Effect of Group Practice of the *Transcendental Meditation* Program on Biochemical Indicators of Stress in Non-Meditators: A Prospective Time Series Study

Kenneth G. Walton
Kenneth L. Cavanaugh
Nirmal D. Pugh
Maharishi University of Management

Randomized longitudinal experiments as well as cross sectional studies have shown that practice of the Transcendental Meditation (TM) technique by individuals reduces cortisol excretion and other biochemical, physiological, and psychological indicators of stress. Other studies report that group practice of an advanced form of the TM program by a small fraction of the population significantly reduces crime, violence, and other behavioral indicators of "social stress" in the entire population. This prospective, quasi-experimental study investigates a proposed psychoneuroendocrine mechanism that may help to mediate these observed societal effects. Dynamic regression analysis of time series observations over the experimental period (77 days) found that the daily change in the size of a TM group was a significant predictor of immediately subsequent mean (natural log) overnight excretion rates of (a) cortisol, (b) the main metabolite of serotonin (5-HIAA), and (c) the ratio of rates for 5-HIAA and cortisol. An increase in the day-to-day change in the size of the group for the afternoon session was a significant predictor of reduced cortisol excretion later that night in a group of 6 non-practitioners living and working up to 20 miles from the group ($t(68) = -2.98, p = .004$). An increase in the daily change in group size also was a significant predictor of increases in both the excretion rate of 5-HIAA ($\chi^2(2) = 7.34$, $p = .03$) and the ratio of the

---

Author's Info: Kenneth G. Walton, Maharishi University of Management, 1000 North 4th Street, Fairfield, Iowa 52557-1005; (641) 472-8370; fax (641) 472-1167; e-mail kwalton@mum.edu.

Authors' Note: This is a revised version of a paper presented at the Symposium on Stress and Human Disease, Northwestern University, October 22–24, 1999.

Journal of Social Behavior and Personality, 2005, *17,* 339–373.

excretion rates of 5-HIAA to cortisol ($t(69) = 4.56$, $p < .0001$). These findings are consistent with those of a prior time series quasi-experiment that examined 5-HIAA excretion in another sample of individuals outside the group. Thus the results of the current study support the hypothesis that group practice of the TM program reduces social stress by producing beneficial neuroendocrine effects in non-meditators outside the group.

Over 40 studies have reported reductions in crime, violence, and other indicators of "social stress" due to daily group practice of the Transcendental Meditation (TM) technique (and its more advanced aspect, the TM-Sidhi program) by a small fraction of the population (Dillbeck, 1990; Hagelin, Rainforth, Orme-Johnson, Cavanaugh, & Alexander, 1999; Orme-Johnson, 2003; Orme-Johnson, Alexander, Davies, Chandler, & Larimore, 1988). An annotated bibliography of these studies is available online (Maharishi University of Management, 1999). This type of effect was predicted over 30 years ago by Maharishi Mahesh Yogi, founder of the TM program (Dillbeck, Cavanaugh, Glenn, Orme-Johnson, & Mittlefehldt, 1987). The "Maharishi Effect," as it has come to be known, appears to defy explanations based on ordinary social interactions and has been cited as evidence for the field nature of consciousness (Dillbeck, 1990; Dillbeck et al., 1987; Hagelin et al., 1999; Orme-Johnson et al., 1988). The present study investigates stress-related neuroendocrine changes in non-meditating members of the population that may mediate the observed beneficial effects on social behavior.

Stress is both an individual and a social phenomenon. On the individual level, it may be defined as the physiological changes produced by challenging conditions or "stressors." One leading authority (Sapolsky, 1992, p. 8) defines stressors as "physiological or psychological perturbations that throw us out of homeostatic balance…" and the stress-response as "the set of neural and endocrine adaptations that help us reestablish homeostasis." In most cases the stress-response involves activation of the hypothalamic-pituitary-adrenocortical (HPA) axis, resulting in increased secretion of the glucocorticoid cortisol, often referred to as the principal "stress hormone." While increases in cortisol are often protective and adaptive in the short run, persistent activation of the HPA axis can cause a prolonged elevation of cortisol that is damaging to health. Extreme, prolonged, or chronic intermittent stress is known to cause long-lasting changes in the HPA axis and other systems of neuroendocrine regulation, resulting in detrimental health consequences and maladaptive behaviors. Many of the latter can be traced to excess levels of cortisol or other glucocorticoids (McEwen, 1998; Sapolsky, 1992; Seeman, Singer, Rowe, Horwitz, & McEwen, 1997).

On the societal level, stress incurred by individuals gives rise to social stress. Social stress has been defined operationally in terms of differences between communities or societies in the level of specific stressful life events or social stressors. Such stressors include unemployment, disasters, divorce, bankruptcies, strikes, etc., which, in turn, can negatively influence individuals in society, increasing the incidence of illness, suicide, crime, aggression, violence, and other social outcomes (Linsky, Bachman, & Straus, 1995; Linsky & Straus, 1986). Like stressors on the individual level, evidence suggests that social stressors produce their detrimental influence on individual behavior and health partly through altering the neuroendocrine mechanisms maintaining homeostasis (Seeman & McEwen, 1996).

In combating the problem of stress, then, an ultimate goal is to restore to optimal function these neuroendocrine mechanisms that maintain homeostasis. Programs that reduce or reverse the effects of stress in individuals produce a variety of benefits to physical and mental health in those individuals (e.g., Alexander et al., 1996; Castillo-Richmond et al., 2000; Orme-Johnson & Walton, 1998). The Transcendental Meditation program is the most extensively investigated of such programs, with over 600 studies reporting beneficial, stress-reducing effects (Jevning, Wallace, & Beidebach, 1992; Orme-Johnson & Walton, 1998).

Several studies support the hypothesis that practice of the TM technique can reverse long-lasting effects of stress on neuroendocrine regulation, including reduction of cortisol excretion and other biochemical indicators of stress (Jevning, Wilson, & Davidson, 1978; Levitsky, 1998; MacLean et al., 1997; Walton, Pugh, Gelderloos, & Macrae, 1995). Decreased blood levels and excretion of cortisol were reported in a random-assignment, longitudinal study of TM practitioners (Levitsky, 1998; MacLean et al., 1997). Increased excretion of 5-HIAA (5-hydroxyindoleacetic acid), a major metabolite of serotonin, also has been reported in individuals practicing the TM technique (Bujatti & Riederer, 1976; Walton et al., 1995). These increases were found to be correlated with reductions in anger, anxiety, aggression and other negative emotions (Walton & Pugh, 2000). Cross-sectional comparison of TM practitioners and non-meditating controls found that the ratio of 5-HIAA to cortisol showed a greater difference between the two groups than was found for 5-HIAA or cortisol excretion alone (Walton & Pugh, 2000). The biochemical changes described above have been linked to decreased health problems such as hypertension and heart disease (Alexander et al., 1996; Walton et al., 1995) as well as to reduced substance abuse and improved rehabilitation of criminal offenders (Walton and Levitsky, 1994; Walton & Levitsky, 2003).

The effects of the TM and TM-Sidhi programs in individual practitioners involve physiological, psychological, and behavioral changes that are thought to be primarily due to periods of "transcending" occurring during the practices. In the process of transcending, the active thinking mind settles down to a state of restful alertness termed "transcendental consciousness," a proposed fourth major state of consciousness with properties different from the states of deep sleep, dreaming, and ordinary waking (Jevning et al., 1992; Mason et al., 1997; Travis & Pearson, 2000; Travis & Wallace, 1997, 1999).

Based on the understanding of consciousness available in the Vedic tradition (from which the TM and TM-Sidhi programs are derived), transcendental consciousness has been equated with the unified field proposed by quantum field theory to underlie all matter and energy in the universe (Dillbeck et al., 1987; Hagelin, 1987). Both transcendental consciousness and the unified field display the fundamental quality of self-interaction or self-referral and have been shown to exhibit many other fundamental qualities that are the same (Hagelin, 1987, 1989). Further discussion of this field-theoretic conception of consciousness is provided by Dillbeck et al. (1987), Orme-Johnson (2003), and Orme-Johnson et al. (1988).

The field of transcendental consciousness is said to be enlivened during the TM and TM-Sidhi programs, not only in those who practice them but also in others within the population who do not practice them (Maharishi Mahesh Yogi, 1975, 1986). Physiological evidence in support of the hypothesized field nature of consciousness has been reported in electroencephalographic (EEG) studies (Orme-Johnson, Dillbeck, Wallace, & Landrith, 1982; Travis & Orme-Johnson, 1989).

Because of the potential benefits of reduction in social stress through the group practice of these programs, there is a pressing need for a better understanding of the mechanism mediating these changes. One possible mechanism involves neuroendocrine changes similar to those reported in individuals practicing the TM technique. According to the field-theoretic view of consciousness, the field of transcendental consciousness enlivened in individuals as they practice the TM and TM-Sidhi programs also gets enlivened throughout society, especially by the group practice of these programs (Maharishi Mahesh Yogi, 1975, 1986). If this field-theoretic perspective is valid, and if the enlivenment of transcendental consciousness gives rise to beneficial neuroendocrine changes, then one would predict that individuals outside the group would exhibit biochemical changes similar to those observed in TM practitioners.

To produce a measurable effect of the group on society, the predicted critical threshold for the number of participants practicing the TM and TM-Sidhi programs together in a group (hereafter called "the TM-group") is the square root of 1% of the population (Dillbeck et al., 1987; Hagelin, 1987; Orme-Johnson et al., 1988). For the site of the current study—the town of Fairfield, Iowa and the surrounding county (population 16,700)—the predicted number of group participants required to create measurable effects outside the group was 20–30. (For a relatively small town such as Fairfield, the square root of 3–5 % of the population is the predicted requirement, rather than the square root of 1%, the threshold applicable to larger populations.) This critical threshold was substantially exceeded on each of the 77 days of the study. During this period, the average number of participants in the TM group for the daily afternoon session was approximately 1400 (standard deviation 172). The mean daily change in group participation (absolute value) was 88, with a standard deviation of 80.

Because the number of participants in the TM group never fell below the predicted critical threshold during the period of this study, it was not possible to test the impact on the biochemical measures of movements in the size of the group from below to above threshold. Rather, the focus of this study was to empirically assess the impact of fluctuations in the size of the TM group in a situation in which the number of group participants remained continuously above the predicted threshold necessary to produce effects in individuals outside the group.

The empirical analysis found that the change in the size of the TM group from the previous day was a significant predictor of the immediately subsequent overnight excretion rates of cortisol and 5-HIAA, as well as the 5-HIAA-to-cortisol ratio. An increase in the day-to-day change in the size of the afternoon TM-group session was a significant predictor of decreased urinary cortisol excretion that same night. Such increases in the size of the group were also a significant predictor of subsequent increases in 5-HIAA excretion as well as in the 5-HIAA-to-cortisol ratio. The finding that daily change in the size of the TM group was a significant predictor of the excretion rates for cortisol and 5-HIAA may suggest some type of habituation response of the biochemical variables to the TM group size.

The empirical results of the current study are consistent with those of a previous time series quasi-experiment that investigated the influence of group practice of the TM program on overnight 5-HIAA excretion in a different sample of non-meditators (Pugh, Walton, & Cavanaugh, 1988). These findings are also consistent with those of two previous time series studies that examined 5-HIAA excretion in TM-group participants (Pugh et al., 1988). Another time series study reported a significant positive effect of the TM group on daytime 5-HIAA excretion in individuals participating in the group (Löliger, 1990).

METHODS

Participants and Data

Participants in the TM group were students, faculty, and staff of Maharishi University of Management in Fairfield, Iowa, and working-age adults living in the Fairfield area. Non-TM participants for the experiment were individuals not practicing the TM technique who lived or worked in Fairfield or the surrounding area and who volunteered to participate in the study after being contacted through their employers. The six non-TM participants were two women clerical workers (one aged 27 years and the other 50), an 18-year-old son of the 50-year-old woman, and three male factory workers (two aged 38 years and one, 41). Although the places of employment of all but the teenage male were in Fairfield, only the 27-year-old woman and one of the factory workers lived inside the city limits. The towns where the others lived were located 12 to 20 miles from Fairfield.

Nightly urine was collected for 77 consecutive days. To ensure that the measured metabolite of serotonin (5-hydoxyindoleacetic acid, 5-HIAA) originated from serotonin synthesized endogenously, foods known to contain substantial amounts of serotonin (e.g. bananas, walnuts, and avocados) were excluded from the diet. Urine collections were in bottles containing 10 grams of boric acid as preservative. The recorded starting time was the last urination in the toilet before bed and ending time was the last collection upon rising in the morning. Total volumes were measured within 3 days and samples were stored at minus 20 degrees centigrade until assay.

Urinary 5-HIAA was analyzed by spectrophotometric assay (Shihabi & Wilson, 1982). The method was supplemented by the simultaneous testing of a sample of a urine pool (combining samples collected from 12 participants) as an external standard. The interassay coefficient of variation was 5.9% for these urine pool samples. Cortisol was analyzed by radioimmunoassay using commercial kits (Diagnostic Products Corp., Los Angeles) with an interassay coefficient of variation of 2–4%.

In the statistical analysis, the 5-HIAA excretion rate was the mean overnight rate for the six non-meditating participants. The cortisol excretion rate used in the analysis was based on the pooled daily sample for all six participants, with each participant's contribution to the pool being proportionate to their overnight urine excretion rate (total urine volume divided by the total hours of their collection period). Thus the measured cortisol excretion rate was equivalent to a weighted mean for all six non-TM participants, with weights proportional to the total urine excretion per hour for each participant. This method of forming the urine pool was chosen because the excretion of cortisol and most other substances is more closely associated with the duration of the collection period than with urine volume. The correlation between rate of urine excretion and rate of cortisol excretion was minimal ($r = .09$, $p = .43$), and therefore it is unlikely that the different urine volumes for each participant had a significant influence on the mean cortisol rate.

Data on daily participation in the TM group program were obtained from the Capitol for the Age of Enlightenment, the nonprofit educational organization that was responsible for administering the TM group meditations in Fairfield. The afternoon group TM program began at 5:20 PM and typically ended between 6:00 and 6:30 PM. Thus the afternoon group session ended approximately 4–5 hours before bedtime (the beginning of the overnight urine collection period for the non-meditating participants) and approximately 12–13 hours before rising (the end of the collection period). Thus the afternoon TM group program for a given day always temporally preceded the overnight collection period that began later that same evening. Consequently, these data did not permit measurement of any possible contemporaneous (lag-zero) effect for the TM-group variable on the biochemical variables, and the shortest measured time lag for the TM variable is denoted as lag one.

Attendance in the daily morning TM group program was not included in the analysis because the larger afternoon group session was much closer in time to the overnight collection period, and thus might be expected to show a stronger statistical relationship to the biochemical measures. The morning group was substantially smaller in size (mean 977 versus 1400 for the afternoon) and highly correlated ($r = .86$) with afternoon attendance. The correlation between daily changes in the morning group attendance and daily changes for the afternoon session was much lower ($r = .33$).

Statistical Analysis

To examine the nature of possible causal relationships between the group practice of the TM program and the biochemical measures, we used a statistical procedure that has been frequently applied in the analysis of time series data (Granger & Newbold, 1986; Hamilton, 1994; Kaufmann & Stern, 1997). Based on a definition of causality developed by Wiener (1956) and Granger (1969), the test for "Granger-causality" relies on the assumption that movements in a causal variable X should temporally precede those in the variable Y that are caused by X. In addition to the assumption that the cause should precede the effect, this approach assumes that X should contain unique predictive information about Y not contained in past values of Y or other explanatory variables (Granger & Newbold, 1986). Thus a time series X is said to cause another time series Y, in the sense defined by Granger and Wiener, if past values of X are statistically significant predictors of current values of time series variable Y, after controlling for the effect on Y of its own past values and for past values of other important predictor variables.

The existence of a causal relationship, as operationally defined by Wiener and Granger, thus implies a statistical causal ordering, or predictive relationship, between two time series variables. The empirical finding of such a predictive relationship between variables does not necessarily imply the existence of "true" causality as variously defined by philosophers of science (Zellner, 1979). Tests for a significant predictive relationship between two time series variables are unlikely to provide useful information about a true causal relationship between them if these variables are selected arbitrarily. However, such predictive tests may offer useful information about true causality when a causal theory linking the two variables exists, and when that theory has testable implications that can be framed in terms of one variable predicting another (Hamilton, 1994). The tests for causal ordering also depend on the set of conditioning variables used in the statistical analysis. Omission of relevant variables may bias parameter estimates and affect the conclusions of the tests.

The tests for causal ordering were based on ordinary least squares (OLS) estimates of linear regression equations that express each response variable as a function of its own past values and those of other predictor variables (Hamilton, 1994). Dynamic regression equations of the following form were estimated:

$$\begin{aligned}\mathrm{LRATIO}_t &= a_{10} + \Sigma_i\, a_{1i}\, \mathrm{LRATIO}_{t-i} + \Sigma_i\, b_{1i}\, \mathrm{DTM}_{t-i} \\ &\quad + \Sigma_i\, c_{1i}\, \mathrm{DTEMP}_{t-i} + u_{1t}\,, \quad t = 1, 2, \ldots T;\ i = 1, 2, \ldots m\end{aligned} \tag{1}$$

$$\begin{aligned}\mathrm{LCORT}_t &= a_{20} + \Sigma_i\, a_{2i}\, \mathrm{LCORT}_{t-i} + \Sigma_i\, b_{2i}\, \mathrm{DTM}_{t-i} + \Sigma_i\, c_{2i}\, \mathrm{LHIAA}_{t-i} \\ &\quad + \Sigma_i\, d_{2i}\, \mathrm{DTEMP}_{t-i} + u_{2t}\,, \quad t = 1, 2, \ldots T;\ i = 1, 2, \ldots m\end{aligned} \tag{2}$$

$$\begin{aligned}\mathrm{LHIAA}_t &= a_{30} + \Sigma_i\, a_{3i}\, \mathrm{LHIAA}_{t-i} + \Sigma_i\, b_{3i}\, \mathrm{DTM}_{t-i} + \Sigma_i\, c_{3i}\, \mathrm{LCORT}_{t-i} \\ &\quad + \Sigma_i\, d_{3i}\, \mathrm{DTEMP}_{t-i} + u_{3t}\,, \quad t = 1, 2, \ldots T;\ i = 1, 2, \ldots m\end{aligned} \tag{3}$$

In these equations, LRATIO_t is the natural log of the ratio of mean 5-HIAA excretion to mean cortisol excretion (multiplied by 10); Σ_i is the summation operator, with summation over time-lag i to maximum lag m; DTM_t is the change in TM-group participation from the previous day for the afternoon session (divided by 100); $LCORT_t$ is the natural log of the mean cortisol excretion rate (μg/hr) at time t; $LHIAA_t$ is the natural log of the mean 5-HIAA excretion rate (μg/hr) (multiplied by 10); and $DTEMP_t$ is the change in average daily temperature from the previous day (divided by 10). The variables u_{1t}, u_{2t}, and u_{3t} are independent and identically distributed random error terms. The natural log transformation was used to reduce substantial positive skewness in the 5-HIAA and cortisol data as well as to stabilize their variances.

The causality testing procedure may be illustrated as follows. In equation (1), the series DTM_t is said to cause the series $LRATIO_t$, in the sense defined by Wiener and Granger, if the estimated regression coefficients on the lagged values of DTM_t are jointly significantly different from zero, indicating rejection of the null hypothesis of no causal ordering. Causality tests for other variables are conducted in an analogous manner.

In the three equations, all variables are expressed as (discrete) rates of change. The change in average daily temperature was included in each regression equation because serotonin (and to a lesser degree, cortisol) have been reported to be affected by temperature (Ghosh, Taneja, Malhotra, Kumar, & Ahuja, 1974; Sarrias, Artigas, Martinez, & Gelpi, 1989). Use of the change in temperature, rather than temperature, was motivated on empirical grounds. Inclusion of the change in TM-group participation as a predictor was suggested by previous empirical analysis of data on 5-HIAA excretion from three other time series quasi-experiments (Pugh et al., 1988). Use of the change in TM-group participation was also supported by formal tests indicating that the changes appeared to be unambiguously stationary with respect to the mean.

Following common practice (Granger & Newbold, 1986), the number of time lags for the predictor variables was empirically determined using an objective criterion for the selection of model order. The number of lags was determined by minimization of the Bayesian Information Criterion (BIC) (Schwarz, 1978), provided that the resulting regression equation satisfied standard diagnostic tests, such as lack of serial correlation of residuals. The BIC criterion is defined as $BIC = T \ln(s^2) + k \ln(T)$, where T is the number of observations, $\ln(s^2)$ is the natural logarithm of the maximum likelihood estimate of the variance of regression residuals, and k is the number of model parameters. The BIC seeks to provide a balance between the competing goals of model simplicity (parsimony) and precision of model fit. Minimization of the BIC has been shown to yield asymptotically consistent estimates of model order

(Enders, 1995). Models with up to a maximum time lag of 3 days for all explanatory variables were considered.

When the BIC criterion led to the selection of regression models that included only one time lag for the explanatory variables, t-tests for the regression slope coefficients were used to test the null hypothesis of no causal ordering. When more than one lag of each predictor was included, joint significance tests were used. On the basis of simulation studies, Wald tests have been recommended for such joint tests of causal ordering (Geweke, Meese, & Dent, 1983). The Wald test statistic was calculated as $T(RSS_c - RSS_u)/RSS_u$, where T is the number of observations, RSS_u is the residual sum of squares for the unconstrained regression, and RSS_c is the residual sum of squares for the constrained regression (Geweke et al., 1983). The Wald statistic has an (asymptotic) chi-square distribution with degrees of freedom equal to the number of constrained parameters.

Prior to the regression analysis, the time series plot as well as the sample autocorrelations and partial autocorrelations for each response and predictor variable were examined for evidence of stationarity. Constancy of mean and variance over time (covariance stationarity) is required for valid statistical inference. Stationarity for each series was also investigated using a formal test for "unit roots," the Phillips-Perron test (Phillips & Perron, 1988). The finding of a unit root in the autoregressive representation of the time series would indicate the presence of a non-stationary random walk (stochastic trend) component that would invalidate all standard statistical tests (Dickey & Fuller, 1979; Enders, 1995).

The Phillips-Perron test for unit roots is based on OLS regression estimates for the equation $\Delta y_t = \alpha + \gamma\, y_{t-1} + \delta\, t + \varepsilon_t$. In this regression, y_t is the variable to be tested for a unit root, Δy_t is the first difference of y_t, α is the regression intercept, γ is the slope coefficient for y_{t-1}, δ is the slope coefficient for the deterministic time-trend variable t, and ε_t is a random disturbance term that need not be serially uncorrelated and identically distributed (Phillips & Perron, 1988). When the trend term in this equation was not significant, the unit root test was based on the regression without the trend, to increase the power of the test (Enders, 1995). In the regressions with or without trend, γ should be equal to zero under the null hypothesis of a unit root.

Critical values for testing the null hypothesis $\gamma = 0$ were calculated by MacKinnon's (1991) response surface method. In the Phillips-Perron procedure, standard errors and t-ratios for the regression estimates were corrected for possible serial correlation in the disturbance ε_t using the Newey-West method (Newey & West, 1987).

Following common practice (e.g. Kaufmann & Stern, 1997), seasonal dummy variables representing the different days of the week were used, when required, to remove any significant serial correlation of regression residuals at the seasonal lag of 7. Significant correlation between residuals 7 days apart indicates weekly seasonality in the regression residuals. Since each regression included an intercept, only six dummy variables were needed to allow the regression intercept to differ for each day of the week (Harvey, 1990).

A battery of diagnostic tests was applied to the estimated regression equations to determine if other key assumptions of the statistical analysis were satisfied. To detect possible serial correlation of the regression residuals, a Lagrange multiplier (LM) test was used, the Breusch-Godfrey test (Breusch, 1978; Godfrey, 1978). The presence of either significant serial correlation of the residuals or heterogeneity of residual variance would result in inefficient parameter estimates and biased and inconsistent standard errors for the regression coefficients that would invalidate standard hypothesis tests (Harvey, 1990; Ramanathan, 1998).

LM tests were used to check for three different forms of heterogeneity of residual variance. Each test was based on an auxiliary regression (with a constant term) for which the squared residuals served as the response variable. To test whether the residual variance was systematically related to the fitted values for the original regression, the squared fitted values served as the independent variable in the auxiliary regression (Pesaran & Pesaran, 1991). To detect possible heteroskedasticity of the regression residuals over time, the independent variable in the auxiliary regression was a linear time trend (Goodrich, 1989). To test whether the residual variance was significantly related to one or more of the explanatory variables, the explanatory variables in the auxiliary regression were all the predictors from the original regression, as well as their squares and cross-products (White, 1980). These three tests for heterogeneity of variance are special cases of a general class of tests that has been shown to be robust to non-normality of the residuals (Koenker, 1981). Because the asymptotic chi-square version of the LM statistic for these tests has been shown to reject the null hypothesis too frequently in smaller samples, the results for the heteroskedasticity and serial correlation tests are reported as an "LM F-statistic" (Charemza & Deadman, 1997; Kiviet, 1986).

Additional diagnostic tests included two tests (Harvey, 1990) for structural change (parameter stability). The split-sample test was based on dividing the sample approximately in half and testing the null hypothesis that the regression parameter estimates for the two subsamples were equal. The predictive failure test examined 8 out-of-sample forecasts of the response variable based on the regression model estimated using the first 65 observations of the sample. The null hypothesis is that the predicted observations come from the same model as the estimated regression equation. The predictive failure test may be interpreted as a general test of model misspecification (Kiviet, 1986; Pesaran, Smith, & Yeo, 1985).

The Jarque-Bera test (Jarque & Bera, 1987) was used to test the null hypothesis that the regression residuals were drawn from a normal (Gaussian) distribution. In addition to the test for normally distributed residuals, a formal t-test for outliers based on the studentized residuals was used to check for outlying observations that might bias the OLS estimates (Weisberg, 1980). The test was implemented using special tabled t-values for the maximum studentized regression residual (Weisberg, 1980).

RESULTS

Prior to estimation of the regression equations, each variable in equations 1–3 was examined for stationarity. In each case, the diagnostic checks for stationarity were satisfactory. The time series plot as well as the sample autocorrelations for each variable appeared consistent with stationarity of mean and variance. For each variable the sample autocorrelations were found to die out quickly at both the seasonal and nonseasonal lags, consistent with stationarity of the mean (Wei, 1990).

Stationarity was also indicated by formal unit root tests. For each series, the unit root tests for stationarity were satisfactory. As shown in Table 1, the null hypothesis of a unit root for each of the variables in equations 1–3 was rejected at the .05 level or better using the Phillips-Perron test. Using Dickey and Fuller's (1981) tabled critical values, the deterministic trend variable was not significant at the .05 level for any of the Phillips-Perron regressions. This implies that unit root tests based on regressions without trend (column three) will have greater power than those with the nonsignificant trend variable (column two) (Enders, 1995). The non-significance of the trend term also indicates that linear detrending would not be appropriate for any of the variables in Table 1.

The ordinary least squares regression estimates for equations 1, 2, and 3—with the number of time lags determined by the BIC—are shown in Tables 2-4. For the log cortisol and log ratio equations, the BIC criterion led to selection of models with a maximum lag of one time period for the explanatory variables. The same lag-length was indicated by another widely used criterion for model selection, the Akaike Information Criterion (AIC) (Wei, 1990). As discussed below, a model with maximum lag of two periods for the predictors was selected for the log 5-HIAA equation. For each estimated regression, the overall (asymptotic)

TABLE 1 Unit Root Tests: Phillips-Perron Test Statistics

Variable	*Test statistic with trend and intercept*	*Test statistic with intercept*
Log cortisol (LCORT)	–7.34**	–7.20**
Log ratio (LRATIO)	–5.87**	–5.82**
Log 5-HIAA (LHIAA)	–7.76**	–7.80**
TM-group participation (TM)	–3.04	–2.95*
Change in TM group (DTM)	–8.79**	8.84**
Temperature (TEMP)	–3.12	–3.05*
Temp. change (DTEMP)	–10.60**	–10.67**

Note: Critical values for testing the null hypothesis of a unit root were calculated by MacKinnon's (1991) response surface method. Three lags were used in the Newey-West correction for residual serial correlation (Bartlett kernel). The number of observations is $T = 73$.

**The null hypothesis of a unit root is rejected at the 0.05 significance level. The critical value for regressions with trend and intercept is –3.47. The critical value for regressions with intercept and no trend is –2.90.*

***The null hypothesis of a unit root is rejected at the .01 significance level. The critical value for regressions with trend and intercept is –4.09. The critical value for regressions with intercept and no trend is –3.52.*

F-statistic was significant, and the scatter plot of the predicted and actual values indicated that the assumption of a linear relationship between response and predictor variables was a reasonable approximation.

All reported p values for the (asymptotic) t-ratios are for two-tailed hypothesis tests. The sample size in each case was the last 73 daily observations of the sample, rather than the full sample of 77; this allowed alternative models with different lag lengths to be estimated using a common sample size. A common sample size was necessary for valid comparison of alternative models using the BIC and AIC criteria, because the latter are proportional to the sample size employed in estimation.

Ratio of 5-HIAA to Cortisol

The OLS regression estimates for the log ratio equation are shown in Table 2. The null hypothesis that change in TM-group participation was not a significant predictor of the (log) ratio of the 5-HIAA-to-cortisol excretion rates was rejected ($t(69) = 4.56$, $p < .0001$). The lag-one regression coefficient for the TM-group variable is the estimated percentage change in the ratio resulting from a one-unit increase in the day-

TABLE 2 Causality Tests for 5-HIAA/Cortisol Ratio: Summary of Ordinary Least Squares Regression Analysis with the Dependent Variable Natural Log 5-HIAA/Cortisol Ratio (73 Observations)

Variable	*Coefficient*	*Standard Error*	*T-Ratio*[a]	*p Value*[b]
DTM_{t-1}	.11	.02	4.56	.0000
LRATIO_{t-1}	.33	.10	3.16	.002
DTEMP_{t-1}	.16	.05	3.29	.002
Constant	–.27	.05	–5.63	.0000

Number of observations 73	SD of dependent variable .31
F-statistic F(3, 69) 14.30 (p = .0000)	Mean of dependent variable –.40
SE of regression .25	R-squared .38
Sum of squared residuals 4.14	Adjusted R-squared .36
BIC 14.88	AIC 5.72

Diagnostic Tests

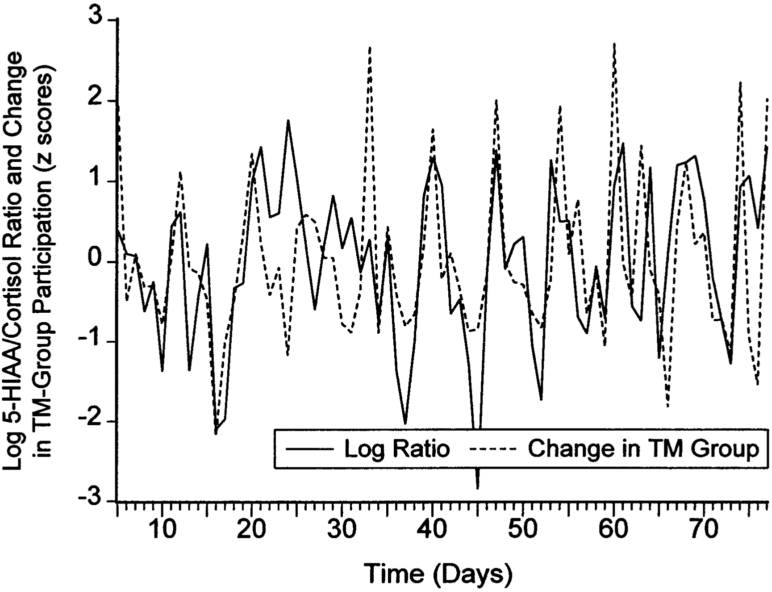
LM serial correlation tests: Lag 1: F(1, 68) = .00 (p = .98) Lags 1–7: F(7, 62) = .65 (p = .71)	LM heteroskedasticity tests: With fitted: F(1, 71) = 6.60 (p = .01) With time: F(1, 71) = 1.44 (p = .23)
Jarque-Bera test for normality: $\chi^2(2) = 1.35$ (p = .51)	With predictors: F(9, 63) = 1.11 (p = .37) Studentized residual test for outliers ($\alpha = .05$):
Split-sample test for structural change: F(4, 65) = .70 (p = .59)	Maximum $\lvert t_i \rvert = 2.98$ ($t_c = 3.55$) Predictive failure test F(8, 61) = .63 (p = .75)

[a] *Standard errors and* t*-ratios were calculated using White's (1980) correction for heteroskedasticity and are robust to heterogeneity of residual variance. The degrees of freedom for all* t*-tests is* T - k *= 69.*

[b] *Two-tailed tests.*

to-day change in group participation (Ramanathan, 1998). Thus an increase of 100 in the daily change in the size of the TM group was predicted to lead to an increase in the 5-HIAA-to-cortisol ratio of approximately 10.5 percent. While some visual exceptions may be seen in Figure 1, the generally positive relationship between changes in afternoon TM-group participation and the ratio of that evening's (log) excretion rates is apparent in Figure 1, which plots the standardized values of each series. The R-squared value of .38 indicates that the regression explained 38.3 percent of the variance in the log ratio.

This finding of a significant causal ordering statistically controls for the previous day's ratio of excretion rates (LRATIO_{t-1}) as well as for the



For clarity, each variable has been standardized by subtracting its sample mean and dividing by its sample standard deviation. Thus the vertical axis is measured in z-score *(standard deviation) units.*

FIGURE 1 Ratio of Daily Mean Overnight 5-HIAA to Cortisol Excretion Rates (natural logarithm) and the Prior Afternoon Change in Daily TM-Group Participation

prior daily change in average temperature ($DTEMP_{t-1}$). An increase in the daily temperature change was found to significantly predict an increase in the log ratio of 5-HIAA to cortisol excretion.

In addition to the predicted increase of 10.5 percent in the log ratio of excretion rates immediately following an increase in the daily change in TM-group size, the estimated regression equation predicts further smaller increases in the log ratio in subsequent periods. These subsequent increases decay rapidly to zero at an exponential rate governed by the parameter for the lagged dependent variable, .33. That the latter coefficient is less than 1.0 in absolute value indicates that the estimated regression equation is dynamically stable (Harvey, 1990). A similar decay was found for the predicted effect of the TM group on log cortisol excretion in the cortisol regression (Table 3), while a higher-order decay

TABLE 3 Causality Tests for Cortisol Excretion Rate: Summary of Ordinary Least Squares Regression Analysis with the Dependent Variable Natural Log Cortisol Excretion Rate (73 Observations)

Variable	Coefficient	Standard Error	T-Ratio[a]	p Value[b]
DTM_{t-1}	–.08	.03	–2.98	.00
$LCORT_{t-1}$	.23	.11	2.05	.04
$LHIAA_{t-1}$	–.15	.17	–0.90	.37
$DTEMP_{t-1}$	–.16	.06	–2.71	.01
Constant	.16	.05	3.12	.00

Number of observations 73
F-statistic F(4, 68) 5.70 ($p = .001$)
SE of regression .26
Sum of squared residuals 4.47
BIC 24.65

SD of dependent variable .29
Mean of dependent variable .25
R-squared .25
Adjusted R-squared .21
AIC 13.19

Diagnostic Tests

LM serial correlation tests:
Lag 1: F(1, 67) = .08 ($p = .78$)
Lags 1-7: F(7, 61)= .40 ($p = .90$)
Jarque-Bera test for normality:
$\chi^2(2) = .06$ ($p = .97$)
Split-sample test for structural change:
F(5, 63) = .87 ($p = .51$)

LM heteroskedasticity tests:
With fitted: F(1, 71) = 2.90 ($p = .09$)
With time: F(1, 71) = 1.76 ($p = .19$)
With predictors: F(14, 58) = .84 ($p = .65$)
Studentized residual test for outliers ($\alpha = .05$):
Maximum $|t_i| = 2.49$ ($t_c = 3.55$)
Predictive failure test F(8, 60) = .89 ($p = .53$)

[a] *The degrees of freedom for all* t*-tests is* T - k = *68.*

[b] *Two-tailed tests.*

was found for the effect on log 5-HIAA (Table 4). Both of the latter equations were also dynamically stable.

Because diagnostic tests indicated significant heteroskedasticity of the regression residuals with respect to the fitted values, all standard errors and t-ratios reported in Table 2 were adjusted for heterogeneity of residual variance (White, 1980). The results of the other diagnostic tests were all satisfactory. Tests for residual serial correlation at lag 1 and lags 1-7 were not significant, nor were tests for heteroskedasticity of residuals with respect to time or the predictors. Stability of the regression parameter estimates was indicated by failure of the split-sample test to reject the null hypothesis of equality of parameters for the two subsamples. The non-significance of the predictive failure test indicated the adequacy of the specification for the regression equation.

The failure to reject the null hypothesis that the regression residuals were drawn from a normal distribution suggests the absence of extreme outliers that might bias the OLS estimates. The absence of outliers was confirmed by the t-statistic for the largest studentized residual (max $|t_i| = 2.98$) (Table 2), which was less than the tabled .05 critical value ($t_c = 3.55$) given in Weisberg (1980).

Cortisol Excretion Rate

The OLS regression estimates for the log cortisol equation are shown in Table 3. The null hypothesis that change in TM-group participation was not a significant predictor of subsequent cortisol excretion was rejected ($p = .004$). The lag-one parameter estimate for the TM variable indicates that an increase of 100 in the daily change in the size of the TM group predicted a decrease in the cortisol excretion rate of approximately 7.7 percent. This finding of a significant causal ordering statistically controls for the previous day's cortisol and 5-HIAA excretion rates as well as for the prior daily change in average temperature. The R-squared statistic indicates that the regression explained 25.1 percent of the variance in log cortisol excretion.

The inverse relationship between the change in TM-group participation and subsequent cortisol excretion is indicated in the time series plot shown in Figure 2. To make this inverse relationship easier to see in the plot, the cortisol rate was multiplied by -1. Thus in this plot, while some visual exceptions may be seen, the generally positive co-movement in the two variables indicates a negative, rather than positive, relationship between the two. A significant inverse predictive relationship between temperature change and cortisol excretion was also found, while 5-HIAA was not a significant predictor of subsequent cortisol excretion.

All diagnostic tests for the estimated cortisol regression were satisfactory (Table 3), indicating that the statistical assumptions of the regression analysis were satisfied. The LM tests for heterogeneity of variance with respect to both the fitted values and the predictors were not significant at the .05 level. The test for heteroskedasticity with respect to time, however, was significant at the .10 level. As a further diagnostic check, all standard errors and t-ratios for the estimated cortisol equation were adjusted using White's (1980) correction for heteroskedasticity. The adjusted t-ratios (not shown) were close to those reported in Table 3 (e.g., $t(68) = -2.99$ for the TM variable), but the parameter for lagged

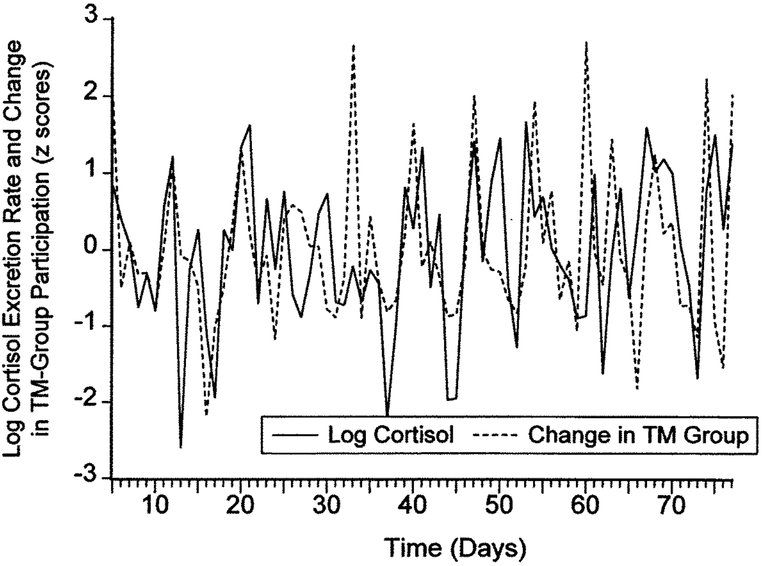


FIGURE 2 Natural Logarithm of Daily Mean Overnight Cortisol Excretion Rate (multiplied by -1.0) and the Prior Afternoon Change in Daily TM-Group participation (z scores)

cortisol excretion was somewhat less significant than before (t(68) = 1.98, p = .05).

5-HIAA Excretion

The OLS regression estimates for the log 5-HIAA equation are reported in Table 4. The reported regression equation, which had two time lags for all explanatory variables, had a slightly higher BIC (–6.94) than an alternative equation with only one time lag for all predictors (BIC = -7.65). However, the latter equation displayed significant second-order serial correlation of residuals, apparently due to the omission of the lagged dependent variable at lag two. Thus the regression with two lags, which had the next lowest BIC (and lowest AIC), was selected for the tests of causal ordering (Table 4). In view of the indication of possible heterogeneity of residual variance with respect to time (p = .06), all standard errors and t-ratios reported in Table 4 were adjusted for heteroskedasticity.

TABLE 4 Causality Tests for 5-HIAA Excretion Rate: Summary of Ordinary Least Squares Regression Analysis with the Dependent Variable Natural Log 5-HIAA Excretion Rate (73 Observations)

Variable	*Coefficient*	*Standard Error*	*T-Ratio*[a]	*p Value*[b]
DTM$_{t-1}$	.06	.03	2.26	.03
DTM$_{t-2}$	.01	.02	.27	.79
LHIAA$_{t-1}$	.12	.11	1.08	.28
LHIAA$_{t-2}$	.41	.10	4.00	.00
LCORT$_{t-1}$	–.23	.11	–2.19	.03
LCORT$_{t-2}$	.03	.10	.36	.72
DTEMP$_{t-1}$	.02	.05	.49	.63
DTEMP $_{t-2}$	–.03	.05	–.50	.62
Constant	–.11	.08	–1.44	.16

Number of observations 73
F-statistic F(14, 58) = 2.20 (p = .02)
S.E. of regression .17
Sum of squared residuals 1.61
R-squared .35
Adjusted R-squared .19
BIC –6.94

SD of dependent variable .19
Mean of dependent variable –.15
Wald tests for causal ordering:
DTM $\chi^2(2) = 7.34$ (p = .03)
LCORT $\chi^2(2) = 7.40$ (p = .03)
DTEMP $\chi^2(2) = .90$ (p = .64)
AIC –41.30

Diagnostic Tests

LM serial correlation tests:
Lags 1: F(1, 57) = .23 (p = .64)
Lags 1–7: F(7, 51)= .36 (p = .92)
Jarque-Bera test for normality:
$\chi^2(2) = 2.33$ (p = .31)

Split sample test for structural change:
F(15, 43) = 1.553 (p = .13)

LM heteroskedasticity tests:
With fitted: F(1, 71) = .07 (p = .79)
With time: F(1, 71) = 3.61 (p = .06)
With predictors: F(22, 50) = .87 (p = .64)
Studentized residual test for outliers ($\alpha = .05$):
Maximum $|t_i| = 2.95$ ($t_c = 3.57$)
Predictive failure test F(8, 50) = .17 (p = .99)

---

[a] *Standard errors and* t-*ratios were calculated using White's (1980) correction for heteroskedasticity and are robust to heterogeneity of residual variance. The degrees of freedom for all* t-*tests is* T - k = *58.*

[b] *Two-tailed tests.*

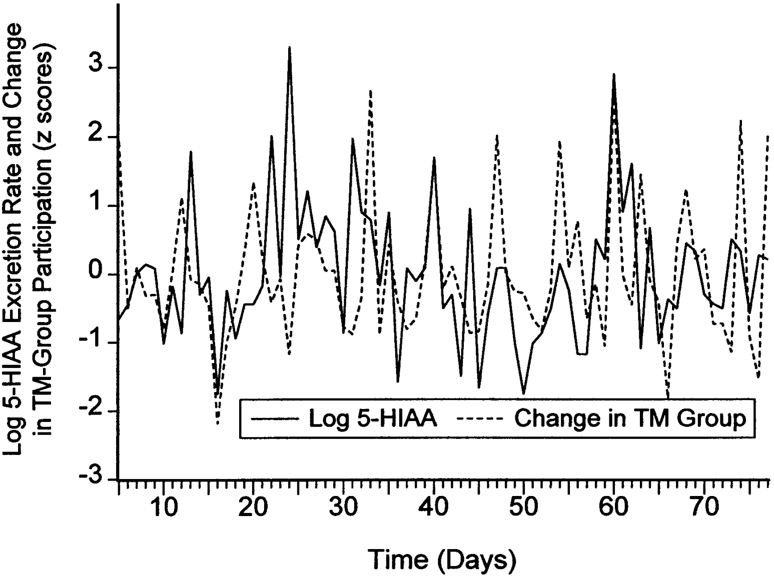


FIGURE 3 Natural Logarithm of Daily Mean Overnight 5-HIAA Excretion Rate and the Prior Afternoon Change in Daily TM-Group Participation (z scores)

An increase in the daily change in size of the TM group was found to be a significant predictor of subsequent increases in 5-HIAA excretion. The lag-one coefficient for the TM variable indicates that an increase of 100 in the daily change in group size predicted a significant increase in overnight 5-HIAA excretion of approximately 5.9 percent. Although the small estimated increase at lag two was not significant, the Wald test for the joint significance of the estimates at both lags was statistically significant ($p = .03$), indicating rejection of the null hypothesis of no causal ordering. The positive correlation between the change in afternoon TM-group participation and the overnight (log) 5-HIAA excretion rate is apparent in Figure 3. The R-squared value indicates that 34.7 percent of the variance in log 5-HIAA excretion was explained by the regression.

A rise in log cortisol excretion was found to significantly predict a decline in log 5-HIAA excretion during the next period, but the parameter estimate at lag two was not significant (Table 4). The estimates at both lags for log cortisol were jointly significant, while those for the change in temperature were not significant either individually or jointly.

Six seasonal dummy variables were included in the regression to model significant serial correlation of the residuals at the weekly seasonal lag 7 (Harvey, 1990). The dummy-variable coefficients (not shown in Table 4, to conserve space) were jointly significant at the .05 level using a Wald test (p = .03). Thus the results in Table 4 statistically controlled for weekly seasonal variaion in 5-HIAA excretion. All diagnostic tests for the estimated regression were satisfactory, indicating that the statistical assumptions of the analysis were satisfied.

Reverse Causality

A test for possible reverse causality (or feedback) was implemented using a regression equation in which the change in daily TM-group participation was the dependent variable and the independent variables were the natural log excretion rates of 5-HIAA and cortisol. This test was expected to yield a nonsignificant result because there seemed to be no plausible reason to expect a causal link between the biochemical excretion rates in non-practitioners outside the group and future changes in TM-group participation. A one-period lag for all explanatory variables (as determined by the BIC) was used in the regression. Six dummy variables were included to model significant weekly residual autocorrelation. Because of significant non-normality of the OLS residuals ($\chi^2(2) = 13.82$, $p = .001$) and the presence of significant outliers (maximum $|t_i| = 3.73$, $t_c = 3.57$), the equation was reestimated after including dummy variables for the three largest outliers.

Consistent with hypothesis, absence of a reverse causal ordering was indicated by the finding that neither past values of the log cortisol excretion rate ($t(59) = -.43$, $p = .67$) nor the log rate of 5-HIAA excretion ($t(59) = .85$, $p = .40$) were significant predictors of changes in future TM-group participation. Similar results were also obtained without adjustment for outliers as well as using a robust M-estimate regression procedure. After adjustment for outliers, increases in temperature were a significant predictor of increased TM-group participation ($t(59) = 2.66$, $p = .01$), but temperature changes were not significantly related to group participation in the absence of adjustment for outliers.

Diagnostic tests for the resulting equation were satisfactory, including normality of the residuals ($\chi^2(2) = 2.88$, $p = .24$), lack of serial correlation of the residuals ($F(7, 52) = .91$, $p = .51$), and heterogeneity of residual variance ($p > .20$).

To further validate the causality-testing procedure, a similar reverse-causality test was implemented with the daily change in temperature as the response variable, with one lag for each explanatory variable. As expected, the OLS regression estimates for this equation indicated that neither log cortisol excretion, log 5-HIAA excretion, nor changes in TM-group participation were significant predictors of future changes in temperature ($p > .30$). The results of all diagnostic tests were satisfactory.

DISCUSSION

This study employed dynamic regression methods to analyze daily data on biochemical indicators of stress obtained from a prospective time series quasi-experiment. The analysis found that the daily change in the number of participants in a group practicing the TM program was a statistically significant predictor of subsequent mean overnight excretion rates (natural log) for both cortisol and 5-HIAA in non-practitioners outside the group. Neither the log cortisol nor the log 5-HIAA excretion rate was a significant predictor of future change in the number of TM-group participants, indicating the absence of feedback or reverse causality. Change in the number of group participants was also found to be a significant predictor of subsequent values of the (natural log) ratio of 5-HIAA to cortisol excretion rates. In each case, these results statistically controlled for past values of the dependent as well as other explanatory variables.

The empirical results indicated that for an increase of 100 in the daily change in the size of the afternoon TM group, the predicted increases in the immediately subsequent overnight values for the 5-HIAA-to-cortisol ratio and for 5-HIAA were 10.5 percent and 5.9 percent respectively, while overnight cortisol excretion was predicted to decline by 7.7 percent. The finding that the daily change in the size of the TM group was a significant predictor of the excretion rates for cortisol and 5-HIAA may suggest some type of habituation response of the biochemical variables to the TM-group size. Possible habituation or adaptation of the neuroendocrine measures to temperature was also suggested by the finding that the daily change in temperature was a significant predictor of cortisol excretion and the 5-HIAA-to-cortisol ratio.

The results of the current study are consistent with those of a previous time series quasi-experiment that investigated the influence of group TM practice on 5-HIAA excretion in a different sample of non-meditators outside the TM group (Pugh et al., 1988). These findings are also consistent with those of two previous time series quasi-experiments that examined 5-HIAA excretion for participants in the TM group (Pugh et al., 1988).

Significant predictive effects of the TM group on each of the three biochemical measures were also obtained using multivariate Box-Jenkins times series (transfer function) methods. The results of the analysis were quite similar to those reported in Tables 2–4. Thus the finding that changes in TM-group participation were a significant predictor of future values of the biochemical measures appears to be robust to the method of statistical analysis.

The robustness of the statistical conclusions to alteration of various other potentially important features of the analysis was further investigated using sensitivity analysis. The sensitivity analysis showed that the results for the TM-group variable in the current study remained significant after the following modifications: (1) analyzing the untransformed values for each biochemical measure instead of the natural logarithm; (2) adding a contemporaneous effect (lag zero) for the change in daily temperature to the regression equations for each biochemical measure (not statistically significant in each case); (3) using LM and likelihood ratio tests rather than Wald tests for joint tests of causal ordering; (4) increasing the maximum number of lags considered from 3 to 4; (5) using t-ratios based on the unadjusted OLS regression estimates rather than the heteroskedasticity-corrected estimates; (6) using an alternative method to adjust the OLS estimates for heterogeneity of variance (Newey and West, 1987); (7) using a robust regression estimation procedure (M-estimator) instead of OLS; (8) employing the Akaike Information Criterion (AIC) instead of the BIC to determine the appropriate number of lags to include in each equation; and (9) analyzing subsamples of the data.

A battery of diagnostic tests indicated that the statistical assumptions of the dynamic regression analysis were satisfied. That the regression residuals in each case were found to exhibit no significant serial correlation indicates that the estimated regression equation satisfactorily accounted for any trends, seasonal variation, or other systematic dynamical behavior for each response variable. Absence of significant serial correlation was also encouraging with respect to the adequacy of the specification for each regression equation, because the omission of important predictor variables, including lagged values of dependent and independent variables, generally may be expected to result in serial correlation of the residuals (Harvey, 1990). Such misspecification of the regression equation can lead to biased parameter estimates and misleading statistical inferences. Adequacy of the specification of the regression equation for each biochemical measure was also indicated by the non-significance of the predictive failure test in each case. The latter test may be interpreted as a general test of misspecification (Pesaran et al., 1985).

The statistical analysis also indicated that the empirical results of this study cannot be attributed to the well-known “spurious regression” phenomenon, which is based on inappropriate analysis of non-stationary variables (Granger & Newbold, 1986; Phillips, 1986). That the statistical results were not based on spurious regressions was confirmed by the rejection of non-stationarity for all regression variables using formal unit root tests as well as by the lack of significant serial correlation of the residuals.

Confidence in the validity of the statistical methods used in this study was also enhanced by the non-significance of three tests for reverse causality or feedback that were expected to yield nonsignificant results. No predictive relationship between log cortisol and log 5-HIAA excretion in the participants outside the group and future changes in TM-group participation was found. Likewise, tests for the predictive effect of the biochemical measures and changes in TM-group participation on future changes in average daily temperature were also nonsignificant. If the causality-testing procedure were valid, the three tests mentioned above should have yielded nonsignificant results because there seems to be no plausible reason to expect a causal link between the biochemical measures in non-meditators and subsequent changes in TM-group participation, or, obviously, between changes in TM-group participation and future temperature changes.

Possible Causal Implications

The statistical analysis employed here used a dynamic regression procedure that has been widely used to test for possible causal relationships between time series variables. In the context of this approach, the finding of a significant predictive relationship between variables indicates the existence of a statistical causal ordering, as operationally defined by Wiener (1956) and Granger (1969).

These tests for a causal ordering may be said to be conservative in the sense that a predictive relationship is deemed significant only after controlling for the intrinsic dynamical behavior of the dependent variable as well as for past values of other explanatory variables. These intrinsic dynamics are modeled by the lagged values of the dependent variable in each dynamic regression equation.

The tests for a causal ordering may also often be conservative because the standard specification of the regression equation in the causality tests—with a common number of lags for each variable—frequently results in the inclusion of nonsignificant lags for one or more variables (e.g. Tables 3 and 4). If an equation is otherwise properly specified, this inclusion of superfluous lags tends to inflate the standard errors for the estimated regression coefficients, thus reducing the power of significance tests (Fiebig & Maasoumi, 1990). Consequently, deletion of the nonsignificant lags in Tables 3 and 4 in the context of an unrestricted dynamic analysis of the data from the current study yielded more precise estimates of the predicted dynamic effects of the change in TM-group participation on each of the three biochemical measures (Cavanaugh, Walton, & Pugh, unpublished results). In the latter analysis, the direction of the predicted effects of the TM group was found to be the same as reported in Tables 2–4 for each biochemical measure, and remained highly statistically significant. These more precise dynamic estimates yielded more accurate estimates of the total cumulative impact of the TM group on each of the three biochemical measures, where the cumulative effects are based on both the immediate (lag one) and higher order dynamic effects. These cumulative impacts were both statistically significant and substantially larger in absolute value (50 to 80 percent higher) than the immediate (lag-one) effects reported in Tables 2-4.

In the tests for causal ordering, the rejection of the null hypothesis of no predictive relationship (statistical causal ordering) does not necessarily indicate the existence of a "true" causal mechanism linking changes in TM-group participation and the biochemical measures. Rejection of the null hypothesis of no significant predictive relationship between TM-group participation and the three biochemical measures is consistent with the hypothesis of a true causal relationship, and, in the context of other evidence discussed below, may lend support to such a causal hypothesis.

The plausibility of inferring the existence of a true causal relationship on the basis of these predictive tests is supported by several considerations. First, changes in the size of the TM group temporally preceded significant changes in all three biochemical variables. Second, two different biochemical substances, cortisol and 5-HIAA, were affected in opposite directions, with these directions being consistent with the literature relating these substances to stress (e.g., Gould, 1999; MacLean et al., 1997; Walton et al., 1995; Sapolsky, 1992, 1996). Third, the results for cortisol and 5-HIAA excretion were further confirmed by a change in the ratio of the two rates in the predicted direction.

The plausibility of a causal interpretation is also enhanced by the fact that the direction of change in the three biochemical measures was the same as that resulting from practice of the TM technique by individuals. Significant negative effects of the TM program on the cortisol excretion rate, as well as a positive effect on both 5-HIAA excretion and the ratio of 5-HIAA to cortisol, have been reported in prior longitudinal and/or cross-sectional studies of TM meditators, including studies with randomized experimental designs (MacLean et al., 1997; Walton et al., 1995). The empirical results reported in this paper are also consistent with the results of a previous time series quasi-experiment (analyzed using Box-Jenkins methods) that investigated the influence of group practice of the TM and TM-Sidhi programs on 5-HIAA excretion in a different sample of non-meditators outside the TM group (Pugh et al., 1988). These results are also consistent with those of two prior time series studies that used Box-Jenkins time series analysis to examine 5-HIAA excretion in participants in the TM group (Pugh et al., 1988). Another Box-Jenkins time series study reported a significant positive effect of the TM group on daytime 5-HIAA excretion in group participants (Löliger, 1990).

Alternative Explanations

Three potential alternative explanations for the empirical findings in this study suggest themselves: (1) behavioral interactions between non-meditating study participants and participants in the TM group; (2) weekly variation in stress levels; and (3) possible omitted variables. The first of these alternative explanations is the "behavioral interaction hypothesis." The practice of the TM technique has been reported to lead to both reduced stress and improved personal relationships (e.g., Alexander et al., 1993). Thus reductions in biochemical indicators of stress in the non-meditating participants might be hypothesized to result from behavioral interaction between members of the TM group and the non-TM participants outside the group. For this explanation to be valid, the total stress-reducing effect of such interactions between TM-group members and non-meditating study participants would have to be directly proportional to the change in total daily participation in the TM group. This proposition has not been empirically investigated. Regular group attendance by the TM practitioners who interacted with the non-meditating study participants would also be required.

The non-meditating participants reported relatively limited interaction with coworkers or others in the work environment who participated in the TM group practice, and no such interaction at home. The two women participants (refer to Methods) worked in different businesses, each of which employed a few participants in the group meditation program. Due to the nature of their work, these two women could have had an hour or more of personal interaction with group participants during the day on workdays. The three male factory workers had more limited interactions with one of their supervisors from the main office who was an infrequent participant in the group program. The sixth non-meditating participant, a teenage boy, held a part-time job in his hometown 12 miles from Fairfield and rarely visited Fairfield. Despite the modest extent of these interactions, a limitation of the design of the current study is that it does not allow behavioral interactions between non-meditating and meditating participants to be ruled out as an explanation of the observed biochemical changes. But it is difficult to see how this small amount of direct interaction could account for the significant predictive relationship found between the biochemical measures and changes in TM-group participation. For example, changes in daytime stress level are not thought to significantly affect overnight urinary cortisol excretion (Seeman et al., 1997).

Moreover, it should be noted that the behavioral interaction hypothesis has been ruled out as a plausible alternative explanation in nearly all of the approximately 20 other studies of the societal impact of the group practice of the TM and TM-Sidhi programs that have been published in refereed journals. In these studies, behavioral interaction was reported to be an implausible explanation for the observed effects either because the group was located at a great distance from the great bulk of the population affected—such as studies of the impact on a whole nation, state, or province (e.g., Dillbeck, 1990; Orme-Johnson et al., 1988)—or because the TM group was a negligible proportion of the population of a city or metropolitan area or physically isolated from the rest of the population (e.g., Hagelin et al., 1999).

Another possible alternative explanation for these results is the "weekend hypothesis." Myocardial infarctions (heart attacks) are believed to be stress-related and are more frequent on Monday mornings than on weekends (Peters, Brooks, Zobie, Liebson, & Seals, 1996), especially in the working population (Willich et al., 1994). If higher stress tended to be incurred on the job, cortisol excretion might be expected to rise during the week and fall during weekends, with 5-HIAA excretion moving in the opposite direction in each case. If participation in the TM group coincidentally tended to be higher on weekends, a spurious negative (positive) relationship between cortisol (5-HIAA) excretion and changes in the size of the TM group might be observed. One empirical difficulty with this hypothesis, however, is that, on average, weekend participation in the TM group was smaller than on weekdays.

To formally test the weekend hypothesis, a binary dummy variable was added to the cortisol and ratio equations, with the dummy variable being equal to 1.0 for weekends and otherwise equal to 0. The weekend variable did not approach significance in either of these regressions. The weekend hypothesis was also not supported for 5-HIAA excretion, as shown by the jointly significant parameter estimates for the TM-group variable reported in Table 4. The latter regression equation statistically controlled for day-of-the week effects via the included seasonal dummy variables. Thus for each of the three biochemical measures, the weekend hypothesis was not empirically supported for these data.

The possibility remains that the observed predictive relationship between TM-group participation and the reduction in biochemical measures of stress in the non-meditating participants could be a spurious one resulting from the omission of an important causal variable from the regression equations. Such an omitted causal variable would have to be positively correlated both with daily changes in TM-group participation and with the rate of 5-HIAA excretion, as well as negatively correlated with cortisol excretion. In addition, the omitted variable would have to explain the observed lead-lag relationship between TM-group participation and the biochemical measures. Thus, for example, the omitted variable would have to first cause an increase in afternoon TM-group participation and then produce changes in the appropriate direction for that evening's overnight cortisol and 5-HIAA excretion rates in the non-TM participants, changes that decay rapidly in subsequent overnight periods.

It is worth noting, as pointed out by one reviewer, that randomization of the hypothesized causal variable, i.e., the size of the TM group, would permit a stronger statistical test of causality. Such randomization of the size of the group would rule out the possibility of an unobserved third variable giving rise to an observed causal relationship between the dependent and independent variables. Unfortunately, such randomization of attendance at the large daily group meditation sessions was not feasible.

A potential omitted causal variable might take the form of a daily stressor common to the experience of all residents of Fairfield and the surrounding area. Increased (decreased) levels of such a stressor might have led to biochemical changes in the non-meditating participants that reflected increased (decreased) stress as well as to increased (decreased) participation in the TM group program. However, the town of Fairfield (population 10,000), in contrast to most major metropolitan areas, had no daily serious traffic jams. Nor, with the possible exception of the weather, did it have any other major, community-wide sources of daily stress during the period of the experiment to disturb the placid, small-town environment.

The generally hot summer weather during the June 16 to August 31 period of the experiment, on the other hand, might conceivably have served as such a common stressor. As noted above, serotonin (and to a lesser degree, cortisol) have previously been reported to be affected by temperature (Ghosh et al., 1974; Sarrias et al., 1989). Weather variables such as temperature also might reasonably be expected to affect daily participation in the group TM program. Thus a possible alternative hypothesis (the "weather hypothesis") is that increases in summer temperatures led to increased biochemical measures of stress in both non-meditators and TM meditators as well as to increased attendance at the daily TM group program by meditators seeking to counteract their increased perceived stress. Thus, in this interpretation, temperature changes might give rise to an apparent, but spurious, association between increased participation in the TM group and decreased biochemical measures of stress in non-meditators.

The weather hypothesis, however, was not supported empirically. As the latter hypothesis predicts, increases in the daily change in mean temperature were a significant predictor of increased participation in the TM group (see Results). Contrary to the weather hypothesis, however, increased temperature was a significant predictor of decreased, rather than increased, cortisol excretion and of increased, rather than decreased, ratio of 5-HIAA to cortisol excretion (see Tables 2–4). Furthermore, over the observed range of temperature during the study, changes in temperature were not a significant predictor of 5-HIAA excretion. Finally, as reported in Tables 2–4, an increase in daily TM-group participation was a statistically significant predictor of reduced stress, as indicated by each of the biochemical measures, even after statistically controlling for the possible influence of temperature (by including the change in temperature in each regression equation).

The latter conclusion was not altered by including another weather variable, daily precipitation, in the analysis. When added along with temperature to each of the three regression equations for the biochemical variables, total daily precipitation did not approach significance in any of the estimated regressions. Inclusion of the precipitation variable also did not substantially alter the significant predictive effect of the change in TM-group participation on each of the biochemical measures. Moreover, precipitation was not a significant predictor of the daily change in TM-group participation when the precipitation variable was added to the reverse-causality regression.

Other than the behavioral interaction hypothesis, weather hypothesis, and weekend-effect hypothesis, we have not conceived of any plausible omitted-variable explanation that would be likely to account for the direction and temporal sequencing of the apparent dynamic effects of the TM group on these biochemical measures. Likewise, no plausible, empirically supported, alternative hypothesis has been advanced that can satisfactorily explain the results of approximately 20 studies of the Maharishi Effect published in peer-reviewed journals over the past 25 years (Hagelin et al., 1999). These empirical studies, as well as more than 30 others investigating the influence of the group practice of the TM and TM-Sidhi program, have reported statistically significant effects of the group practice in reducing a wide range of behavioral indicators of societal stress. It has been proposed that the theory of field effects of consciousness offers the most parsimonious explanation for these diverse findings (Hagelin et al., 1999).

As a direction for future research, replication of this study would be desirable, especially using a time series, quasi-experimental design that eliminates the possibility of behavioral interactions between the non-meditating study participants and participants in the TM-group. While a larger sample of participants might also be desirable, it is difficult to recruit participants willing to collect urine samples daily for an extended period, such as the 77 days of the current study. However, for time series studies, the number of participants may be less important than in the case of two-group, pre-post designs.

Because the current study used a non-probabilistic, convenience sample of self-selected volunteer participants, the degree to which the results of this study may be generalized beyond the current sample is not clear. Some form of random sampling, if feasible, would obviously be preferable in future research. Random selection of participants, as opposed to random assignment to treatment and control groups, however, is rare in psychological research (Shaughnessy & Zechmeister, 1990, pp. 164–166). In principle, it would be possible to randomly select participants from all adult residents of Fairfield and Jefferson County. However, in this case, given the burdensome nature of the 77-day research protocol, it is likely that a high proportion of the randomly selected participants would decline to participate, resulting in another form of self-selection. For this particular type of study, even random assignment to treatment and controls, however, raises difficult issues. This is because, under the maintained hypothesis, the daily size of the TM group was large enough to influence the biochemical measures in all individuals living or working in Fairfield and the surrounding area (as well as all of Iowa and other adjacent states). Thus participants would have to be randomly assigned to live either in the Fairfield area during the period of the study (experimental group) or live outside the theoretically predicted range of the group's influence (control group).

Another potentially useful direction of future research is investigation of a range of health-related measures that might plausibly be affected by any biochemical changes produced by the group practice of the TM and TM-Sidhi programs. Reduction in the societal incidence of infectious diseases may be an appropriate example. Because immune function is impaired by elevated cortisol, it is plausible that the rate of infectious disease will be influenced by the group practice of these programs. Support for the latter hypothesis is provided by a previous study that found significant effects of group practice of these programs on the incidence of infectious diseases in the U.S. and Australia (Orme-Johnson et al., 1991). Other possible related societal measures include hospital admissions, phone calls to psychological crisis hotlines, and sudden death from stroke and coronary heart disease.

In conclusion, this study may provide empirical support for a postulated psycho-neuroendocrine mechanism that could mediate, at least in part, the observed reductions in behavioral indicators of social stress reported in previous research on the group practice of the TM and TM-Sidhi programs.

REFERENCES

Alexander, C.N., Schneider, R.H., Staggers, F., Sheppard, W., Clayborne, B.M., Rainforth, M., Salerno, J., Kondwani, K., Smith, S., Walton, K.G., & Egan, B. (1996). Trial of stress reduction for hyptertension in older African Americans: II. Sex and risk subgroup analysis. *Hypertension, 28*, 228–237.

Alexander, C.N., Swanson, G.C., Rainforth, M.V., Carlisle, T.W., Todd, C.C., & Oates, R.M. Jr. (1993). Effects of the Transcendental Meditation program on stress reduction, health, and employee development: A prospective study in two occupational settings. *Anxiety, Stress, and Coping, 6*, 245–262.

Breusch, T. (1978). Testing for autocorrelation in dynamic linear models. *Australian Economic Papers, 17*, 334–355.

Bujatti, M., & Riederer, P. (1976). Serotonin, noradrenaline, dopamine metabolites in Transcendental Meditation technique. *Journal of Neural Transmission, 39*, 257–267.

Castillo-Richmond, A., Schneider, R.H., Alexander, C.N., Cook, R., Myers, H., Nidich, S., Haney, C., Rainforth, M., Salerno, J. (2000). Effects of stress reduction on carotid atherosclerosis in hypertensive African Americans. *Stroke, 31*, 568–573.

Charemza, W.W., & Deadman, D.F. (1997). *New directions in econometric practice: General to specific modelling, cointegration and vector autoregression* (2nd ed.). Cheltenham, UK: Edward Elgar.

Dillbeck, M.C. (1990). Test of a field theory of consciousness and social change: Time series analysis of participation in the TM-Sidhi program and reduction of violent death in the U.S. *Social Indicators Research, 22*, 399–418.

Dillbeck, M.C., Cavanaugh, K.L., Glenn, T., Orme-Johnson, D.W., & Mittlefehldt, V. (1987). Consciousness as a field: The Transcendental Meditation and TM-Sidhi program and changes in social indicators. *The Journal of Mind and Behavior, 8(1)*, 67–104.

Dickey, D., & Fuller, W.A. (1979). Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association, 74*, 427–431.

Dickey, D., & Fuller, W.A. (1981). Likelihood ratio statistics for autoregressive time series with a unit root. *Econometrica, 49*, 1057–1072.

Enders, W.E. (1995). *Applied econometric time series*. New York: Wiley.

Fiebig, D.G., & Maasoumi, E. (1990). Specification analysis in dynamic models. *Journal of Business and Economic Statistics, 8*, 443–451.

Geweke, J., Meese, R., & Dent, W. (1983). Comparing alternative tests of causality in temporal systems: Analytic results and experimental evidence. *Journal of Econometrics, 21*, 161–194.

Ghosh, P., Taneja, R.L., Malhotra, S.C., Kumar, V., & Ahuja, M.M. (1974). A study of the circadian rhythm of plasma cortisol and urinary excretion of 17-hydroxycortico-steroids in relation to (a) changes in the environmental temperature, (b) glomerular filtration rate. *Indian Journal of Medical Research, 62*, 1392–1401.

Godfrey, L.G. (1978). Testing for higher order serial correlation in regression equations when the regressors include lagged dependent variables. *Econometrica, 46*, 1303–1310.

Goodrich, R.L. (1989). *Applied statistical forecasting*. Belmont, MA.: Business Forecast Systems.

Gould, E. (1999). Serotonin and hippocampal neuro-genesis. *Neuropsychopharmacology, 21*, 465–515.

Granger, C.W.J. (1969). Investigating causal relations by econometric models and cross spectral methods. *Econometrica, 37*, 428–438.

Granger, C.W.J., & Newbold, P. (1986). *Forecasting economic time series* (2nd Ed.). Orlando: Academic Press.

Hagelin, J.S. (1987). Is consciousness the unified field? A field theorist's perspective. *Modern Science and Vedic Science, 1*, 29–87.

Hagelin, J.S. (1989). Restructuring physics from its foundation in the light of Maharishi's Vedic Science. *Modern Science and Vedic Science, 3*, 3–72.

Hagelin, J.S., Rainforth, M.V., Orme-Johnson, D.W., Cavanaugh, K.L., & Alexander, C.N. (1999). Effects of group practice of the Transcendental Meditation program on preventing violent crime in Washington, DC: Results of the national demonstration project, June-July, 1993. *Social Indicators Research, 47*, 153–201.

Hamilton, J.D. (1994). *Time series analysis*. Princeton, New Jersey: Princeton University Press.

Harvey, A. (1990). *The econometric analysis of time series* (2nd Ed.). Cambridge: MIT Press.

Jarque, C.M., & Bera, A.K. (1987). A test for normality of observations and regression residuals. *International Statistical Review, 55*, 163–172.

Jevning, R., Wallace, R., & Beidebach, M. (1992). The physiology of meditation: A review. A wakeful, hypometabolic, integrated response. *Neuroscience and Biobehavioral Reviews, 16*, 415–424.

Jevning, R., Wilson, A.F., & Davidson, J.M. (1978). Adrenocortical activity during meditation. *Hormones and Behavior, 10*, 54–60.

Kaufmann, R.K., & Stern, D.I. (1997). Evidence for human influence on climate from hemispheric temperature relations. *Nature, 388*, 39–44.

Kiviet, J.F. (1986). On the rigour of some misspecification tests for modelling dynamic relationships. *Review of Economic Studies, 53*, 241–261.

Koenker, R. (1981). A note on studentizing a test for heteroscedasticity. *Journal of Econometrics, 17*, 107–112.

Levitsky, D.K. (1998). *Effects of the Transcendental Meditation program on neuroendocrine indicators of chronic stress*. Unpublished doctoral dissertation, Maharishi University of Management.

Linsky, A.S., Bachman, R., & Straus, M.A. (1995). *Stress, culture, and aggression*. New Haven: Yale University Press.

Linsky, A.S., & Straus, M.A. (1986). *Social stress in the United States: Links to regional patterns in crime and illness*. Dover, Massachusetts: Auburn House.

Löliger, S.A. (1990). *Relationship between subjective bliss, 5-hydroxy-3-indoleacetic acid and the collective practice of Maharishi's Transcendental Meditation and TM-Sidhi program*. Unpublished doctoral dissertation, Maharishi University of Management.

MacKinnon, J.G. (1991). Critical values for cointegration tests. In R.F. Engle & C.W.J. Granger (Eds.), *Long-run economic relationships* (pp. 267–276). Oxford: Oxford University Press.

MacLean, C.R.K., Walton, K.G., Wenneberg, S.R., Levitsky, D.K., Mandarino, J.V., Waziri, R., Hillis, S.L., & Schneider, R.H. (1997). Effects of the Transcendental Meditation program on adaptive mechanisms: Changes in hormone levels and responses to stress after 4 months of practice. *Psychoneuroendocrinology, 22*, 277–295.

Maharishi Mahesh Yogi (1975). *Inauguration of the dawn of the Age of Enlightenment*. Rheinweiler, Germany: Maharishi International University Press.

Maharishi Mahesh Yogi (1986). *Life supported by natural law*. Washington, DC: Age of Enlightenment Press.

Maharishi University of Management (1999, September 7). *Scientific research on the Transcendental Meditation and TM-Sidhi program: An annotated bibliography of published papers*. Available: <http://www.mum.edu/tm_research/tm_biblio/welcome.html>

Mason, L.I., Alexander, C.N., Travis, F.T., Marsh, G., Orme-Johnson, D.W., Gackenbach, J., Mason, D.C., Rainforth, M., & Walton, K.G. (1997). Electrophysiological correlates of higher states of consciousness during sleep in long-term practitioners of the Transcendental Meditation program. *Sleep, 20*, 102–110.

McEwen, B.S. (1998). Protective and damaging effects of stress mediators. *New England Journal of Medicine, 338*, 171–179.

Newey, W., & West, K. (1987). A simple positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix. *Econometrica, 51*, 703–708.

Orme-Johnson, D.W. (2003). Preventing crime through the Maharishi Effect. *Journal of Offender Rehabilitation, 36,* 257–281.

Orme-Johnson, D.W., Alexander, C.N., Davies, J.L., Chandler, H.M., & Larimore, W.E. (1988). International peace project in the Middle East: Effects of the Maharishi Technology of the Unified Field. *Journal of Conflict Resolution, 32*, 776–812.

Orme-Johnson, D.W., Cavanaugh, K.L., Alexander, C.N., Gelderloos, P., Dillbeck, M., Lanford, A.G., & Abou Nader, T.M. (1991). The influence of the Maharishi Technology of the Unified Field on world events and global social indicators: The effects of the Taste of Utopia Assembly. In R. Chalmers, G. Clements, H. Schenkluhn, & M. Weinless (Eds.), *Scientific research on Maharishi's Transcendental Meditation and TM-Sidhi Programme: Collected papers, volume 4* (pp. 2730–2762). Vlodrop, the Netherlands: Maharishi Vedic University Press.

Orme-Johnson, D.W., Dillbeck, M.C., Wallace, R.K., & Landrith, G.S. III (1982). Intersubject EEG coherence: Is consciousness a field? *International Journal of Neuroscience, 16*, 203–209.

Orme-Johnson, D.W., & Walton, K.G. (1998). All approaches to preventing or reversing effects of stress are not the same. *American Journal of Health Promotion, 12*, 297–299.

Pesaran, M.H., Smith, R.P., & Yeo, S. (1985). Testing for structural stability and predictive failure: A review. *Manchester School, 53*, 280–285.

Pesaran, M.H., & Pesaran, B. (1991). *Microfit 3.0, an interactive econometric software package: User manual*. Oxford: Oxford University Press.

Peters, R.W., Brooks, M.M., Zobie, R.G., Liebson, P.R., & Seals, A.A. (1996). Chronobiology of acute myocardial infarction: Cardiac arrhythmia suppression trial (CAST) experience. *American Journal of Cardiology, 78*, 1198–1201.

Phillips, P. (1986). Understanding spurious regressions. *Journal of Econometrics, 33*, 311–340.

Philips, P., & Perron, P. (1988). Testing for a unit root in time series regression. *Biometrika, 75*, 335–346.

Pugh, N.D.C., Walton, K.G., & Cavanaugh, K.L. (1988). Can time series analysis of serotonin turnover test the theory that consciousness is a field? *Society for Neuroscience Abstracts, 14*, 372.

Ramanathan, R. (1998). *Introductory econometrics with applications* (4th ed.). Fort Worth: Dryden Press.

Sapolsky, R.M. (1996). Stress, glucocorticoids, and damage to the nervous system: the current state of confusion. *Stress, 1(1)*, 1–19.

Sapolsky, R.M. (1992). *Stress, the aging brain, and the mechanisms of neuron death*. Cambridge: MIT Press.

Sarrias, M.J., Artigas, F., Martinez, E., & Gelpi, E. (1989). Seasonal changes of plasma serotonin and related parameters: Correlation with environmental measures. *Biological Psychiatry, 26*, 695–706.

Schwarz, G. (1978). Estimating the dimensions of a model. *Annals of Statistics, 6*, 461–464.

Seeman, T.E., & McEwen, B.S. (1996). Impact of social environment characteristics on neuroendocrine regulation. *Psychosomatic Medicine, 58*, 459–471.

Seeman, T.E., Singer, B.H., Rowe, J.W., Horwitz, R.I., & McEwen, B.S. (1997). Price of adaptation—Allostatic load and its health consequences. *Archives of Internal Medicine, 157*, 2259–2268.

Shaughnessy, J.J., & Zechmeister, E.B. (1990). *Research methods in psychology* (2nd ed.). New York: McGraw-Hill.

Shihabi, Z.K., & Wilson, E.L. (1982). Colorimetric assay of urinary 5-hydroxy-3-indoleacetic acid. *Clinical Biochemistry, 15*, 106–108.

Travis, F.T., & Orme-Johnson, D.W. (1989). A Field model of consciousness: EEG coherence changes as indicators of field effects. *International Journal of Neuroscience, 49*, 203–211.

Travis, F.T., & Pearson, C. (2000). Pure consciousness: Distinct phenomenological and physiological correlates of "consciousness itself." *International Journal of Neuroscience, 100*, 77–89.

Travis, F.T., & Wallace, R.K. (1997). Autonomic patterns during respiratory suspensions: Possible markers of transcendental consciousness. *Psychophysiology, 34*, 39–46.

Travis, F.T., & Wallace, R.K. (1999). Autonomic and EEG patterns during eyes-closed rest and Transcendental Meditation (TM) practice: The basis for a neural model of TM practice. *Consciousness and Cognition, 8*, 302–318.

Walton, K.G., & Levitsky, D.K. (1994). A neuroendocrine mechanism for the reduction of drug use and addictions by Transcendental Meditation. *Alcoholism Treatment Quarterly, 11*, 89-117.

Walton, K.G., & Levitsky, D.K. (2003). Effects of the Transcendental Meditation program on neuroendocrine abnormalities associated with aggression and crime. *Journal of Offender Rehabilitation, 36,* 67–87.

Walton, K.G., & Pugh, N.D.C. (2000). *Psychological and biochemical effects of stress reduction: Differences in excretion of amino acids, hormones, and neurotransmitter metabolites*. Manuscript in preparation.

Walton, K.G., Pugh, N.D.C., Gelderloos, P., & Macrae, P. (1995). Stress reduction and preventing hypertension: Preliminary support for a psychoneuroendocrine mechanism. *Journal of Alternative and Complementary Medicine, 1*, 263–283.

Wei, W.S. (1990). *Time series analysis: Univariate and multivariate methods*. Redwood City, California: Addison-Wesley.

Weisberg, S. (1980). *Applied linear regression*. New York: Wiley.

White, H. (1980). A heteroskedastic-consistent covariance matrix estimator and a direct test for heteroskedasticity. *Econometrica, 48*, 817–838.

Wiener, N. (1956). The theory of predicting. In E.F. Beckenback (Ed.), *Modern mathematics for the engineer, Series 1* (chapter 8). New York: McGraw-Hill.

Willich, S.N., Lowel, H., Lewis, M., Hormann, A., Arntz, H.R., & Keil, U. (1994). Weekly variation of acute myocardial infarction: Increased Monday risk in the working population. *Circulation, 90*, 87–93.

Zellner, A. (1979). Causality and econometrics. *Carnegie-Rochester Conference Series on Public Policy* (supplement to *Journal of Monetary Economics*), *10*, 9–54.