal region, there were hemispheric asymmetry differences for both happy and sad emotions, regardless of condition or hypnotic level. There was significantly ($p < 0.001$) greater Beta 25 activity in the right than left parietal region for both sadness (right = 1.26, left = 1.08) and happiness (right = 1.48, left = 1.31). There was significantly ($p < 0.001$) more Beta 25 activity during happiness than sadness in both left ($p < 0.001$) and right ($p < 0.001$) parietal regions.

4.2.10. Beta 31 (31.4–37.45 Hz)

There was significantly ($p < 0.001$) greater Beta 31 activity during happiness than sadness at the frontal, central and parietal regions. In addition, in the parietal region, there was significantly greater Beta 31 activity in the right ($M = 1.32$) than left ($M = 1.12$) parietal hemispheres. There were no significant effects involving either hypnotic level or condition.

4.2.11. 40-Hz beta (37.5–41.7 Hz)

There was significantly greater 40-Hz activity during happiness than sadness at the frontal, central, and parietal regions ($p < 0.01$). In the frontal region, this emotion effect occurred only for highs but not for lows. Highs had significantly ($p < 0.001$) more 40-Hz activity during happiness ($M = 1.53$) than sadness ($M = 1.21$), whereas lows did not differ between happiness ($M = 1.29$) and sadness ($M = 1.26$).

There was significantly ($p < 0.01$) greater 40-Hz activity in the right than left hemisphere at the central and parietal regions, whereas there was no significant asymmetry in the frontal region.

4.3. Intensity and EEG activity

Are there relationships between self-reports of emotional intensity and EEG activity? Recent work by Heller and her associates (Heller, 1993; Heller et al., 1995) suggests a relationship between right-parietotemporal hemispheric function and autonomic and behavioral arousal during emotional processing. Correlations between intensity reports for happy and sad emotions and EEG activity within the various frequency bands at the parietal region are presented in Table 2. The only significant ($p < 0.05$) correlations observed were for high alpha activity in the happy emotion during waking (P3, 0.41; P4, 0.45) and for Beta 19 activity in the happy emotion during hypnosis (P4, 0.40).

Further post hoc correlations assessed possible relationships between intensity and hemispheric magnitude ratios (right − left/right + left) in the various frequency bands at the parietal region. Only two significant correlations emerged: during sadness in hypnosis, Beta 13, 0.36 ($p < 0.05$); and Beta 16, 0.40 ($p < 0.05$). We also assessed relationships between intensity, vividness and effort reports and EEG activity at all sites. While there were a few significant correlations, no meaningful patterns emerged. These correlation tables are available to the reader from the first author (HJC).

4.4. Intensity, vividness and effortless ratings

For the happy, sad, and neutral emotions during wake and hypnosis, the means and standard deviations for lows and highs on ratings of intensity, vividness, effort and hypnotic depth are presented in Table 3. t-tests between low and highly hypnotizable subjects for each measure are also reported in Table 3.

4.4.1. Comparison of happy and sad conditions

Highs found the self-induced happy and sad emotions to be significantly more intense and vivid during hypnosis than waking, whereas the lows reported no significant difference between the two conditions. Thus, there were significant Hypnotic Level × Condition interactions for reports of intensity, $F(1,29) = 13.18$, $p < 0.001$, and vividness, $F(1,29) = 11.07$, $p < 0.002$.

For intensity reports, there was also a significant Emotion × Condition interaction, $F(1,29) = 6.52$, $p < 0.02$. Sadness was rated to be more intensely experienced during hypnosis than waking, while happiness did not differ significantly. As reported earlier, a verification of the success of the emotional inductions was that for all subjects, both happy and sad emotions were perceived as being more intense than that experienced during the neutral condition.

Table 2
Relationships between intensity of emotional experience and EEG activity: parietal region

	Sadness		Happiness	
	P3	P4	P3	P4
Low theta (3.5–5.45 Hz)				
Wake	−0.12	−0.08	0.08	−0.04
Hypnosis	−0.19	−0.11	−0.03	−0.03
High theta (5.5–7.45 Hz)				
Wake	−0.11	0.02	0.14	0.06
Hypnosis	−0.19	−0.16	−0.01	0.06
Low alpha (7.5–9.45 Hz)				
Wake	0.06	0.15	0.15	0.06
Hypnosis	−0.08	−0.07	−0.04	0.06
Mid alpha (9.5–11.45 Hz)				
Wake	0.22	0.28	0.33	0.26
Hypnosis	0.05	0.19	0.25	0.30
High alpha (11.5–13.45 Hz)				
Wake	0.08	0.13	0.41 [a]	0.45 [a]
Hypnosis	−0.21	−0.03	0.22	0.27
Beta 13 (13.5–16.45 Hz)				
Wake	0.07	0.08	0.18	0.13
Hypnosis	−0.07	−0.02	0.10	0.17
Beta 16 (16.5–19.45 Hz)				
Wake	0.01	0.07	0.07	0.01
Hypnosis	−0.08	0.09	0.21	0.31
Beta 19 (19.5–25.45 Hz)				
Wake	0.10	0.21	0.08	−0.03
Hypnosis	0.10	0.21	0.30	0.40 [a]
Beta 25 (25.5–31.45 Hz)				
Wake	−0.02	0.16	−0.05	−0.11
Hypnosis	0.09	0.27	0.05	0.23
Beta 31 (31.5–37.45 Hz)				
Wake	0.12	0.21	0.06	−0.05
Hypnosis	0.13	0.18	0.19	0.24
40-Hz Beta (37.5–41.7 Hz)				
Wake	−0.04	0.06	−0.11	−0.06
Hypnosis	0.06	0.33	0.23	0.23

[a] $p < 0.05$, two-tailed.

Table 3
Intensity, vividness, and effort ratings for happy and sad self-generated emotions and for a neutral condition during waking and hypnosis: comparisons of low and highly hypnotizable men

Ratings [a]	Lows ($n = 16$)		Highs ($n = 15$)			
	Mean	S.D.	Mean	S.D.	$t(29)$	$p <$
Intensity						
Happy: waking	5.00	2.34	5.87	2.36	1.03	n.s.
Happy: hypnosis	4.13	1.86	8.00	1.69	6.08	0.001
Sad: waking	3.63	2.28	5.73	2.22	2.61	n.s.
Sad: hypnosis	4.13	2.48	8.40	1.24	6.02	0.001
Neurtral: waking	3.00	2.24	2.46	2.46	0.59	n.s.
Neutral: hypnosis	2.47	1.36	3.91	3.05	1.63	n.s.
Vividness						
Happy: waking	5.13	2.16	5.53	2.42	0.50	n.s.
Happy: hypnosis	5.06	2.87	8.00	1.81	3.42	0.01
Sad: waking	4.06	1.98	5.53	2.48	1.83	n.s.
Sad: hypnosis	4.31	2.47	8.20	1.66	5.11	0.001
Neurtral: waking	4.27	2.82	4.27	2.94	0.01	n.s.
Neutral: hypnosis	4.33	2.99	6.73	2.20	2.24	0.03
Effort						
Happy: waking	4.87	2.62	5.79	2.99	0.88	n.s.
Happy: hypnosis	6.20	2.15	8.07	2.20	2.32	0.03
Sad: waking	3.25	4.20	3.33	3.73	0.06	n.s.
Sad: hypnosis	5.40	2.90	8.21	2.19	2.93	0.007
Neurtral: waking	7.67	2.99	7.18	2.79	0.42	n.s.
Neutral: hypnosis	7.53	2.90	8.00	2.10	0.45	n.s.
Depth						
Happy: waking	0.88	1.25	0.60	0.99	0.67	n.s.
Happy: hypnosis	1.56	1.50	8.73	2.69	9.25	0.001
Sad: waking	0.75	1.13	0.87	1.25	0.27	n.s.
Sad: hypnosis	0.75	1.13	0.87	1.25	0.27	n.s.
Neurtral: waking	0.56	0.81	0.60	1.06	0.11	n.s.
Neutral: hypnosis	1.88	1.75	7.67	1.54	9.76	0.004

[a] Intensity: 1 (neutral) to 10 (extremely intense emotion); Vividness: 1 (no image) to 10 (extremely vivid); Effort: 1 (very effortful) to 10 (extremely effortless).

For effortlessness, there was a significant Hypnotic Level × Condition interaction, $F(1.29) = 5.36$, $p < 0.03$. Highs reported the production of the emotions were significantly more effortless during hypnosis, whereas the lows reported they were more effortful during hypnosis. Overall, subjects reported it took greater effort to produce sad than happy emotions.

As expected, highs reported themselves to be significantly more hypnotized during hypnosis, whereas lows did not change their hypnotic depth ratings during hypnosis. Hypnotic depth did not differ as a function of emotion.

5. Discussion

During self-generated sad and happy emotions, as anticipated, there were hemispheric asymmetry differences between happy and sad emotions in low alpha (7.5–9.45 Hz), but not mid to high alpha (9.5–13.45 Hz). Furthermore, as predicted, this was limited to the parietal region regardless of condition, waking or hypnosis, or hypnotic susceptibility level. Greater right hemisphere involvement during sadness than happiness can be inferred from these data. In the parietal region only, a similar hemispheric asymmetry for sadness but not happiness was observed in low but not high theta activity.

Typically the beta frequency bands are given less emphasis or are ignored in studies of EEG correlates of emotion, yet our data suggest they are quite relevant. In contrast to low alpha activity, in the Beta 13 (13.5–15.45 Hz) band highly significant Emotion × Hemisphere interactions were observed in the frontal and central, but not parietal regions. Opposite direction hemisphere asymmetries were observed at the frontal and central regions during sadness during waking only, whereas during hypnosis these asymmetries disappeared (Fig. 4). Sadness was accompanied by significantly greater activity in the frontal region in Beta 16 (16.5–19.45 Hz), and this was moderated by hypnotic level. In Beta 19 (19.5–24.45 Hz) significantly greater activity was observed in the frontal region during happiness, but the reverse occurred at the central region. In frontal, central and parietal regions in the higher beta frequencies (25–41.7 Hz) there was significantly more activity during happiness than sadness.

As anticipated, highly hypnotizable individuals showed substantially greater hemispheric asymmetries in the parietal region than did low hypnotizables, regardless of emotion or condition. This greater right parietal activity was evident among the highs in high theta (5.5–7.45 Hz), high alpha (11.5–13.45 Hz), Beta 16 (16.5–19.45 Hz), and Beta 19 (19.5–25.45 Hz) frequency bands. Hypnotic susceptibility level also moderated several other effects.

These major findings are placed within a theoretical discussion in the following sections. The first section addresses EEG correlates of happy and sad emotions. The second section addresses brain dynamic differences associated with hypnotic susceptibility level.

5.1. *Comparisons of happy and sad emotional conditions during wake and hypnosis*

Of theoretical importance are the findings that hemispheric differences in low alpha activity (7.5–9.45 Hz) differentiated between self-generated happy and sad emotional states, whereas mid to high alpha (9.5–13.45 Hz) did not. This was limited to the parietal region and was not present in the frontal and central regions. Specifically, both emotions showed less low alpha activity in the left than right parietal regions, but this was more pronounced during happiness than sadness (Fig. 2). The low alpha activity within each hemisphere did not differ significantly between emotions, but the relative contribution of the two hemispheres within each emotion did. Interestingly, this same pattern was observed in low but not high theta. Low theta activity, associated with decreased arousal or cognitive activity (Schacter, 1977; Vogel et al., 1968), was significantly greater in the right than left parietal region during happiness, while there were no significant hemispheric differences during sadness.

It should be stressed that our research points out the importance of discriminating low alpha activity from mid and high alpha activity. The findings herein support a growing body of literature that indicates low alpha activity is more functionally associated with fluctuations in alertness and should be separately evaluated from higher alpha activity which may be more associated with cognitive workload (e.g., Bosel, 1992; Crawford et al., 1995b; Klimesch, 1995; Klimesch et al., 1990; Mecklinger and Bosel, an et al., 1994). Recent factor analytic ncharova and Davidson (1995) differeneen low alpha (9–10 Hz) and high alpha) and provided further support for the hat there are functionally meaningful difetween these alpha components. Specifireported that low alpha activity recorded en and eyes-closed conditions (no emotion orrelated strongly with positive affectivity, d by the PANAS, in a broad brain region from anterior frontal to centro-parietal arto be addressed is whether studies of aplated and withdrawal-related stimuli that ronmentally generated (e.g., watching film ll find differential contributions of low and ha to previously observed distinct patterns of right frontal and anterior temporal broad frequency band activity (e.g., Davidson, ; Fox, 1994).

ming that suppressed low alpha (and low activity indicates more relative cortical inent during the emotion in the measured ung region, as supported by research reviewed introduction, these findings might suggest that e left parietal region was more emotionally than the right during both happy and sad onal conditions, and (2) the right parietal rewas relatively more emotionally involved durdness than during happiness. Yet, as is somedone when laterality ratios of alpha activity are oyed, it cannot be concluded that the right sphere is more involved in emotional processing the left if we use alpha activity as our only sure. The greater relative involvement of the t hemisphere during sadness is suggested in the ent data, but overall greater absolute right hemiere involvement is not. Although hemispheric os can assist us in the understanding of individual ferences in emotional processing (e.g., Davidson l., 1990; Tomarken et al., 1990, 1992), we must sensitive to their limitations and their inability to vide information about the absolute spectral magude present in the left and right hemispheres (for cellent discussions of this issue, see Beaumont et ., 1984; Gevins and Schaffer, 1980).

Our findings of low alpha activity hemispheric ifferences associated with emotional processing upports prior research of self-generated positive and negative emotional states that found parietal alpha activity differences (e.g., Collet and Duclaux, 1987; Meyers and Smith, 1986, 1987; Smith et al., 1989, 1987; Tucker et al., 1981; Tucker and Dawson, 1984). Developing an affective set before listening to positive (laugh, baby coo) and negative (cry, scream) emotional stimuli resulted in hemispheric alpha asymmetries in the parietal region (Meyers and Smith, 1986, 1987; Smith et al., 1987, 1989, 1990).

By contrast, our findings are not consistent with studies of the processing of positive and negative emotional stimuli in the environment (e.g., film clips) which typically report observed alpha activity differences in the frontal and anterior temporal regions (for reviews, see Davidson, 1988, 1992a,b; Dawson, 1994; Derryberry and Tucker, 1992; Fox, 1994). External visual sensory emotion recognition has been associated with right anterior cingulate and bilateral prefrontal and frontal cortex activation (George et al., 1993). Differences in recording with eyes open and closed across these studies may have contributed to these inconsistent findings. While posterior alpha activity is more predominant during eyes closed conditions, it still is evident in eyes open conditions; less is known about anterior alpha activity (Barlow, 1993).

Taken together, these studies suggest that both the anterior and posterior regions of the brain are differentially involved in emotional processing. According to Luria (1966) and Pribram (1981, Pribram, 1991), during self-generated emotional experiences, the posterior region of the brain forms a program of action, while the frontal region compares this program with the actual course. There is a ''balance between the parietal and frontal (including temporal pole) portions, which is organized and enhanced by parietal and selectively inhibited (made context sensitive) by frontal cortical functioning'' (Pribram, 1981, p. 118). Studies involved in the evaluation of, and subsequent emotional involvement in viewed emotionally-laden material (e.g., films) require subjects to evaluate external stimuli over time that calls upon prefrontal lobe planning, organization, and context updating (e.g., Pribram, 1991). Thus, it is not surprising that more differential frontal lobe involvement has been observed under these latter conditions. Yet, when subjects were asked to mentally review from memory previously shown positive and negative film-sequences, Collet and Duclaux (1987) were unable to replicate the frontal alpha lateralization asymmetries as a function of emotion, but found asymmetries in the centro-parietal regions.

Furthermore, such low alpha differences noted in these two emotional conditions support work by Ray and Cole (1985; Cole and Ray, 1985; see also Aftanas et al., 1994; Valentino and Dufresne, 1993) that intake and rejection attentional processing of emotional stimuli activate different regions of the brain. Specifically, observing and evaluating emotional stimuli may activate the executive planning and organizing aspects of the frontal region in a different manner than the recall and imagery of past emotional events. Secondly, recalling past memories is more likely to activate the more posterior temporal and parietal regions associated with memory and imagery processes (for a review, see Crawford, 1996). Thus, differences in imagery formation and vividness may contribute also to the observed differences. Another theoretical view is the model of Heller (1993) which proposes that the right temporoparietal region is activated due to arousal, whereas the frontal regions are differentially activated due to differences in emotional valance. Future research needs to address the processing of external emotional stimuli and self-generated emotional stimuli within the same individuals to elucidate these possible differences.

Since other frequency bands did show differential activation in the frontal region, as discussed below, and a cerebral metabolism study (Pardo et al., 1993) showed prefrontal activation during self-induced dysphoria, the present study cautions us to be more alert to the limitations of depending upon alpha activity alone. As researchers have access to equipment that can evaluate substantially more scalp locations than the present study did, further understanding of emotional processing will be possible. Of particular theoretical relevance would be additional recordings from the prefrontal and temporal regions.

5.1.1. Beta frequency bands

Some theoretically important emotion effects were observed in some of the beta bands. In Beta 13 (13.5–15.45 Hz), it was in the frontal and central regions in which there were highly significant emotion by hemisphere interactions that were further influenced by condition (waking vs. hypnosis). No differences were observed in the parietal region. Most intriguing, yet unexpected, was the highly significant reversal of hemispheric dominance in Beta 13 activity in the frontal and central regions evident during sadness in waking (Fig. 4). Why these asymmetries during happiness disappeared during hypnosis is unaccountable for at present.

Within Beta 13 and extending into high alpha frequency bands, oscillatory SMR activity, generated within the ventrobasal thalamus in cats (Sterman and Bowersox, 1981; Sterman, 1996), has been shown to be enhanced during quiet vigilance but suppressed during movement over the motor and premotor cortex (for a review, see Sterman and Mann, 1995). It is should be noted that both SMR and the analogous mu rhythm have only been observed in the central region and suppressed during movement (for reviews, see Barlow, 1993; Sterman and Mann, 1995). Thus, we may not be evaluating these rhythms in the present study. Our subjects were sitting quietly without obvious movement and with their eyes closed in all conditions. Whether possible hemispheric differences in vigilant emotional processing in the frontal and central regions contributed to these asymmetries is worthy of further investigation.

The Beta 13 hemispheric asymmetries differed both for emotion and region, and were greater in wake than hypnosis conditions. The shifts away from hemispheric asymmetry during hypnosis, regardless of hypnotic level, have not been noted previously in the literature. This may have been due to shifts in attentiveness or involvement in the suggested emotion, shifts in strategy, or some other unknown factors. Correlations between reported emotional intensity rarely correlated significantly with EEG activity. Since Beta 13 activity has not been addressed adequately in prior emotion research, further replication is necessary.

Sadness produced significantly greater activity in the frontal region in Beta 16 (16.5–19.45 Hz) than did happiness, but this effect was only observed in highs and not lows. In the Beta 19 (19.5–25.45 Hz) frequency band, there was significantly more activity during happiness than sadness at the frontal region, but the reverse was the case at the central region only in the highs. In frontal, central and parietal regions, there was significantly more activity in the higher beta frequencies (25–41.7 Hz) during happiness than sadness. Condition was not a factor. Further moderating effects from hypnotic susceptibility level are discussed in the next section.

Hemispheric effects were also noted. In Beta 25 (25.5–31.45 Hz) there was significantly more activity in the right than left parietal regions, more so for happiness than sadness. In the 40-Hz band there was significantly more activity in the right central and parietal regions in both emotions. Several other emotion studies (Schellberg et al., 1990, 1993; Stenberg, 1992) have reported greater right hemispheric beta activity. Taken together these findings are suggestive of more focused attention in the right hemisphere during certain emotional processing (Sheer, 1976, 1989). Past research has reported inconsistently that either happiness or sadness produces significantly more temporal or right temporal activity in various beta bands (Cole and Ray, 1985; Schellberg et al., 1990; Stenberg, 1992; Ray and Cole, 1985). Moderating influences from hypnotic susceptibility are discussed further below.

Since less is known about EEG activity within these particular beta bands or at different brain regions, particularly in light of emotional processes, we can only encourage future research to closely examine narrower bands of beta activity. Attention needs to be directed to specific beta frequency oscillations, in addition to magnitude within frequency bands, as they are thought to reflect states of neuronal networking of specific cortical and subcortical cell assemblies during emotional and cognitive processing (e.g., Basar, 1990; Lopes da Silva, 1991). Furthermore, we need to be careful in our interpretations of higher beta activity as it is vulnerable to muscle artifact. Since differential facial muscle activation (e.g., smiling during happiness, crying during sadness) may have occurred during the two emotional conditions, it is suggested that future work evaluate muscle activity simultaneously and covariate out its possible effect on accompanying EEG (e.g., Davidson et al., 1990; Ekman et al., 1990).

5.2. How do low and highly hypnotizable individuals differ from one another?

As anticipated, highly hypnotizable individuals showed greater hemispheric asymmetry, favoring the right hemisphere in the parietal region, than lows in several frequency bands associated with focused attention: high theta, high alpha, Beta 16, and Beta 19. Like other studies (for reviews, see Crawford, 1989, 1994a), low hypnotizables were more equally activated in both hemispheres. This supports prior research that highs show greater emotional and cognitive flexibility, reflected in greater hemispheric specificity (e.g., Crawford, 1989, 1994a; MacLeod-Morgan and Lack, 1982). Importantly, low and highly hypnotizable subjects did not show any significant differences in those EEG frequency bands most associated with drowsiness, specifically low theta (Vogel et al., 1968) and low alpha (Shagass, 1972) activity. Neither did they differ in Beta 13 activity.

5.2.1. High theta

All subjects showed greater high theta activity in the right than left parietal region during sadness and happiness, possibly reflective of focused attention (arousal) in internally generated emotional experiences and accompanying imagery. As anticipated, highly hypnotizable subjects showed even greater right parietal hemispheric dominance than did the lows in the parietal region. Like the study of cold pressor pain of Crawford (1990), highs showed greater significant asymmetries of high theta activity while lows did not. Highs tended to generate more high theta activity in the right parietal region than did low hypnotizables during the emotional states.

Theta activity is associated with emotional (Cohen et al., 1976; Schwarz et al., 1982; Simonov, 1986; Stenberg, 1992; Talairach et al., 1973; Walter, 1959, cited in Stenberg, 1992) and cognitive (Crawford, 1994a; Crawford and Gruzelier, 1992; Schacter, 1977) activity. The higher right relative to left parietal theta activity among highs may reflect enhanced focused attention and/or enhanced imagery (Sabourin et al., 1990). Many experiments (e.g., Stoyva, 1973; for review, see Schacter, 1977) have shown that psychological phenomena related to imagery production accompany theta activity. Since Stenberg (1992) found the most significant theta correlate of emotional processing to be located at the lateral frontal region (F7), possibly reflective of asymmetric limbic processing of emotional stimuli, further research needs to determine whether such hypnotic susceptibility correlates would also be observed in this region. While intensity reports did not differ during waking, highs did report more intense emotional states than did lows during hypnosis; yet, condition was not a significant factor in this EEG interaction as might be anticipated.

Unlike prior research that evaluated more cognitive processing (e.g., Sabourin et al., 1990), we found no differences in theta activity between low and high hypnotizables in the central and frontal regions during emotional processing.

5.2.2. *Alpha activity*

There were no differences between lows and highs in the low alpha activity band which argues for no differences in arousal level either in waking or hypnosis conditions. In the mid alpha frequency band, there was an interaction between hypnotic level and emotion at the frontal region. Highs generated more mid alpha activity than did lows during happiness, yet there was no difference during sadness.

Highs showed a significant high alpha asymmetry in the parietal region, while lows did not. The highs had significantly more high alpha activity in the right than left parietal region. Similarly, previous work by Crawford, Mészáros and their associates (Crawford, 1989; Mészáros et al., 1989) found highs to have greater right parieto-occipital dominance than lows in rest, math, and a visual discrimination task. Our present analyses did not permit the verification of a possible hypothesis leading out of recent work by Klimesch and his associates (Klimesch, 1995; Klimesch et al., 1990, 1993). They find good memory performers have a significantly higher mean alpha frequency. Our highs reported greater intensity and vividness of emotional experiences than did the lows, particularly during hypnosis. As one anonymous reviewer suggested, highs may have a higher mean alpha frequency than low hypnotizables, at least in the right relative to left parietal region.

5.2.3. *Beta activity*

Highly hypnotizable individuals demonstrated significant hemispheric asymmetries in beta activity between 16 and 25 Hz in the parietal region, while lows had no significant asymmetries. Consistently, highs had significantly greater right than left parietal activity. Similar asymmetries in the beta frequency band was reported by Sabourin et al. (1990). We argue against these asymmetries being caused by asymmetries in muscle activity, as the interactions were not present in the higher beta frequency bands in the present study. Increased beta activity in the 16 to 20 Hz frequency range, and possibly higher, has been associated with high vigilance and focused attentiveness (Lopes da Silva et al., 1980; Rougeul et al., 1979) and efficient, error-free cognitive performance (Makeig and Inlow, 1993). Recent research from Crawford's laboratory (Crawford et al., 1995b; Crawford and Vasilescu, 1995c) found high sustained subjects produced more Beta 16 activity than did low sustained individuals. Such findings suggest that the high hypnotizables may be exhibiting greater vigilant, sustained attentional processing that is associated with the right hemisphere. Certainly, at the behavioral level, highs have been shown to have greater sustained attentional abilities (e.g., Crawford et al., 1993a). Whether these neurophysiological differences are task-specific or a reflection of enduring trait differences associated with hypnotic susceptibility needs further inquiry.

It is of further theoretical interest that highs consistently showed greater magnitude activity in the right than left parietal region not only in the beta frequency bands between 16.5 and 25 Hz, hypothesized to be associated with sustained attention, but also in two previously discussed bands (high theta, high alpha) that have also been associated with, respectively, focused attention (e.g., Schacter, 1977) and general mental workload (Pfurtscheller and Klimesch, 1991).

In a recent neurophysiological model of emotion, Heller (1993) posits that the right parietotemporal region is seen as playing an essential role in the overall modulation of emotional states, while the frontal region is associated with valence. Furthermore, Levy et al. (1983) proposed that the large variability in hemispheric activity may be due, in part, to individual variation in patterns of asymmetric parietotemporal hemispheric activity. If so, this would suggest that the greater right than left parietal activity observed in highly hypnotizable individuals is reflective of their greater involvement (arousal) during emotional processing.

Recently, Crawford et al. (1995a) reported that highly hypnotizable subjects were significantly faster in their reaction times to emotional facial stimuli than lows, and that they had asymmetries in the left and right visual fields, whereas lows did not. This too suggests indirectly that highs exhibit higher right-hemisphere activity during emotional processing. As discussed by Heller (1993, p. 480), right parietal lesions produce slowing of reaction times (e.g., Benton, 1986) and "non-brain-damaged individuals who exhibit higher right-hemisphere activity as inferred from behavioral measures showed faster reaction time when orienting toward visual stimuli (Levine et al., 1992)" (Heller, 1993, p. 480).

Significant hypnotic level by emotion interactions were observed at the frontal region for Beta 16, Beta 25, and Beta 40 with nonsignificant trends in the same direction for the Beta 19 and Beta 31. Specifically, highs had significantly more beta activity in the frontal region for happiness than sadness across conditions of waking and hypnosis, while lows did not exhibit any significant differences. Whether this is due to differential involvement of the frontal region during the two emotions or to increased frontal muscle activity during happiness among the highs are two competing hypotheses.

De Pascalis and his associates have demonstrated that highly hypnotizable subjects showed greater 40-Hz EEG density, not correlated with muscle activity, at both left and right parieto-occipito-temporal cortex junctions during induced emotional states compared to rest, whereas low hypnotizables did not, in both nonhypnotic (De Pascalis et al., 1987) and hypnotic (De Pascalis et al., 1989) conditions. Highs showed bilateral hemispheric 40-Hz density increases during the recollection of positive emotions, and a reduction of density in the left and an increase in the region during negative emotions. In the present data there were no such hypnotic susceptibility level effects in the parietal region. Since De Pascalis et al. (1987, De Pascalis et al., 1989) used different montages and methodologies, we cannot compare the present results with theirs.

6. General concluding comments

Our present study demonstrated that during self-generated happy and sad emotional states when one evaluates alpha activity, it is the *low alpha frequency band that differentiates happy from sad emotional states in the parietal region, but not in frontal and central regions.* Thus, it replicates prior work that when self-generated emotional states are produced, usually with eyes closed, the posterior region of the brain shows hemispheric asymmetries within the alpha activity band. The posterior imaginal memory systems may become more activated (e.g., for a review, see Crawford, 1996). This is in contrast to frontal and anterior temporal alpha activity asymmetries noted rather consistently when individuals process externally presented emotional stimuli (for reviews, see Davidson, 1992a,b). Additionally, the right anterior cingulate and bilateral prefrontal and frontal cortex have been associated with external visual sensory emotion recognition (George et al., 1993). *Our findings did reveal Emotion effects present in other frequency bands in the frontal and central region, suggestive of differences between happy and sad emotions.*

Such divergent findings suggest that future research needs to evaluate the two emotion methodologies, in both eyes open and eyes closed conditions, that activate separate, but overlapping, emotional systems (e.g., Pribram, 1981, 1991) within the same individuals. In addition, our work shows that the parietal and frontal regions show differential EEG activation patterns across the frequency bands. It may well point to a way in which we can use EEG studies to evaluate the recent model of Heller (1993) that postulates the existence of two distinct neural systems associated with emotions: one involving the modulation of autonomic arousal in the parietotemporal region, and one modulating emotional valence located in the frontal lobes.

Here and elsewhere we have argued that highly hypnotizable individuals possess more efficient controlled attention and inhibitory systems (e.g., for reviews, see Crawford, 1994a; Crawford and Gruzelier, 1992). The present study supported our hypotheses that highs would show greater hemispheric asymmetries in certain EEG frequency bands and that they would respond differently at a neurophysiological level during the emotion states than would low hypnotizables. A greater right than left parietal activity in high theta, high alpha, and beta bands between 16 and 25 Hz was found in highs but not low hypnotizables. This suggests highs exhibit relatively higher right hemisphere activity during emotional processing. Our data is supportive of prior conclusions that "the behavioral differences related to hypnotic susceptibility are correlated with and influenced by neurophysiological mechanisms, thus providing some support for a trait view of hypnotizability.... " (Crawford and Gruzelier, 1992, p. 263).

We wish to note one limitation of our study. Our study used only men, whereas many of the earlier emotion studies, particularly from the laboratories of Davidson, Fox and Schwartz, employed women only. Our original decision to include only men in our first study of EEG correlates of emotion was based upon the common finding that men have greater asymmetries than do women (Kolb and Whishaw, 1990). Men and women have been found to differ in cerebral EEG activity during induced emotions (e.g., Meyers and Smith, 1987). During self-induced dysphoria, Pardo et al. (1993) found unexpected gender differences in inferior and orbitofrontal activity – a bilateral distribution was observed in women compared with prominent asymmetries in men. Furthermore, greater lacrimal flow during induced sadness was observed in women than in men (Delp and Sackeim, 1987). Replication is needed to address these potential gender differences. As was so well put by Pardo et al., "The differences observed could be the result of learning or the outcome of genetic, hormonally mediated specializations of the human brain. The more than two-fold predominance of depression in women than men and the importance of sex, even over race or ethnicity, in personality variables attest to the importance of gender in affective processing and in human cognition" (1993, p. 718). We must remain sensitive to possible methodological and theoretical problems whenever comparisons are made between men and women, be it at a behavioral or neuroanatomical level (for an excellent discussion, see Nyborg, 1994).

Most commonly, EEG approaches have evaluated raw or ratio scores of spectral magnitude and power activity, referenced to Cz, linked ears or an average reference (e.g., Henriques and Davidson, 1990). To a lesser extent they have examined coherence spectral analysis (e.g., Hinrichs and Machleidt, 1992), EEG dimensional complexity (e.g., Aftanas et al., 1994), and event-related evoked potentials (e.g., Chung et al., in press; Kostandov and Arzumanov, 1986). As new technologies and data analysis approaches become available, we can further address the questions raised within this present study to understand how the brain processes emotion and how this is impacted by individual differences in emotional processes.

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Appendix A

Verbatim instructions for happy and sad emotions are provided below.

A.1. Happiness

We would like you to think of a very happy and joyous experience you had at some time and re-experience this very happy and joyous emotion as much as you can. You are to remain sitting still in the chair so that we can record your EEG while you feel this emotion of happiness. As you think of happiness and perhaps a specific event that produced happiness for you, you begin to have the feelings of happiness... more and more intensely... more and more vividly. You are becoming more and more happy... there is a feeling of being in good spirits... a cheerful sort of feeling... You begin to feel more and more happy... perhaps even without knowing why. You feel wonderful. As if something marvelous has just happened... or, is happening... You feel more and more exhilarated... exuberant... ecstatic... euphoric with happiness... Now, this happiness feeling is becoming more and more vivid as you feel it more and more with your mind and your body... You will feel this way more and more intensely... You feel this sense of happiness throughout your body. It is an exuberant feeling. This happiness will last until I suggest to you that you no longer feel this particular sensation of happiness. Now I am going to count from 1 to 10 and as I count you will find that your feeling of happiness deepens. 1... 2... 3... more and more happy... 4... 5... a true sense of happiness... 6...

7... 8... 9 more and more happy... 10... You feel happy and joyous... you feel so happy, ecstatic and euphoric. Now just sit quite still with your eyes closed... experiencing this tremendous feeling of happiness... until you are told otherwise.

A.2. Sadness

We would like you to think of a very sad experience you had at some time and re-experience this very sad emotion as much as you can. You are to remain sitting still in the chair so that we can record your EEG while you feel this emotion of sadness. As you think of sadness and perhaps a specific event that produced sadness for you, you begin to have the feelings of sadness... more and more intensely... more and more vividly. You are becoming more and more sad... there is a feeling of being somber... a sad sort of feeling... You begin to feel more and more sad... perhaps even without knowing why. You feel so sad. As if something very sorrowful has just happened... or, is happening... You feel more and more sad... listless... sad... low with sadness... Now, this sadness feeling is becoming more and more vivid as you feel it more and more with your mind and your body... You will feel this way more and more intensely... You feel this sense of sadness throughout your body. It is a sorrowful feeling. This sadness will last until I suggest to you that you no longer feel this particular sensation of sadness. Now I am going to count from 1 to 10 and as I count you will find that your feeling of sadness deepens even more. 1... 2... 3... more and more sad... 4... 5... a true sense of sadness... 6... 7... 8... 9 more and more sad... 10... You feel so sad and unhappy... you feel so sad, unhappy... so sad. Now just sit quite still with your eyes closed... experiencing this tremendous feeling of sadness... until you are told otherwise.

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