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Relations between depressed mood and vocal parameters before, during and after sleep deprivation: a circadian rhythm study

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Summary

The mechanism underlying improvement after total sleep deprivation (TSD) was studied in 14 major depressed patients. The suggestions that (1) circadian processes and/or (2) dimensions of arousal may play a role in the response to TSD were investigated. Diurnal variation of depressed mood and of mood- and arousal-related vocal parameters was studied in relation to the effect of TSD on depressed mood and vocal parameters. During 3 baseline days, during TSD and 2 days after TSD vocal parameters and depressed mood were assessed 6 and 3 times daily respectively.

The mean fundamental frequency (frequency of vocal fold vibration, F0) (presumably reflecting aspects of arousal) as well as the range of the F0 (proposed to reflect sadness) showed a clear circadian pattern with a peak at about 4.00 p.m. TSD affected the circadian organization of the mean F0 and advanced the peak of the curve. After one night of subsequent sleep this effect disappeared. In addition, improvement after TSD coincided with an increase of the mean F0. The diurnal variation of mood before TSD predicted the mood response to TSD, whereas diurnal variation of vocal parameters did not. Moreover, circadian changes in vocal parameters were not related to changes in depressed mood. These findings suggest that the diurnal variations in mood and vocal parameters are regulated by different mechanisms. Data support the presumption that circadian as well as arousal processes are involved in the mood response to TSD. Circadian changes in vocal parameters due to TSD are not likely to reflect changes in the biological clock.

Key words: Sleep deprivation; Depression; Vocal parameters; Diurnal variation

Introduction

About 50% of endogenously depressed patients respond to total sleep deprivation (TSD) with

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clinical improvement (Gerner et al., 1979; Gillin, 1983; Gillin et al., 1984; Elsenga and Van den Hoofdakker, 1987). This suggests a causal link between sleep and depression. Various hypotheses have been advanced to account for this relationship.

Firstly, much emphasis is laid on the possibility that changes in the circadian organization of behavioral, physiological and biochemical processes may be of causal importance (Wehr and Goodwin, 1981; Gillin, 1983; Halaris, 1987). It was found that TSD affects circadian organized parameters, such as body temperature (Gillin, 1983; Gillin et al., 1984) and cortisol excretion (Yamaguchi et al., 1978; Goetze and Tölle, 1987; Bouhuys et al., 1990). On the other hand, the circadian pattern of mood the day prior to TSD has been reported to predict the mood response to TSD (Roy-Birne, 1984; Elsenga and Van den Hoofdakker, 1987): patients with positive mood changes the day before TSD show a better clinical response to TSD.

Another suggestion, explaining the mechanism of sudden mood changes after TSD, is that the mood response to TSD might be related to TSD-induced changes in arousal. It was found that observed behaviors which were related to arousal (i.e., self-manipulative hand movements) could predict the mood response to TSD (Bouhuys et al., 1988). In addition, TSD-induced changes in depressed mood were found to be related to changes in subjective arousal (Van den Hoofdakker et al., 1989). Moreover, TSD induced an increase in subjective energetic arousal (activation) and a decrease in tense arousal (stress) (Bouhuys et al., 1985; Van den Hoofdakker et al., 1989).

The voice plays an important role in communicating affect and affect disturbances. Extensive studies have reported on relationships between specific vocal parameters and specific emotions in normal subjects (Scherer, 1986). The pitch of the voice (i.e., the frequency of the vocal fold vibration; fundamental frequency; F0) seems to be a reliable indicator of psychological arousal (Scherer, 1981). The higher the mean F0, the more stressed people are. The variation of the pitch is found to be related to sadness and dejection (see Scherer, 1987). A low variation of F0 gives the impression of monotonous speech. In depressed patients authors agree upon depressed mood coinciding with a low sound pressure level (intensity) of voices and a long duration of pauses during a conversation (Bouhuys and Mulder, 1984; Nilsonne, 1987; Scherer, 1987). Moreover, the duration of counting from 1 to 10 turned out to be a valid indicator of the degree of retardation (slowing down of motor and cognitive functions) and a change in counting speed was related to the degree of improvement in depressives (Szabadi et al., 1976; Greden et al., 1980). In depressed patients no consistent results are found on the relationships between the degree of depression and parameters such as voice pitch or variation in pitch (Hargreaves and Starkweather, 1964; Darby and Hollien, 1977; Darby, 1981; Tolkmitt et al., 1982; Nilsonne, 1987; Scherer, 1987).

In the context of the above-mentioned hypotheses explaining sudden mood changes after TSD, those vocal parameters are of particular interest that are related to depressed mood and/or to arousal. These are the mean F0 and its variation. The aim of the present study is to report on these two parameters and depressed mood in relation to TSD.

The present study is part of an extensive study on biological rhythms and arousal in depressed patients. Data on observed behavior, cortisol excretion, subjective arousal and sleep in relation to TSD are presented elsewhere (observed behavior: Bouhuys et al., 1988; cortisol: Bouhuys et al., 1990; subjective arousal: Van den Hoofdakker et al., 1989).

In this paper we show that vocal parameters have a circadian pattern. Subsequently, relationships between mood and vocal parameters are studied during baseline and during and after sleep deprivation. Two different strategies have been followed. Firstly, covariation of mood changes and changes in vocal parameters are studied. Secondly, it is investigated whether vocal parameters preceding TSD are related to the mood response to TSD. If arousal-related vocal parameters have predictive value, this would support an arousal-related explanation of sudden mood changes. If circadian organization of vocal parameters has predictive properties with respect to the mood response to total sleep deprivation, this would support an explanation related to circadian organization.

Method

Subjects

Fourteen drug-free depressed patients (major depressive and bipolar disorder; DSM-III, 1980) (11 females, 3 males; age 45.9 ± 13.5 (SD) years, range 25–72 years) took part in an extensive study on circadian rhythms in depression in which a series of measurements were taken over a period of 6 days and 5 nights (called day 1–day 6, and night 1–night 5, starting after day 1). For a detailed description of the experiment see Bouhuys et al. (1990). Only measurements of depressed mood and voice quality are presented here. All patients gave written informed consent. At the start of the experimental period the patients had been medication-free for at least 7 days and at that moment the severity of depression was assessed by two independent raters (HRSD, 25.7 ± 5.0 (SD), range 17–34) (Hamilton, 1967; 21-item version). The patients were totally deprived of sleep during night 4 and day 4 (TSD). Naps were not allowed.

Vocal parameters

In order to sample speech, patients read a standard text (for a maximum of 3 min). These speech samples were collected at 3-h intervals from 7.00 a.m. to 10.00 p.m., with the exception of day 1. On that day the speech sampling started at 10.00 a.m. During TSD additional samples were collected at 1.00 p.m. and 4.00 p.m. The last sample was taken on day 6 at 7.00 a.m. A small Elektret microphone was built into a perspex house of 15 mm diameter. This house was attached to the neck of the patients with EEG electrode stickers. The speech signal was recorded in a quiet room on a Revox (A77) tape recorder.

Two vocal parameters were derived from this speech signal: the mean of the fundamental frequency (mean F0) and the range of F0 (range F0). The fundamental frequency is extracted from the recorded speech samples by using an F-J Electronics A/S Fundamental Frequency Meter, Type FFM 650. The signal is prefiltered with a Krohn-Hite bandpass filter; the band width covered about one octave, depending on the roughly estimated voice range of the speaker. The FFM 650 logarithmic output was fed directly to a Mingograph inkwriter EM 800. An extra Krohn-Hite low-pass filter was used to obtain simultaneously a smoothed display of the F0 curve. Calibration was done for each patient, by feeding a tape-recorded series of sinusoidal calibration tones to the F0 analyzer, ranging from well above to well below the estimated voice range. In this way a reliable ruler was obtained, with an accuracy of at least one semitone.

The complete set of 32 speech samples per subject has been plotted. Evaluation of the mean F0 and the range F0 was done visually on three intervals of the recorded material, i.e., the first, middle and last 15-s periods of each speech sample. The averaged score over these three intervals represented the mean F0 (semitones). The difference between the highest and the lowest value of the mean F0 represents the range F0 per 15-s period. The averaged scores over the three intervals are defined as the range F0 (semitones).

In order to account for differences between male and female voices with respect to the mean F0, this parameter was normalized per patient. From each mean F0 value the averaged value of all 32 scores was subtracted.

Self-rated depressed mood was assessed thrice daily at times corresponding to the moments at which speech samples were taken: 7.00 a.m., 1.00 p.m. and 10.00 p.m. (Adjective Mood Scale, AMS, von Zerssen, 1976, 1986).

Effect of TSD

The effect of TSD on depressed mood and vocal parameters was defined as the difference of the averaged scores on the day after TSD and those of the day before TSD.

Circadian organization

Two aspects of circadian organization were considered. Firstly changes in mean F0, range F0 and depressed mood over days and over nights were considered. *Diurnal variation* was represented by the 10.00 p.m. minus the 7.00 a.m. scores of the vocal parameters and mood, and the *nocturnal variation* by the 7.00 a.m. scores minus the 10.00 p.m. scores of the vocal parameters. The other parameter which describes aspects of circadian organization is the *peak time* of the vocal parameters. The peak was defined as the highest value of the six samples taken in the periods from 7.00 a.m. to 10.00 p.m. If the same value occurred at different time points within a day, the first time point was chosen as the 'peak'.

Statistics

For statistical evaluation of the results, non-parametric tests were applied. The within-group comparisons were made with the Wilcoxon matched pairs test (Wilc). Comparisons between groups were performed with the Mann–Whitney *U*-test (MW). Relationships between vocal param-eters and mood were calculated usir rank order correlations. If other stat ods were applied this is indicated in t

Results

Circadian organization of vocal param

In Fig. 1 the averaged course of ı and the range F0 of the 14 depressed depicted as well as the averaged cı depressed mood. The starting level of course of the mean F0 values correspc

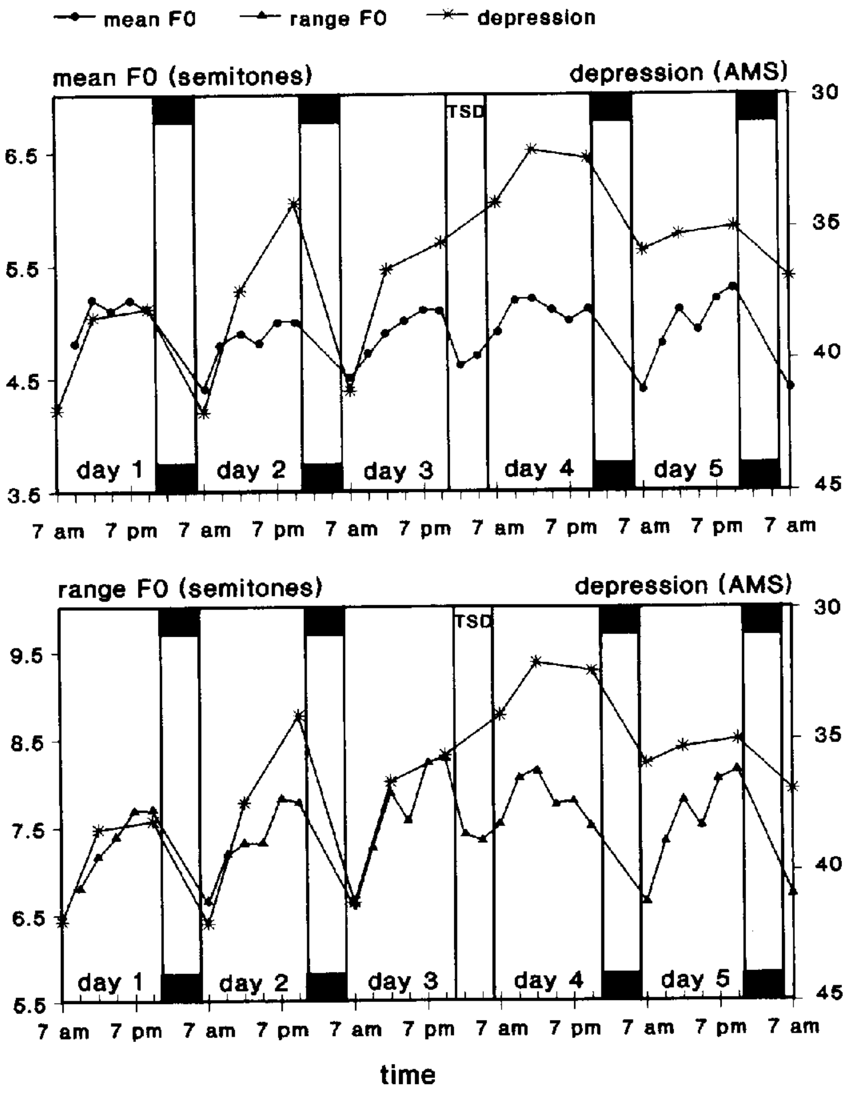

Fig. 1. Course of mood, mean F0 and range F0 before, during and after TSD in 14 depressed patient

averaged mean F0 over 14 patients and 32 scores. A circadian pattern is evident in all those variables.

With a Friedman ANOVA (repeated measures) we tested whether a significant pattern exists in mean F0, range F0 and depressed mood. This test was applied on all scores before TSD, as well as on those collected after TSD (starting from 7.00 a.m.). This was done twice separately, in order to detect possible effects of TSD on circadian patterning. Before as well as after TSD the mean F0 and the range F0 scores showed a significant pattern, whereas no significant variation in depressed mood could be detected, either before or after TSD (Friedman ANOVA by ranks, $n = 14$; mean F0 before: $df = 16$; $P = 0.001$; mean F0 after: $df = 12$; $P = 0.005$; range F0 before: $df = 16$; $P < 0.002$; range F0 after: $df = 13$; $P = 0.009$; depressed mood before: $df = 8$; $P = 0.617$; depressed mood after: $df = 6$; $P = 0.901$). After this global testing, the significance of the circadian pattern was tested by comparing the early morning scores (7.00 a.m.) with the late evening scores (10.00 p.m.) (i.e., changes over the day), and the 10.00 p.m. scores with the 7.00 a.m. scores (i.e., changes over the night). The results are presented in Table 1. The results during and after TSD will be discussed below. The Table shows that the mean F0 as well as the range F0 values are organized in a circadian pattern, and suggests that the nocturnal variation contributes more to this pattern than the diurnal variation.

TABLE 1

P-VALUES (WILCOXON; $n = 14$) OF DIFFERENCES IN MEAN AND RANGE F0 OVER DAYS (DV: 7.00 a.m.–10.00 p.m.) AND NIGHTS (NV: 10.00 p.m.–7.00 a.m.)

		Mean F0	Range F0
Before TSD			
Day 1	DV		
	NV	0.01	0.47 NS
Day 2	DV	0.02	0.20 NS
	NV	0.01	0.05
Day 3	DV	0.03	0.05
During and after TSD			
	NV	0.05	0.01
Day 4	DV	0.12 NS	0.78 NS
	NV	0.01	0.04
Day 5	DV	0.003	0.01
	NV	0.003	0.01

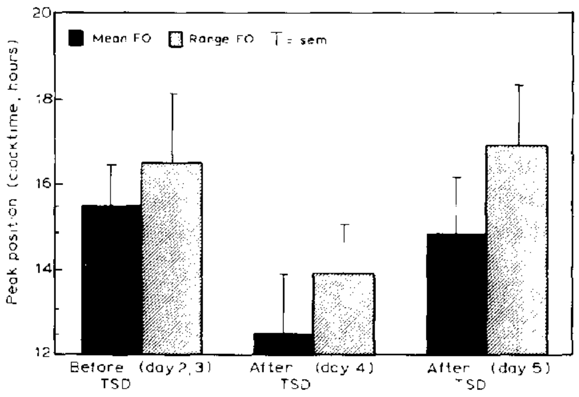

Fig. 2. Effect of TSD on the peak position of mean F0 and range F0 in 14 depressed patients. 'Before TSD' represents the averaged values of days 2 and 3.

The effect of TSD on vocal parameters

The effect of TSD on vocal parameters was tested by comparing the averaged scores of the mean F0 and the range F0 on the day before TSD with the averaged scores on the day following TSD. No significant effects of TSD on the levels of the vocal parameters were found (Wilc).

As was shown for the baseline scores before TSD, after TSD there is also a significant pattern in the mean and in the range F0, whereas the pattern of the depressed mood was not significant, either before or after TSD (Friedman ANOVA: see above). Table 1 shows that on the day after TSD there was no significant difference between the morning and the evening scores.

The position of the peak of a curve is one aspect of circadian organization. Visual inspection of Fig. 1 suggests that the peak of the mean F0 and the range F0 shifted to an earlier moment during and after TSD. The peak position was measured on the two baseline days preceding TSD and the two days during and following TSD. The averaged peak positions of mean F0 and range F0 before and after TSD are presented in Fig. 2. The averaged peak position over the two days before TSD was then compared with the day after TSD as well as with the following day (Wilc: the mean F0 before TSD compared with day 4 after TSD: $P = 0.017$ and with day 5: $P = 0.463$; the range

F0 before TSD compared with day 4 after TSD: $P = 0.084$ and with day 5: $P = 0.845$; $n = 14$). Only the peak of the mean F0 shifted significantly to an earlier moment. The change in the peak position of the range F0 showed a tendency in the same direction. Fig. 3 depicts the baseline course of the mean F0 (averaged over 2 days) in comparison with the course of the mean F0 during and after TSD. During TSD the patients show their lowest value at 1.00 a.m., the first moment of their sleep-deprived period. From 1.00 a.m. the curve inclines, resulting in an earlier maximum of the mean F0 on the day following TSD than on the baseline days before TSD.

In conclusion, TSD has no effects per se on the levels of the mean F0 and the range F0. TSD shifted the maximum of mean F0 to an earlier moment. This effect of TSD on the peak position of mean F0 is transient.

Relationships between vocal parameters and depressed mood

Relations between vocal parameters and mood were investigated in three different ways. Firstly, for each time point before TSD the levels of mood

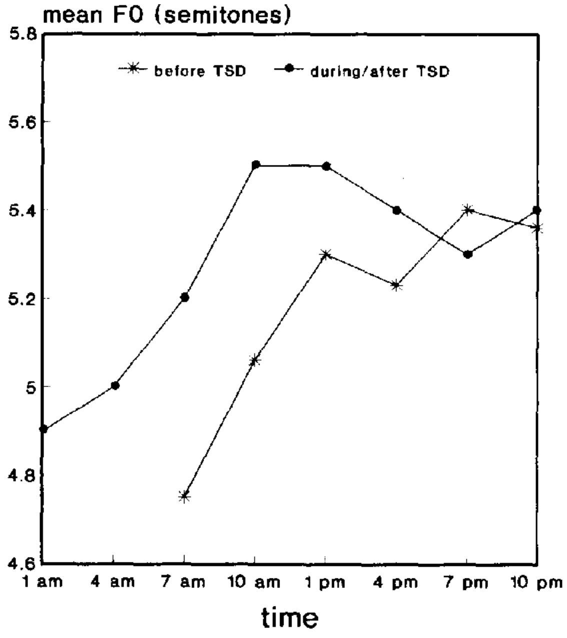

Fig. 3. Course of mean F0 in depressed patients before and during/after TSD. 'before': averaged scores of days 2 and 3.

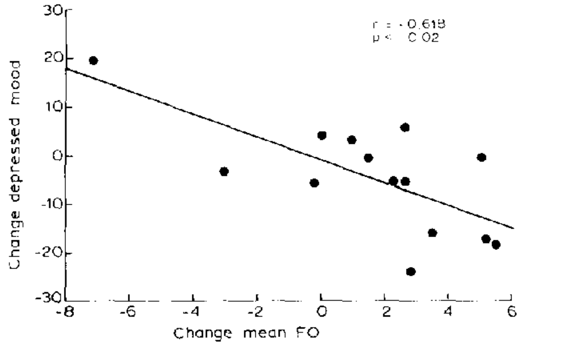

Fig. 4. Correlation between the mood response to TSD and the mean F0 response to TSD.

were correlated with the range F0. This procedure was not followed for the mean F0 scores, because these scores were normalized for each individual patient. Secondly, changes in mood over baseline days and nights were correlated with corresponding changes in the mean F0 and the range F0. Thirdly, the change in depressed mood as a response to TSD was correlated with the change in the two vocal parameters.

(1) No significant relationships were found between the baseline levels of depressed mood and the corresponding values of the range F0.

(2) Changes in depressed mood over days 2 and 3 (7.00 a.m.–10.00 p.m.) and nights 1 and 2 (10.00 p.m.–7.00 a.m.) are correlated with the corresponding changes in vocal parameters. In spite of the resemblance in mood pattern and patterns on mean F0 and range F0 (Fig. 1), only the change in mood and the range F0 over night 2 are significantly correlated ($r = -0.703$, $n = 12$; $P < 0.01$).

(3) The mood response to TSD was significantly correlated with the mean F0 response to TSD ($r = -0.618$; $n = 14$; $P < 0.02$) (Fig. 4). The relationship between the range F0 response and the mood response to TSD was not significant ($r = -0.449$; $n = 14$; NS).

The prediction of the mood response to TSD

Different parameters were studied for their predictive properties. (1) The averaged day scores of the range F0 and mood preceding TSD, (2) the diurnal and nocturnal variation in both vocal parameters and mood. The results are presented in Table 2. It was found that only the diurnal and

TABLE 2

SPEARMAN RANK CORRELATIONS BETWEEN TSD PRECEDING DIURNAL VARIATION (DV) AND NOCTURNAL VARIATION (NV) IN LEVELS OF MEAN F0, RANGE F0 AND MOOD ON THE ONE HAND AND THE MOOD RESPONSE TO TSD ON THE OTHER

	Mean F0			Range F0			Depressed mood	
	DV	NV	m day score	DV	NV	m day score	DV	NV
Day 1			−0.024 (14)			−0.264 (14)	0.687 * (14)	
Day 2	−0.021 (12)	0.261 (12)	0.035 (14)	−0.038 (12)	0.063 (12)	−0.324 (14)	0.568 * (14)	−0.499 (14)
Day 3	−0.420 (11)	0.175 (12)	−0.018 (14)	−0.368 (11)	0.271 (12)	−0.361 (14)	0.728 ** (14)	−0.607 (14)

Figures in parentheses are numbers of subjects. * $P < 0.05$; ** $P < 0.01$.

nocturnal variation in mood could predict the mood response to TSD.

Discussion

Circadian organization of vocal parameters

It was found that the vocal parameters mean F0 and range F0 show a clear circadian pattern. This pattern is of interest in the context of the assumption that circadian mechanisms play a role in TSD-induced mood changes. Despite the impression that depressed patients showed considerable diurnal variation in depressed mood (Fig. 1), this patterning in mood was not significant for the entire group of patients. Only seven of the 14 patients had a diurnal variation of at least 6 units on the AMS on two of the three baseline days. This number is in line with other findings (Stallone et al., 1973). The finding that diurnal patterning in vocal parameters is present in all patients but diurnal variation of depressed mood in only 50% suggests that the underlying mechanisms regulating the diurnal variation in vocal parameters and mood are not the same. Other findings support this interpretation. Several authors reported a positive correlation between diurnal variation in mood on the day preceding TSD and the mood response to TSD (Roy-Birne et al., 1984; Elsenga and Van den Hoofdakker, 1987). In the present study this finding was confirmed for the 3 days preceding TSD (Table 2). In contrast to this relationship, both diurnal and nocturnal variation in mean F0 or range F0 before TSD were significant, but not related to the mood response to TSD.

The temporal course of the mean F0 and the range F0 may give some clues as to their regulation. With respect to the regulation of the circadian system two types of processes are proposed (Daan et al., 1984). On the one hand there is a set of rhythms predominantly regulated by an internal biological clock. On the other hand, there is a set of rhythms under the direct control of the sequencing of sleeping and waking. Sleep deprivation is a good technique to discriminate between the two extreme possibilities.

TSD had no effect on the averaged day levels of the mean F0 and on those of the range F0 after TSD in comparison with the averaged scores on the day before TSD. Moreover, also in the night of TSD a significant nocturnal variation exists of the mean and the range F0. Hence, the (nocturnal) variation as well as the amplitude of the curve is not affected by TSD. This finding indicates that these aspects of patterning of both vocal parameters are not sleep-dependent, suggesting that they may be ruled by an internal clock. However, in two respects circadian patterning of vocal parameters was affected by TSD. Firstly, on the day following TSD the diurnal variation in mean F0 and range F0 was not significant. This effect may be explained by the changes in peak position of both parameters, which will be considered next (Table 2). Secondly, TSD shifted the maximum of the mean F0 over an interval of 3 h to an earlier moment (Figs. 1–3). For the range of F0 a tendency was found in the same direction. Data on the 'peak position' of the vocal parameters should be considered with caution: they are a rough estimate of group means, based on measures collected at 3-h intervals. Peak timing is very sensitive to random fluctuations. A better estimate can be obtained from studying the shift of the slope of the curve. Fig. 3 reveals an averaged shift of 5 h. The slope shifts of the F0 curves, together with the finding that the level of the maximum of the F0 curves did not change after TSD, may explain the relatively small and consequently non-significant diurnal variation as assessed between 7.00 a.m. and 10.00 p.m. on the day directly after TSD (Table 1).

The shift of the maximum of the mean F0 is transient. After one night of subsequent sleep it disappeared. In the same group of patients comparable results were found with respect to cortisol excretion curves: TSD induced, besides an increase in urinary cortisol excretion, an advance of the maximum of the excretion curve. After one night of sleep this effect disappeared (Bouhuys et al., 1990). In addition the shift of the peak position of the mean F0 is significantly correlated with the cortisol response to TSD ($r = 0.599$; $P = 0.036$; $n = 13$). It is unlikely that this shift of the curves is ruled by the biological clock, because sleep-wake manipulations do not induce such large phase shifts in the biological clock (Wever, 1979). Thus, the shift of the maximum should be ascribed to other factors than those ruled by the internal clock. To summarize, the circadian variation in vocal parameters is very pronounced. Vocal parameters show circadian changes due to TSD, and the mood response to TSD is related to the mean F0 response to TSD. However, in contrast to diurnal variation in mood, diurnal variation in vocal parameters did not predict the mood response to TSD. Apparently mood and vocal parameters are regulated by different mechanisms. Sleep deprivation may alter circadian rhythms in depressed patients, but the data on vocal parameters do not support the hypothesis that clinical improvement depends upon altering mean F0 or range F0 curves.

Relationships between vocal parameters, arousal and mood

In non-depressed subjects the mean F0 is related to arousal (Scherer, 1987; Darby, 1981). The relation between the cortisol excretion response to TSD and the peak advance of the mean F0 also suggests a relation of the mean F0 with arousal. The finding that TSD affects mood as well as this mean F0 does not contradict the assumption that arousal may play a role in the mood response to TSD.

In the present study vocal parameters and depressed mood were measured over a 3-day baseline period. Seven patients showed a clear diurnal variation in mood. The diurnal variation and nocturnal variation in mood were not related to the diurnal and nocturnal variation in both vocal parameters. As discussed earlier, the diurnal patterning of mood and vocal parameters may have different origins. In addition, the mood response to TSD was negatively correlated with the mean F0 response to TSD. Hence no clear relationships were found between mood and range and mean F0.

Nilsonne (1987) reported a significant increase in the variation in F0 (SD) in improved depressed patients compared with their depressed state, whereas the opposite was also found (see Scherer, 1987). Moreover, Darby and Hollien (1977) did not find that changes in the variation of pitch parallel changes in depression after electroconvulsive shock treatment. With respect to the mean F0, the data of Hargreaves and Starkweather (1964), who found that an increase in mean F0 coincides with improvement of depression in some depressed patients, are in line with our data concerning the TSD response. Darby and Hollien (1977) and Nilsonne (1987) did not find a consistent relationship between improvement and changes in the mean F0, whereas Tolkmitt et al. (1982) found that improvement coincided with a small decrease in the mean F0.

Many uncontrolled factors may account for the lack of clear relationships between mood on the one hand and mean F0 and range F0 on the other. In the present study depressed patients were studied only during their depressed state, whereas in other reports (Tolkmitt et al., 1982; Nilsonne, 1987; Scherer, 1987) depressed patients were studied during their depressed state as well as during remission. Another confounding factor may be that different degrees of agitation and/or retardation have occurred in the depressed groups studied. Agitated patients can be expected to show high F0 and a wide F0 range. Patients in the retarded category, on the other hand, would be likely to manifest low F0 and a small F0 range. As demonstrated in the present study, the diurnal variation in mood and F0 parameters may be an important source of error. In order to compare mood and vocal parameters at different times, these parameters should be assessed at the same time of the day. None of the aforementioned studies reported on assessment time of the vocal and mood parameters.

The diurnal organization of vocal parameters may have practical consequences: results of voice tests in clinical practice should be controlled for the time of assessment. Although this suggestion is based on a depressed group of patients, circadian patterns of mood and arousal-related parameters have also been reported in non-depressed subjects, suggesting that circadian organization of vocal parameters may not be confined to a depressed population (Thayer, 1967; Clemens et al., 1976).

Concluding remarks

In the context of the hypothesis that circadian organization may be related to mood disturbances it is unfortunate that behavioral/physiological indicators of the underlying organization are scarce, in contrast to biochemical or endocrinological indicators. On the behavioral level self-ratings of mood and arousal, measures reflecting cognitive processes (such as finger tapping, time estimation), and sleep-wake timing are usually measured as possible indicators of the internal biological clock (Wever, 1979; Monk, 1987). Voice parameters may be a valuable addition to this list. Considering the levels of measurement mentioned above, voice parameters may fill the gap between on the one hand the biochemical and physiological levels, reflecting unconscious processes, and on the other hand the behavioral level, reflecting conscious processes.

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