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Cognitive performance after sleep deprivation: does personality make a difference?

Daniel J. Taylor[a,*], Robert M. McFatter[b]

[a]*Department of Psychology, 202 Psychology Building, The University of Memphis, Memphis, TN 38152, USA*

[b]*Department of Psychology, PO Box 4-3131, The University of Louisiana at Lafayette, Lafayette, LA 70504, USA*

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Abstract

The relations between personality and cognitive performance under sleep deprivation were examined in a college age (17–25 years) sample ($n=28$) using the Eysenck Personality Questionnaire (Eysenck, H.J., & Eysenck, S.B.G., 1975), and a computerized battery of eight neuropsychological tests from the Automated Neuropsychological Assessment Metrics, version 3.11 (Kane, R.L., & Reeves, D.L., 1997, Perez, W.A., Masline, P.J., Ramsey, E.G., & Urban, K.E., 1987). The specific tasks analyzed were time estimation, immediate recall, delayed recall, match to sample, spatial processing, finger tapping, digit span, and the Stroop color-word tasks. Sleep deprivation had an overall negative effect on accuracy in the time estimation, immediate recall, delayed recall, and digit span tasks. There were also significant interactions between extraversion and sleep deprivation on accuracy in the time estimation, immediate recall, delayed recall, Stroop color-word, and finger tapping tasks. Extraverts performed worse than introverts on all of these tasks except the Stroop, on which extraverts had more variability in performance through the night. Finally, there were significant interactions between extraversion and neuroticism in predicting performance on the time estimation and the Stroop color-word tasks. The general findings were that the poorer performance of extraverts compared with introverts was even more pronounced in neurotics than stables.

Keywords: Sleep deprivation; Personality; Extraversion; Introversion; Cognitive performance

A report by the National Commission on Sleep Disorders Research indicates a current trend for people to restrict their sleep below acceptable limits (Holden, 1993). College students have

* Corresponding author.
E-mail address: djtaylor@memphis.edu (D.J. Taylor).

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reported sleep depriving themselves for 24–48 h around examination periods, and nearly 82% of oil refinery shift-workers complain of inadequate amounts of sleep (Hawkins & Shaw, 1992; Kogi, 1971). One review discovered physicians slept an average of only 2.8 h during "on-call" nights (Bonnet, 1994). Another poll found that nearly one out of 10 adults say they occasionally or frequently fall asleep at work, and one out of five say they occasionally or frequently make errors at work due to sleepiness (National Sleep Foundation, 2000). These data indicate certain areas of our work force may be sleep deprived.

Short-term sleep deprivation has been shown to have a negative effect on cognitive performance. One meta-analysis of 19 sleep deprivation studies found that cognitive performance on a variety of tasks (e.g. logical reasoning tasks, mental addition tasks, Torrence tests) decreased an average of 1.39 standard deviations after short-term (<45 consecutive hours) sleep deprivation (Pilcher & Huffcutt, 1996). Another study found that college students who were sleep deprived for 24 h performed significantly worse than non-deprived participants on cognitive tasks (Pilcher & Walters, 1997).

Sleep deprivation studies in general have found that arousal, as measured by Electroencephalograph (EEG), decreases as amount of sleep deprivation increases (Naitoh, Kales, & Kollar, 1969; Naitoh, Pasnau, & Kollar, 1971; Rodin, Luby, & Gottlieb, 1962). In these studies, subjects were sleep deprived for at least 120 h, and consistently showed a decrease in EEG arousal levels. Further, this decrease in EEG arousal corresponded closely with a decrease in tracking performance in one study (Naitoh et al., 1969). Therefore, it is possible that this decrease in EEG arousal causes the cognitive performance decrements seen after sleep deprivation.

Eysenck's (1967) theory of personality gives reason to believe that the personality traits of extraversion and neuroticism could moderate the effects of sleep deprivation. Eysenck believed that resting state cortical arousal is the physiological basis for the personality construct of extraversion. Introverts were theorized to have a higher-than-optimal level of basal arousal and extraverts to have a lower-than-optimal level.

Studies have attempted to test this theory indirectly, using the inverted-U hypothesis (Yerkes & Dodson, 1908). In this hypothesis, performance is greatest at optimum levels of cortical arousal, but as arousal level goes further below or above optimal levels, performance will begin to decrease. As noted above, introverts were thought to have above optimum arousal, thus they were predicted to perform better than extraverts in environments of low to moderate stimulation (e.g. sleep deprivation), which would lower their arousal down to optimum levels. Extraverts were predicted to do better in highly stimulating environments that push their levels of arousal up to optimum levels.

Studies looking at vigilance, time estimation, short-term memory, and long-term memory have found that introverts generally perform better in moderately stimulating environments. Extraverts preformed worse than introverts on vigilance tasks (e.g., Bakan, 1959; Harkins & Geen, 1975; Hogan, 1966; Koelega, 1992), exhibited a greater tendency toward overestimation of time (Eysenck, 1959; Lynn, 1961; Wudel, 1979), and were inferior at long-term recall but superior on short-term recall (Howarth & Eysenck, 1968; Osborn, 1972). Other research indicates that introverts exhibit more cortical arousal than extraverts under moderately stimulating environments (Eysenck, 1994; Gale, 1987; Gale & Edwards, 1983; Stelmack, 1981; Zuckerman, 1991). Stelmack's (1990, 1997) reviews of the literature suggest that the evidence actually indicates that, rather than differing in base levels of arousal, introverts and extraverts differ in reactivity to sensory stimulation with introverts being more reactive than extraverts.

In the present study, we examined performance on several cognitive tasks and one motor (tapping) task after sleep deprivation. Whether differences in arousal between introverts and extraverts be due to differing base levels of arousal or differential reactivity to sensory stimulation, we expected that dearousal due to sleep deprivation would more negatively affect performance of extraverts than introverts. After sleep deprivation, introverts should perform better than extraverts because their arousal levels would be closer to optimum, either as a result of higher base levels of arousal or a greater reactivity to sensory stimulation of the tasks.

Some research has already been done in this area (Corcoran, 1965, 1972; Jha, 1988; Smith & Maben, 1993). Introverts were more accurate than extraverts on a visual vigilance task and a serial reaction time task after sleep deprivation (Corcoran, 1965; Jha, 1988). Sleep deprived extraverts have also been shown to perform worse in reaction time on logical reasoning and auditory vigilance tasks (Smith & Maben, 1993).

Further, neuroticism has been shown to enhance the differences often seen between extraverts and introverts (Eysenck, 1987; Hotard, McFatter, McWhirter, & Stegall, 1989; McFatter, 1994; Wallace, Bachorowski, & Newman, 1991). Some researchers see neuroticism as reflecting the reactivity of a nonspecific arousal system (NAS) and theorized that the NAS serves to prepare an organism to react to either threatening (e.g., fight/flight) situations or rewarding (e.g., food or procreation) situations (Wallace et al., 1991). The NAS may or may not be connected to the kind of arousal system associated with sleep deprivation. The current study attempted to clarify that issue. There is little reason to think that neuroticism alone would have any necessary relation to performance differences due to sleep deprivation. However, if the NAS is related to sleep deprivation dearousal, neuroticism might well serve to enhance the differences seen between introverts and extraverts on all of the tasks.

Individual differences in extraversion may help predict performance on certain cognitive measures after sleep deprivation. Several tests were used here to measure various cognitive functions, allowing for a more comprehensive comparison of the cognitive abilities of introverts and extraverts after sleep deprivation than has been performed in the past. It was predicted that whereas sleep deprivation would negatively affect all participants, it would be more detrimental to extraverts. Furthermore, it was predicted that neuroticism would enhance the differences seen.

1. Methods

1.1. Participants

Participants were selected from undergraduates in lower level psychology classes which had been previously administered the Eysenck Personality Questionnaire (Eysenck & Eysenck, 1975). Researchers recruited students from these classes to participate in a sleep deprivation study in return for class extra credit. Volunteers were first screened using a sleep disorders questionnaire and a health questionnaire. Any participants displaying the following conditions or habits were excluded to avoid health problems and confounds: (a) pregnancy; (b) hypertension or heart problems; (c) possible mental illness; (d) poor sleep habits, a possible sleeping disorder, or working shift work; (e) drank more than 15 units of alcohol per week; (f) was a smoker. There was adequate representation of people high and low on extraversion in the final sample. Thirty-two students (four males, 28 females: 17–25 years) met the inclusion criteria and participated in the experiment. However, as a result of computer malfunctions, data were only obtained on 23–29 participants, depending on the task.

1.2. Measures

We used the Eysenck Personality Questionnaire (EPQ; Eysenck & Eysenck, 1975) to measure extraversion (E) and neuroticism (N).

Cognitive performance was assessed using a computerized battery of eight neuropsychological tests from the Automated Neuropsychological Assessment Metrics, version 3.11 (ANAM; Kane & Reeves, 1997; Perez, Masline, Ramsey, & Urban, 1987). Tests included: (1) Code Substitution; (2) Immediate Recall: (3) Delayed Recall; (4) Digit Span; (5) Stroop Color-Word; (6) Finger Tapping; (7) Match to Sample; (8) Spatial Processing. Some of the above tests monitor cognitive functions associated with specific areas of the cerebral cortex. This test battery was chosen because it is an established testing tool that measures several of the cognitive areas previously shown to be affected by either sleep deprivation or personality. However, these cognitive abilities have not been measured in a study examining both sleep deprivation and personality simultaneously. Therefore, it was hoped that these measures might give a richer picture of the effects of sleep deprivation on different personality types than vigilance tests alone could give.

Participants also completed a time estimation task. Participants were to press the space bar on a computer keyboard, and when they believed 60 s had passed, they were to press the space bar again. They did this a total of four times. The participant's score was the mean of the last three estimates. Participants were not allowed to wear a watch, and there was no flashing cursor during this task. Participants were allowed to count to themselves.

1.3. Analysis

An individual growth modeling procedure (Bryk & Raudenbush, 1992; Goldstein, 1995; Longford, 1993; Willett & Sayer, 1994) was used to analyze the data. A complete cubic polynomial model of change over four time points (21:00, 24:00, 03:00, and 06:00 h) was fit for each participant on each dependent variable. The parameter estimates from each model were used as criterion variables in regression analyses predicting those parameter estimates from E and N in a between-subjects model. Accordingly, there was a within-subjects cubic individual change model and a between-subjects model predicting the individual change curves from E and N. The between-subjects model chosen was one that included E, N, and the cross product of E and N.

The within-subjects cubic individual change models were computed using the following procedure. A cubic model was written using orthogonal contrast coefficients as follows:

$$Y_i = M_{Y+}a_1c_{1i} + a_2c_{2i} + a_3c_{3i}$$

where M_Y is the mean over the four sessions on Y, c_{1i} through c_{3i} are orthogonal linear (−1.5, −0.5, 0.5, 1.5), quadratic (1, −1, −1, 1) and cubic (−1, 3,−3, 1) contrast coefficients for the i = 1, ..., 4 sessions, and a_1 through a_3 are the parameter estimates of the model. Values for M_Y, a_1, a_2, and a_3 were computed for each participant using standard methods (Keppel, 1991) and used as criterion variables in regression analyses predicting them from E, N and E×N. Both E and N were standardized (M = 0, S.D. = 1) prior to constructing cross products.

1.4. Procedure

Once students met health and sleep inclusion criteria, they were allowed to choose one of four nights to participate. These included a Friday or a Saturday on two weekends within the same month, early enough in the semester to avoid interference with finals. On the day of the experiment, participants were called at 08:00 to ensure they were awake. They were reminded not to take any naps during the day, abstain from alcohol, caffeine, and nicotine and report to the lab at 20:00. Upon arrival at the lab, participants were assigned to groups of less than 10. They were brought into the lab every 3 h, starting at 21:00, to complete 30–45 min of computer administered performance measures. Participants were tested in rooms that had three to four workstations in them. Although other participants were working on the other stations, participants could not see the screens of the other participants. Practice trials were provided for each task. Tones were emitted from the computer indicating correct and incorrect responses for all but the tapping and time estimation tasks. Investigators monitored performance during practice trials to ensure participant understanding and compliance.

Participants were monitored throughout the night by experimenters who were blind to personality scores. Participants were not allowed to use any products with nicotine, caffeine, or alcohol, and they were not allowed to take naps. Between test periods, participants were kept in one main room and allowed to occupy themselves with various activities (i.e., reading, board games, cards, watching television, drawing, etc.). The participants were released at 07:00 the next morning.

2. Results

The E ($M = 11.5$; S.D. = 4.8) and N ($M = 13.0$; S.D. = 5.6) scores for this sample of subjects were somewhat negatively correlated, $r = -0.36$, $P = 0.06$, but the means were fairly typical of scores found previously in much larger samples from this subject population.

All figures to follow are derived from their respective tables, and the terms Extraverts, Introverts, Neurotics, and Stables, will refer to individuals at one S.D. above and below the means on E and N, respectively. It is important to note that the points (and their standard errors of prediction) plotted in the figures for the different personality groups are values computed from the regression equations in the relevant tables by setting the standardized E and N values to ± 1 as appropriate. This is a more satisfactory approach to dealing with continuous predictors, such as E and N, than artificially dichotomizing them and looking at four separate groups of subjects (Aiken & West, 1991; Cohen, 1983; Maxwell & Delaney, 1993). The following tables show the regression equations predicting individual time curve parameter estimates from E and N for the respective dependent variables. The intercept rows represent the time curve parameter estimates for the overall sleep deprivation effects when E and N are at the mean. The E row gives the relations between time curve parameter estimates and E for individuals at the mean on N. The N row gives the relations between time curve parameter estimates and N for individuals at the mean

Table 1
Regression equations predicting individual time curve parameter estimates from E and N for time estimation task

	Individual time curve parameter estimate			
	Mean	Linear	Quad	Cubic
Intercept	48.70 (20.55***)	−1.44 (−3.86***)	−0.409 (−0.51)	−0.250 (−0.81)
E	−5.40 (−2.18**)	0.571 (1.46)	0.094 (0.11)	−0.577 (−1.78*)
N	−3.12 (−1.30)	−0.269 (−0.71)	0.113 (0.14)	0.286 (0.91)
E × N	−2.56 (−1.16)	0.762 (2.20**)	−0.985 (−1.32)	0.073 (0.25)
R^2	0.226	0.271	0.093	0.260
n	23	23	23	23
MSE	114.201	2.8404	13.116	1.957

Values in parentheses are *t*-ratios. *MSE* = mean square error. Unstandardized coefficients are reported here from analyses in which E and N were standardized variables. $*P<0.10$. $**P<0.05$. $***P<0.01$.

on E. The E×N row gives the relations between time curve parameter estimates and the linear by linear E×N interaction.

2.1. Time estimation

In Table 1, the intercept row indicates a significant linear trend, $t(19)=-3.86$, $P<0.01$, in time estimations over sessions. Individuals at the mean on E and N were predicted to guess one minute had passed after only 48.7 s in the first session, and their guesses decreased by 1.44 s each period, indicating that time estimation ability decreased as sleep deprivation increased.

The E row of Table 1 shows a negative effect in the Mean column, $t(19)=-2.18$, $P<0.05$. The variable being predicted here (i.e., Mean) represents the average time estimate for each participant over all four sessions. Introverts had a predicted mean time estimation of 54.1 s, and extraverts had a predicted mean time estimation of 10.8 s less than introverts, indicating that neither group was particularly good at estimating time, but extraverts were significantly worse than introverts were.

There was also a significant E×N interaction for the linear slope parameters, $t(19)=2.20$, $P<0.05$. As Fig. 1 shows, the difference between the slopes for extraverts and introverts is greater for neurotics than stables. The slope for neurotic introverts is quite steep, while that for neurotic extraverts is essentially zero. Among stables, both introverts and extraverts have moderate slopes.

Eysenck theorized that the introversion–extraversion differences seen in time estimation reflect differences in the generation of inhibition in response to an external stimulus (i.e., target time period). We do not think this was the case here since we did not use a target stimulus. On the other hand, because individuals were asked to estimate when 1 min had passed four times in a row, each trial's estimate could have served as an external stimulus for the next. Thus, reactive inhibition could have developed over trials so as to decrease the overall mean estimate.

2.2. Immediate recall

The intercept row of Table 2 indicates that there was a significant quadratic trend, $t(24)=-3.19$, $P<0.01$, in accuracy over sessions. Accuracy was relatively low in the first session,

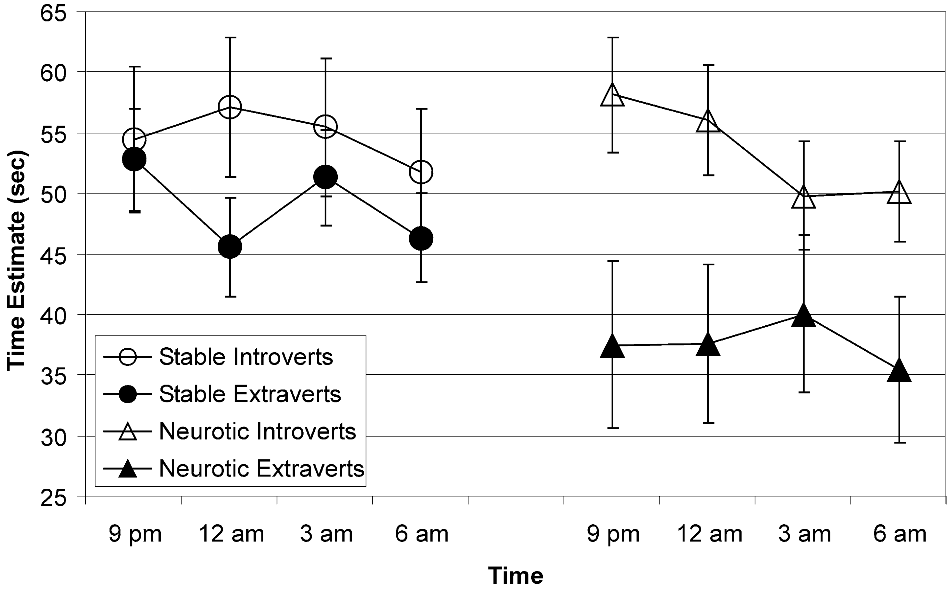

Fig. 1. Predicted time estimation scores for neurotic introverts, neurotic extraverts, stable introverts, and stable extraverts, over four testing periods.

Table 2
Regression equations predicting individual time curve parameter estimates from E and N for immediate recall accuracy

	Individual time curve parameter estimate			
	Mean	Linear	Quad	Cubic
Intercept	84.413 (42.12***)	−1.023 (−0.79)	−3.237 (−3.19***)	0.248 (0.53)
E	−6.195 (−2.96***)	−2.065 (−1.52)	−1.328 (−1.25)	0.148 (0.30)
N	−1.666 (−0.82)	−0.393 (−0.30)	−0.636 (−0.62)	0.277 (0.59)
E × N	−3.695 (−1.93*)	−0.723 (−0.58)	−0.486 (−0.50)	−0.243 (−0.55)
R^2	0.297	0.090	0.065	0.028
n	28	28	28	28
MSE	99.32	41.92	25.50	5.33

Values in parentheses are *t*-ratios. *MSE* = mean square error. Unstandardized coefficients are reported here from analyses in which E and N were standardized variables. $^*P<0.10$. $^{**}P<0.05$. $^{***}P<0.01$.

tended to improve during the second, then dropped off as the night progressed. The initial improvement may indicate individuals were learning the task in the first session, whereas the performance decrements in sessions three and four were probably due to sleep deprivation.

A significant negative effect of E, $t(24)=-2.96$, $P<0.01$, and a nearly significant E×N interaction, $t(24)=-1.93$, $P<0.10$, in predicting mean accuracy were also found. As Fig. 2 shows, the poorer mean accuracy of extraverts in comparison to introverts was more pronounced for neurotics than stables.

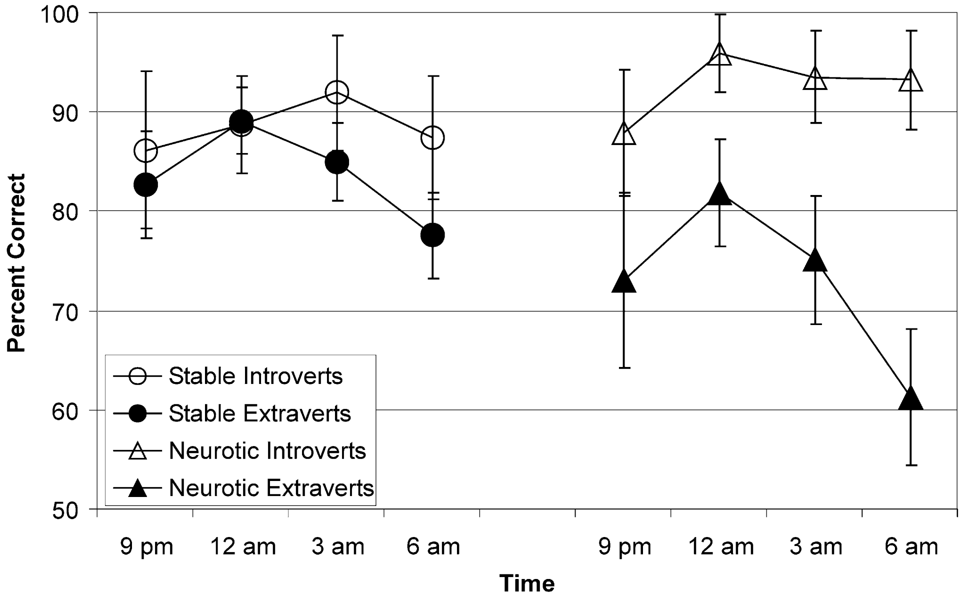

Fig. 2. Predicted accuracy scores on the Immediate Recall task, for neurotic introverts, neurotic extraverts, stable introverts, and stable extraverts, over four testing periods.

Reaction times (RT) to correct responses in the immediate and delayed recall tasks were also analyzed. In the RT analyses there was only one significant effect, a negative linear trend, $t(24) = -4.17$, $P < 0.01$, in median RT for correct responses over sessions, indicating that for individuals at the mean on E and N, the predicted RT decreased by an average of 125 ms per session. No significant effects were found relating extraversion or neuroticism to RT. It is worth noting that as RT decreased over sessions, so did accuracy. This would suggest an overall speed-accuracy trade off as amount of sleep deprivation increased.

2.3. Delayed recall

The patterns of results for accuracy and RT for the delayed recall task were similar to those of the immediate recall task. As with the immediate recall results, there was a significant negative effect of E, $t(25) = -3.29$, $P < 0.01$, and a nearly significant ExN interaction, $t(24) = -1.94$, $P = 0.064$, in predicting mean accuracy. The general pattern of the relations of the variables E and N to accuracy in both recall tasks after sleep deprivation is well captured by the results shown in Fig. 2 for the immediate recall task. The RT results in the delayed recall task showed a similar negative linear trend over sessions, $t(25) = -2.20$, $P < 0.05$, to that of the immediate recall task.

2.4. Digit span

The intercept row in Table 3 indicates that there were significant linear, $t(24) = 2.18$, $P < 0.05$, and quadratic, $t(24) = -2.15$, $P < 0.05$, trends in overall accuracy. For individuals at the mean on E and N, predicted accuracy increased by an average of 2.27% per session. However, from the

Table 3
Regression equations predicting individual time curve parameter estimates from E and N for digit span accuracy

	Individual time curve parameter estimate			
	Mean	Linear	Quad	Cubic
Intercept	86.60 (35.81***)	2.27 (2.18**)	−2.53 (−2.15**)	0.235 (0.73)
E	−3.75 (−1.48)	0.212 (0.19)	−2.45 (−2.00*)	0.119 (0.35)
N	−2.02 (−0.83)	−0.994 (−0.94)	−0.536 (−0.45)	−0.095 (−0.29)
E × N	−2.50 (−1.08)	−0.197 (−0.20)	0.205 (0.18)	−0.089 (−0.29)
R^2	0.11	0.054	0.163	0.022
n	28	28	28	28
MSE	144.66	26.97	33.96	2.55

Values in parentheses are *t*-ratios. MSE = mean square error. Unstandardized coefficients are reported here from analyses in which E and N were standardized variables. $^*P<0.10$. $^{**}P<0.05$. $^{***}P<0.01$.

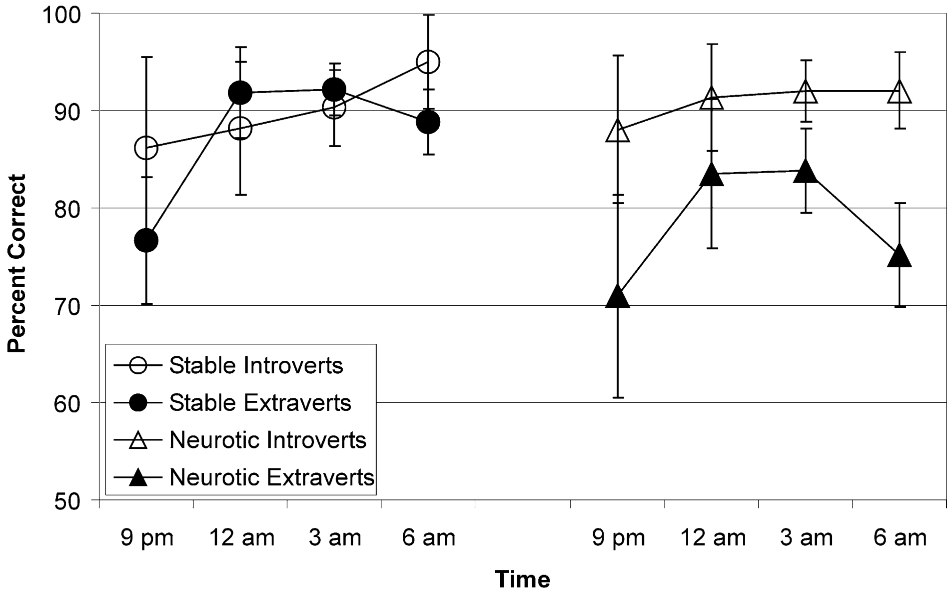

Fig. 3. Predicted accuracy scores on the Digit Span task, for neurotic introverts, neurotic extraverts, stable introverts, and stable extraverts, over four testing periods.

second to the fourth sessions performance leveled off, even showing a slight decline by session four. There was also a nearly significant negative relation between E and the quadratic trend in accuracy over sessions, $t(24)=-2.00$, $P=0.057$. As Fig. 3 reveals, introverts continued to improve on accuracy as the night progressed, while extraverts' accuracy started off lower in session one, improved in sessions two and three, and then decreased in session four. This pattern suggests that extraverts' performance on the digit span task was more adversely affected by sleep deprivation than introverts'.

Table 4
Regression equations predicting individual time curve parameter estimates from E and N for Stroop color-word accuracy

	Individual time curve parameter estimate			
	Mean	Linear	Quad	Cubic
Intercept	92.91 (131.43***)	−0.234 (−0.61)	−0.275 (−0.67)	−0.245 (−1.62)
E	−1.05 (−1.41)	0.142 (0.35)	−0.402 (−0.93)	−0.435 (−2.74**)
N	−0.330 (−0.46)	−0.359 (−0.91)	−0.385 (−0.92)	0.017 (0.11)
E × N	−1.44 (−2.07**)	0.405 (1.06)	−0.297 (−0.73)	−0.000 (−0.00)
R^2	0.187	0.084	0.068	0.28
n	27	27	27	27
MSE	12.24	3.64	4.16	0.558

Values in parentheses are *t*-ratios. MSE = mean square error. Unstandardized coefficients are reported here from analyses in which E and N were standardized variables. *$P<0.10$. **$P<0.05$. ***$P<0.01$.

Analyses of RT in the digit span task revealed that E was nearly significantly negatively related to the overall mean reaction time, $t(24)=-2.08$, $P<0.10$. A one standard deviation increase in E was associated with a 72 ms decrease in mean reaction time. No other effects were significant.

2.5. Stroop task

Table 4 shows the regression equations predicting individual time curve parameter estimates from E and N for accuracy on the third (color-word) task of the Stroop test.

Table 4 reveals a significant relation between E and the cubic trend in accuracy, $t(23)=-2.74$, $P<0.02$. Fig. 4 shows that whereas introverts' accuracy scores remained relatively stable over sessions, extraverts' accuracy scores decreased in the second session, increased in the third, and decreased again in the fourth. We have no explanation for this pattern.

There was also a significant ExN interaction, $t(23)=-2.07$, $P=0.05$, for mean accuracy. The poorer mean accuracy of extraverts in comparison to introverts was more pronounced for neurotics than stables.

The only significant effect for RT in the Stroop color-word task was a significant linear trend, $t(24)=-3.73$, $P<0.002$, in median reaction time for correct responses over sessions. For individuals at the mean on E and N, the predicted reaction time decreased by an average of 46 ms per session.

2.6. Finger tapping

One participant was left handed and therefore excluded from the analysis of the finger tapping data. An initial repeated measures multivariate regression analysis including both left and right handed tapping data revealed no interactions of E, N, or E×N with hand in predicting time curve parameter estimates (all *P*s > 0.24). The only significant effect of hand was a main effect, $F(1, 24)=7.99$, $P<0.01$; the mean number of left hand taps ($M=48.9$) was lower than that of right hand taps ($M=53.2$). Therefore, tapping data from both hands were averaged to provide a single tapping analysis.

The results of the analysis for the combined tapping data are shown in Table 5 and the corresponding Fig. 5. The intercept row in Table 5 indicates that there was a significant linear trend,

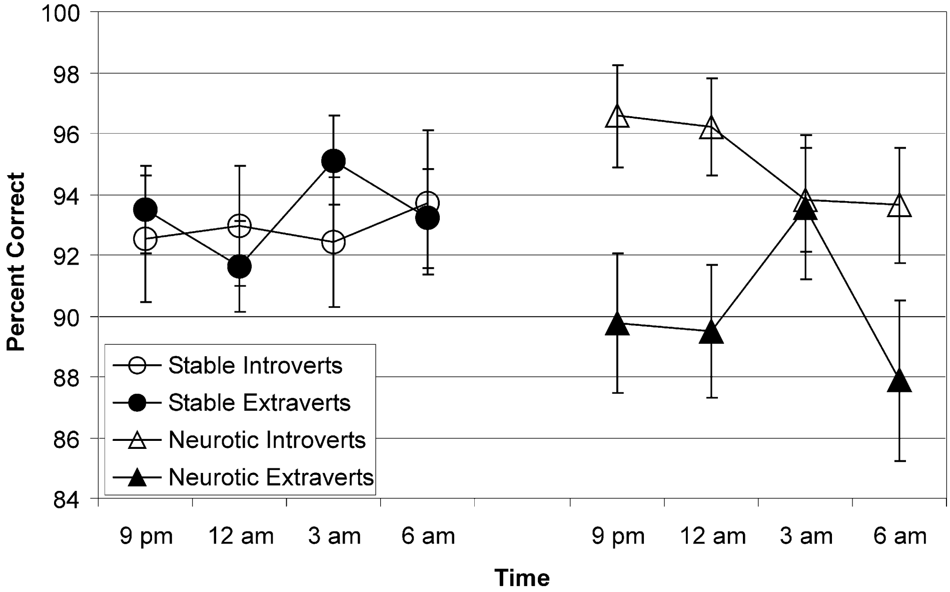

Fig. 4. Predicted accuracy scores on the Stroop color-word task, for neurotic introverts, neurotic extraverts, stable introverts, and stable extraverts, over four testing periods.

Table 5
Regression equations predicting individual time curve parameter estimates from E and N for combined left and right hand finger tapping

	Individual time curve parameter estimate			
	Mean	Linear	Quad	Cubic
Intercept	50.67 (46.97***)	1.55 (3.43***)	−0.674 (−1.63)	0.324 (2.34**)
E	−2.38 (−2.11**)	0.065 (0.14)	−0.173 (−0.40)	−0.119 (−0.82)
N	−2.17 (−1.99*)	0.138 (0.30)	−0.053 (−0.13)	−0.045 (−0.32)
E × N	−1.07 (−1.04)	0.118 (0.27)	0.012 (0.03)	−0.014 (−0.10)
R^2	0.222	0.007	0.008	0.028
n	28	28	28	28
MSE	28.78	5.06	4.24	0.475

Values in parentheses are *t*-ratios. MSE = mean square error. Unstandardized coefficients are reported here from analyses in which E and N were standardized variables. *$P<0.10$. **$P<0.05$. ***$P<0.01$.

$t(24)=3.43$, $P<0.01$, in tapping over sessions such that for individuals at the mean on E and N, the predicted tap rate increased by an average of 1.55 taps per session. The significant cubic trend, $t(24)=2.34$, $P<0.05$, reflects the fact that the general increase in tap rate over sessions tended to be interrupted by something of a decline in the 03:00 session.

Overall tap rate was significantly related to both E, $t(24)=-2.11$, $P<0.05$, and N, $t(24)=-1.99$, $P=0.058$, with extraverts and neurotics showing lower overall tap rates.

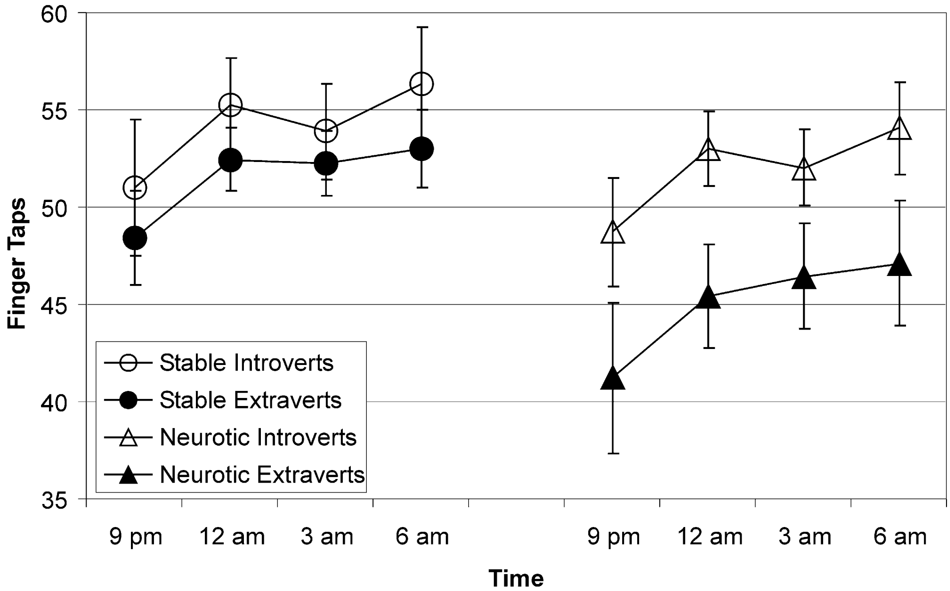

Fig. 5. Predicted number of taps for neurotic introverts, neurotic extraverts, stable introverts, and stable extraverts, over four testing periods.

These results are similar to Eysenck's (1964) finger tapping results. It was theorized that extraverts build up reactive inhibition faster than introverts, and are slower to let it dissipate. This reactive inhibition perhaps caused extraverts to sometimes put less pressure on the tapping instrument, resulting in a half tap, which was not recorded. We had no way of analyzing if extraverts did attempt half taps as a result of involuntary rest pauses.

2.7. *Match-to-sample and spatial processing*

The match-to-sample and spatial processing tasks revealed no performance differences that were related to E or N. Moreover, performance in both these tasks tended to improve over sessions. In the match to sample task there was a linear increase in accuracy and a linear decrease in RT over sessions, $t(25)=2.52$, $P<0.02$, and, $t(25)=-2.78$, $P<0.02$, respectively. No other effects were significant. In the spatial processing task the only significant effect was a linear decrease in RT over sessions, $t(25)=-4.52$, $P<0.001$.

3. Discussion

These results show that short-term sleep deprivation negatively affects performance on time estimation, immediate recall, delayed recall, and digit span tasks. Furthermore, extraverts performed worse than introverts on the time estimation, immediate recall, delayed recall, and finger tapping tasks. Finally, significant interactions between extraversion and neuroticism in predicting performance on time estimation, immediate recall, delayed recall, and Stroop tasks were found such that neuroticism exaggerated the differences seen between extraverts and introverts. These results are consistent with previous findings (Eysenck, 1987; Hotard et al., 1989; McFatter, 1994; Wallace et al., 1991). The poorer accuracy of extraverts in comparison to introverts was more pronounced for neurotics than stables. Neuroticism alone was not significantly related to sleep deprivation effects. If neuroticism reflects differences in the reactivity of the NAS, as hypothesized by Wallace et al., the present results would suggest that the individual differences in NAS reactivity are not tied to performance differences induced by sleep deprivation. This could be because this system is closely tied to survival type behaviors (i.e., fight/fight), and it could be precarious if it were easily affected by sleepiness.

The overall effects of sleep deprivation provide partial support to findings indicating short-term sleep deprivation negatively affects performance on cognitive measures (Pilcher & Huffcutt, 1996; Pilcher & Walters, 1997). These effects were most likely due to the decreased arousal caused by sleep deprivation, but could also be a result of a speed-accuracy trade off, where participants were more concerned with responding quickly than responding accurately in order to finish the tasks faster. The match to sample, spatial processing and Stroop tasks were not significantly affected by sleep deprivation, indicating that the cognitive processes measured by these tasks did not appear to be sensitive to short-term sleep deprivation.

These results also provide partial support for findings that extraverts perform worse on cognitive measures than introverts in low to moderately stimulating environments (Corcoran, 1965, 1972; Eysenck, 1959; Jha, 1988; Lynn, 1961; Smith & Maben, 1993; Wudel, 1979). Some support was found in both the immediate and delayed recall tasks for the hypothesis that the differences between extraverts and introverts would get consistently greater as the night progressed (see Fig. 2). The pattern found here is similar to that reported by Corcoran (1972), though in his data the effect did not become pronounced until after 2–3 days of sleep deprivation. It is important to mention that there were no significant differences between extraverts and introverts on reaction times, indicating that extraverts did not show more of a speed accuracy tradeoff than introverts. Therefore, differences seen between the two groups were more likely due to arousal level than motivation.

The data obtained on the recall tasks contradict previous studies that found extraverts to be better on short-term memory and introverts to be better on long-term memory (Howarth & Eysenck, 1968; Osborn, 1972). The data here indicate that introverts performed significantly better on both short-term and long-term memory tasks. It is unclear at this point why this discrepancy occurred. It may be due to type of task used to measure memory in those earlier studies. However, we obtained similar results with both the immediate recall and digit span tasks, which both measure short-term memory.

Future research might well look at the cognitive functions of shift workers in relation to personality. It would also be interesting to extend sleep deprivation to 48 h to determine if circadian variables are at work. Finally, investigating the number of on the job mistakes made by individuals with different personality types who are chronically and frequently sleep deprived (e.g., doctors and soldiers) would also be useful.

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