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Computerized Assessment of Sustained Attention: Interactive Effects of Task Demand, Noise, and Anxiety*

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ABSTRACT

In a sample of 163 college undergraduates, the effects of task demand, noise, and anxiety on Continuous Performance Test (CPT) errors were evaluated with multiple regression and multivariate analysis of variance. Results indicated significantly more omission errors on the difficult task. Complex interaction effects of noise and self-reported anxiety yielded more omissions in quiet intermittent white noise, particularly for high-anxious subjects performing the difficult task. Anxiety levels tended to increase from pretest to posttest, particularly for low-anxious subjects in the quiet, difficult-task condition, while a decrease was seen for high-anxious subjects in the loud, easy-task condition. Commission errors were unrelated to any predictor variables, suggesting that "attention" cannot be considered a unitary phenomenon. The variety of direct and interactive effects on vigilance performance underscore the need for clinicians to use a variety of measures to assess attentional skills, to avoid diagnosis of attention deficits on the basis of a single computerized task performance, and to rule out anxiety and other contributors to poor vigilance task performance.

The ability to sustain attention is an important concomitant of performance capability across the life-span, from kindergarten to college to the workplace. The study of this ability has led to the development of "watchkeeping" tasks, also known as vigilance tests. In a wide variety of test formats, subjects must maintain alertness for small changes in a static display, or for specified stimuli occurring in a continuously changing display. Measures such as omission errors ("misses"), commission errors ("false alarms"), and response latencies may be taken, and also can be used to compute measures of decline in speed or accuracy over time (the "vigilance decrement"), overall perceptual sensitivity (*d′*), or response criterion (*Beta*). These measures are thought to reflect the subject's ability to sustain attention (Barkley, 1988; Corkum & Siegel, 1993; Davies, Jones, & Taylor, 1984; Kirchner & Knopf, 1974; Knopf & Mabel, 1975; J.F. Mackworth, 1970; N.H. Mackworth, 1950, 1957; McGrath, Harabedian, & Buckner, 1968; Mirsky, Anthony, Duncan, Ahearn, & Kellam, 1991; Parasuraman, 1984; Parasuraman & Davies, 1984; Warm, 1984).

One variation of the vigilance task is the Continuous Performance Test (CPT), originally devised by Rosvold, Mirsky, Sarason, Bransome, and Beck (1956). In this task, individual letters, numerals, or other symbols are displayed consecutively on a computer monitor or other device. The subject must watch for a specific symbol or series of symbols and respond by pressing a spacebar or key when this "critical signal"

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occurs (Barkley, 1988, 1990; Conners, 1985; Corkum & Siegel, 1993; Davies et al., 1984; Gordon & Mettleman, 1988; Halperin et al., 1988; Halperin, Matier, Bedi, Sharma, & Newcorn, 1992; Halperin, Wolf, Greenblatt, & Young, 1991; Kirchner & Knopf, 1974; Klee & Garfinkel, 1983; Kupietz, 1990; Mirsky et al., 1991; Rosvold et al., 1956; Warm, 1984). The CPT is thought to be more cognitively demanding than vigilance tasks in which only a sensory change must be detected, particularly when detection of a series of symbols requires increased memory capacity (Berch & Kanter, 1984; Davies et al., 1984; Davies & Parasuraman, 1982; Kupietz, 1976; Parasuraman, 1984; Parasuraman & Mouloua, 1987; Sykes, Douglas, & Morganstern, 1973; Warm & Jerison, 1984).

The CPT has become a popular instrument for use in clinical diagnosis of Attention Deficit Hyperactivity Disorder (ADHD; American Psychiatric Association, 1994). Several versions are available commercially. Many clinicians advocate the importance of using a "laboratory-based" measure to supplement other diagnostic procedures (Barkley, 1990; Bauermeister, Berrios, Jimenez, Acevedo, & Gordon, 1990; Conners, 1985; Gordon, 1986, 1987; Gordon & Mettleman, 1988; Irwin & Mettleman, 1989; Klee & Garfinkel, 1983; Post, Burko, & Gordon, 1990; Seidel & Joschko, 1991; J.M. Swanson, 1985), although opinions are mixed (Barkley, DuPaul, & McMurray, 1990; Corkum & Siegel, 1993; DuPaul, Anastopoulos, Shelton, Guevremont, & Metevia, 1992; Halperin et al., 1992; Milich, Pelham, & Hinshaw, 1986; Trommer, Hoeppner, Lorber, & Armstrong, 1988).

However, results of more than 50 years of research using a variety of CPT and other vigilance tasks indicate that vigilance performance is affected by many factors other than clinical status. Table 1 lists examples from three categories of factors that affect vigilance task performance. Reviews of a large body of empirical work in several branches of psychology suggest that factors affecting vigilance performance include specific parameters of the task itself (Baker, 1959; Broadbent & Gregory, 1965; Chee, Logan, Schachar, Lindsay, & Wachsmuth, 1989; Hancock, 1984; N.H. Mackworth, 1948, 1957; J.F. Mackworth, 1970; McGrath et al., 1968; Parasuraman, 1985; Warm, 1977, 1984; Warm & Jerison, 1984), environmental or situational conditions during task performance (Broadbent & Gregory, 1965; Hancock, 1984; Hancock & Warm, 1989; Hockey, 1984; Jerison, 1959; Koelega & Brinkman, 1986; Krueger, 1989; Loeb, 1981; Loeb & Alluisi, 1977; McGrath, 1968; Warner & Heimstra, 1972), and a variety of individual variations in subject characteristics (Barkley, 1977; Beale, Matthew, Oliver, & Corballis, 1987; Berch & Kanter, 1984; Buckner, Harabedian, & McGrath, 1968; Corkum & Siegel, 1993; Davies et al., 1984; Earle-Boyer, Serper, Davidson, & Harvey, 1991; Matthews, Davies, & Lees, 1990; Mirsky et al., 1991; Mirsky et al., 1992; Parasuraman & Haxby, 1993; Parasuraman, Mutter, & Molloy, 1991; Rund, Orbeck, & Landro, 1992; Rutschmann, Cornblatt, & Erlenmeyer-Kimling, 1986; L. Swanson, 1981; Tarver & Hallahan, 1974).

Although many of these effects have been replicated, inconsistencies across studies suggest the possibility of interactive effects. Existing models of attention are insufficient to explain the variety of well-demonstrated vigilance phenomena or the diversity of factors shown to affect vigilance performance. Many researchers therefore have suggested instead the use of an elemental, or interactive approach to explaining vigilance performance variations (Hancock, 1984). Such an approach involves a factorial consideration of the main and interactive effects of task parameters, environmental stressors, and subject variables, which may yield complex interaction effects on overall vigilance performance and on performance decrements over time (Hancock, 1984; Hockey, 1984; Loeb, 1981; Loeb & Alluisi, 1977; Lysaght, 1982; Parasuraman, 1985; Parasuraman & Davies, 1977; Warm, 1977). Variations in the effects of specific factors, such as environmental noise, therefore, may depend on levels of other factors, such as task difficulty and/or subject characteristics.

Some evidence supports the view that both additive and multiplicative effects are produced by the interaction of subject characteristics with other subject or situational variables (Aylward, Verhulst, & Bell, 1990; Davies & Davies, 1975;

Table 1. Factors Affecting or Related to Performance on Vigilance Tasks.

Task Parameters	Environmental Factors	Subject Characteristics
Information to subjects	Environmental stressors	Demographics
Instructions	Thermal stress	Age
Subjects' Expectancies	Vibration	Socioeconomic Status
Practice	Noise	IQ below normal
Reinforcement		
Feedback		
Type of task	Situational factors	Personality factors
Sensory Modality	Crowding	Intro/Extraversion
Sensory or Symbolic	Presence of Observers	Field Dependence
Task Duration	Time of Day	Temperament
Background events	Performance of the task	Clinical symptoms
Static or changing	Performance stress	ADHD, LD, MR, BD
Rate of presentation		Schizophrenia
Interstimulus interval		Brain Damage
Event duration		Seizure Disorder
		Dementia
Critical signals		Physiological states
Amplitude/Size		General arousal level
Frequency		Electrodermal lability
Duration		Cortical arousal
Detectibility		Fatigue
Signal-to-Noise Ratio		Sleep deprivation
		Drugs, alcohol
		Medication

Note. See text for references.

Kaufmann, Fletcher, Levin, Miner, & Ewing-Cobbs, 1993; Kendler et al., 1991; Koelega, 1989; Kupietz, 1990), by the interaction of subject characteristics with task parameters (Chee et al., 1989; Deaton & Parasuraman, 1993; Dittmar, Warm, Dember, & Ricks, 1993; Geen, 1985; Mussgay & Hertwig, 1990; Parasuraman & Giambra, 1991; Parasuraman, Nestor, & Greenwood, 1989; Schiff & Knopf, 1985; Tomporowski & Allison, 1988), by the interaction of task parameters with other task or environmental factors (Auburn, Jones, & Chapman, 1987; Craig, Davies, & Matthews, 1987; Deaton & Parasuraman, 1993; Hancock, 1984; Hancock & Warm, 1989; Lanzetta, Dember, Warm, & Berch, 1987; Linnoila, Erwin, Cleveland, Logue, & Gentry, 1978; McGrath & Hatcher, 1968; Patel, 1988; Smith & Miles, 1986), and by differential effects of various factors on different measures (Koelega, Brinkman, Hendriks, & Verbaten, 1989; Matier, Halperin, Sharma, Newcorn, & Sathaye, 1992). Such interactive effects often are assumed or inferred. However, no studies have examined the possibility of interactions from all three sources of effects simultaneously.

The present study therefore was designed to examine the main and interactive effects on vigilance performance of three categories of factors. As in early vigilance paradigms (N.H. Mackworth, 1950), task difficulty was manipulated by varying the number of computer screens to be monitored simultaneously. Environmental factors were held constant except for background white noise, which was varied both in terms of volume level and constancy. Finally, between-subjects variability in anxiety state immediately prior to performance of a vigilance

(CPT) task was measured via the State-Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). The resulting factorial design included two levels each of three experimentally manipulated variables: task parameters (high or low processing demand), environmental noise type (constant or intermittent static), and noise volume (high or low). Also included as a nonmanipulated subject variable was anxiety level, a characteristic of interest both to clinicians and to researchers exploring the relation of arousal to vigilance performance (Matthews et al., 1990; Pliszka, 1992). The subject characteristic (pretest state anxiety) was evaluated both as a continuous variable through regression analyses, and as a between-subjects factor (high and low anxiety) in multivariate analysis of variance. Dependent measures included CPT omission errors, CPT commission errors, and changes in anxiety state. Complex interaction effects were hypothesized on the basis of prior research results, attention theories, and Spielberger's State-Trait theory of anxiety (Epstein, 1972; Gaudry & Spielberger, 1971; Glanzmann & Laux, 1978; Sinclair, 1969; Spielberger, 1966, 1983; Spielberger, Gorsuch, & Lushene, 1970; Spielberger, Vagg, Barker, Donham, & Westberry, 1980). Greater task demand was expected to produce higher rates of omission and commission on the CPT, as well as larger increases in state anxiety. It also was predicted that poorer performance on the difficult task would be most pronounced for subjects with high anxiety levels.

METHOD

Subjects

Subjects were 163 undergraduates recruited from introductory psychology classes at a private southeastern university. Class credits were awarded for participation in this study. Subjects were aware that their participation would require approximately 40 minutes, that they would perform a computer task and respond to questionnaires, and that a static machine would be used "to mask outside noise." Ninety-three percent were U.S. citizens, while the remaining 7% were U.S. residents for at least 5 years prior to the study. All reported English as their primary language. Females comprised 59.5% of the sample. Racial/ethnic representation included 84.7% White, 6.7% Black, and 8.7% Asian or other. Mean age of the sample was 18.69 years, with a range of 17 to 22 years of age. The majority (51.5%) were 18 years old. The 46% of subjects who reported needing glasses or contact lenses were required to use these during the computer task.

Materials

Sustained Attention Tasks

Locally produced computerized CPTs were run and scored by Apple IIe computers with Mountain Clock cards, 80-column cards, and standard green monitors. A 24-s practice period was followed by a 20-min test. Stimuli were single, angular letters 5mm in height, and were displayed in the center of the computer monitor for a duration of 0.2 s. The interstimulus interval was 1.0 s. The critical stimulus, to which the subject responded by pressing the spacebar, was the letter "A" followed by the letter "X." These targets occurred at randomly determined times during the test. Each of 13 other angular letters was displayed an equal number of times in a randomly determined sequence at remaining points. Scores included the number of critical stimuli to which the subject failed to respond (omission errors), as well as the number of responses to noncritical stimuli (false alarm or commission errors). Correct detections included responses occurring within 0.2 and 1.0 s following presentation of a critical signal.

Subjects were assigned randomly to one of two tasks. In both tasks, a total of 35 critical stimuli were presented during the 20-min vigil. In the *low processing* demand, or "easy" condition, a single computer screen was monitored. A low signal-to-background event ratio of 1:28 was employed to avoid ceiling effects found in studies using higher ratios (Edley & Knopf, 1987). In the *high processing* demand, or "difficult" condition, the subject simultaneously monitored two computer displays during the 20-min vigil, with stimulus presentation on the two monitors offset by 0.5 s. Monitors were placed side-by-side, yielding a distance of 9 in. between target presentation sites. In the difficult condition, critical stimuli were evenly divided between the two monitors, and occurred at the same time intervals as those of the easy condition. The two-monitor task therefore was more "difficult" due to a decreased signal-to-noise ratio, increased background event rate, increased scanning demands, and increased sequential memory requirements.

Static Generator
A Marsona 1200 sound conditioner generated noise during performance of the vigilance task. Two noise variables were manipulated. The level of noise (dB) was set at either "loud" (approximately 90 dB) or "quiet" volume (approximately 30 dB). The constancy of noise was set to generate either constant white noise ("rain") or intermittent waves of static ("surf"). In the "surf" condition, onset of noise occurred at irregular intervals. The maximum volume of noise was equivalent to the 30 or 90dB of constant noise conditions. The ratio of noise-on to noise-off was high (approximately 60% noise-on).

Spielberger State/Trait Anxiety Inventory (Self-Evaluation Questionnaire) (STAI)
The Spielberger Self-Evaluation Questionnaire, Form Y (Spielberger et al., 1983) was used to assess trait-like anxiety as well as the subjects' present anxiety states (Spielberger, 1966; Spielberger et al., 1970; Spielberger et al., 1983; Spielberger et al., 1980). The STAI includes two sets of 20 statements descriptive of feeling states or behaviors. One set evaluates state anxiety, or how the respondent feels "at the present moment." Response options, on a 4-point Likert scale, reflect the intensity of the respondent's current state (Spielberger et al., 1980). A high level of internal consistency (median alpha coefficient .93) has been demonstrated for this scale. Test-retest reliability is generally lower, reflecting the tendency of state anxiety to vary with situations (Spielberger et al., 1970; Spielberger et al., 1983). The second scale of the STAI evaluates trait anxiety, or how the respondent "generally" feels. Response options for these items reflect the frequency of occurrence of the feelings or behaviors (Spielberger et al., 1980). Internal consistency for the trait anxiety items generally is high, with a median alpha coefficient of .90 (Spielberger et al., 1980), as is test-retest reliability (Spielberger et al., 1970; Spielberger et al., 1983). Trait anxiety, as measured by the STAI (Spielberger et al., 1983) is described as reflecting an individual's tendency to perceive situations as ego-threatening.

The STAI was administered before and after the subject's participation in the computer task. Positively worded items on each scale were reverse-scored and item scores were summed. Higher scores indicated higher levels of trait or state anxiety. Scores from the "State" section were utilized in subsequent analyses. For MANOVA analysis, STAI pretest anxiety-state scores were split at the median to form "high anxiety" and "low anxiety" groups. For REGRESSION analysis, pretest anxiety-state scores were retained as interval data. An anxiety-change score was calculated by subtraction of the pretest from the posttest anxiety-state score. Positive change-scores therefore represented an increase in self-reported anxiety, while negative scores indicated a decrease.

Procedure
Subjects reported individually for the experiment during afternoon or evening hours. The trait section of the STAI was administered first, followed by the state section, with the examiner reading the standard instructions aloud. Subjects were assigned randomly to one of eight conditions formed by two levels each of task difficulty, noise type, and noise volume. The CPT was administered in a separate room with minimal distractions and partial sound-proofing. Each subject was seated at a comfortable arms-length from the computer keyboard, yielding an average distance of about 36 in. from the subject's eyes to the computer screen. In the easy-task condition, the subject sat directly facing a single computer screen. In the difficult-task condition, the subject sat in a centered position between the two screens. Instructions on the procedure for the CPT were read aloud to the subject, emphasizing both speed and accuracy. The practice segment was administered, with two critical stimuli occurring among 20 total stimuli. The experimenter then started the static generator and the CPT, left the room, and subsequently observed through a one-way mirror. Following completion of the computer task, the STAI was administered a second time, with the state section given first.

RESULTS

Examination of the Data
No demographic variables were significantly associated with experimental or outcome variables. All anxiety measures were relatively normally distributed, with mild positive skew in pretest anxiety-state. For the total sample, pretest anxiety-state scores ranged from 21 to 63 (M = 34.41; SD = 9.26). Pretest anxiety-trait scores ranged from 21 to 54 (M = 36.31; SD = 7.34). Posttest anxiety-state scores ranged from 20 to 77 (M = 39.31; SD = 12.09), and posttest anxiety-trait scores ranged from 20 to 59 (M = 36.02; SD = 8.79). Anxiety-change scores were relatively normally distributed from −23 to +50

(M = 4.95; SD = 10.29) with mild positive kurtosis noted.

The distributions both of CPT false alarms and CPT omission errors showed extreme positive skew and kurtosis, as well as univariate outliers. Error scores beyond the 98th percentile of each distribution therefore were recoded to one more than the 98th percentile score. For CPT omissions, two scores of greater than 12 errors were recoded to 13. For CPT false alarms, four scores of greater than 15 were recoded to 16. The recoding improved kurtosis and skewness, and reduced the effect of the extreme scores without sacrificing interpretability. Although the distributions of the recoded variables remained non-normal, the predominance of error scores near zero was expected, and sufficient variability in the relatively large sample allowed further analysis. For the total sample, mean recoded omission scores ranged from 0 to 13 (M = 1.13; SD = 2.46), and mean recoded false alarm scores ranged from 0 to 16 (M = 1.41; SD = 3.31).

Two-tailed significance tests were applied to the correlations between each of the measured variables. All anxiety measures were significantly intercorrelated, as predicted by State-Trait theory. Pretest anxiety-trait unfortunately was correlated with both task difficulty (r = .267), $p < .01$) and with volume level (r = .187, $p < .05$), and was therefore dropped as a predictor variable. Pretest anxiety-state also was correlated with volume level (r = .23, $p < .01$), with a greater proportion of low-anxious subjects assigned to quiet-noise conditions, but was not correlated with task difficulty. Because cell sizes were still comparable across conditions, this variable was retained as a predictor. Among the dependent variables, as expected, CPT omissions and false alarms were significantly correlated (r = .407, $p < .001$), with persons making errors of omission more likely to make errors of commission as well. In addition, omissions were significantly correlated both with posttest anxiety-state (r = .307, $p < .001$) and with anxiety-change (r = .274, $p < .001$), indicating that greater increases in anxiety were associated with greater numbers of omission errors. False alarm errors were significantly associated with posttest anxiety-state (r = .212, $p < .05$), but not with the change in anxiety state from pretest to posttest (r = .172, $p > .05$).

Regression results

A series of multiple regression procedures was employed to predict recoded CPT omissions, recoded CPT false alarms, and anxiety-change scores. Predictor variables were pretest anxiety state (ANXIETY), task difficulty (TASK), volume level (VOLUME), and type of noise (NOISE). Dichotomous variables were contrast-coded as +1 or −1. Interaction terms were produced by multiplication (Cohen & Cohen, 1983), and included Task × Volume, Task × Noise, Noise × Volume, Task × Noise × Volume, Anxiety × Task, Anxiety × Noise, Anxiety × Volume, Anxiety × Task × Noise, Anxiety × Task × Volume, Anxiety × Noise × Volume, and Anxiety × Task × Noise × Volume. SPSS-PC REGRESSION and SPSS-PC FREQUENCIES were used to evaluate assumptions and conduct the analysis.

Because of significant associations between independent variables with shared terms, each regression analysis was conducted first as a standard regression to determine the unique contribution of each predictor variable and interaction term to the prediction of the outcome variable. A hierarchical regression was conducted next to assess the additional contribution of state anxiety and interaction terms including anxiety to prediction after accounting for shared variance with experimental variables.

Prediction of CPT Omissions

The first multiple regression analyzed prediction of recoded CPT errors of omission by the set of independent variables. After entry of all predictor variables in a standard regression equation, R was significantly different from zero, R = 0.5329, $F(15,147) = 3.887$, $p < .0001$. Significant contributions to prediction of CPT omissions were made by the regression coefficients for Anxiety × Task × Volume ($sr^2 = 0.0261$, F = 5.349, p = .02), pretest Anxiety ($sr^2 = 0.0244$, F = 5.005, p = .02), and Anxiety × Volume (sr^2 = 0.0205, F = 4.216, p = .04), but these variables contributed unique explanations of only 7.1% of the variance. All predictors in combination contributed another 21.3% in shared, or overlapping variability. Altogether, the 15 independent variables predicted 28.4% of the variance in CPT errors of omission.

Because of the correlations among IVs, hierarchical regression analysis was conducted to determine the additional prediction of CPT omissions offered by the subject variable, pretest anxiety-state, and its interaction terms, after accounting for effects of manipulated variables. Table 2 displays the multiple R, R^2, and adjusted R^2 after each step of the analysis. The table also shows the incremental squared semipartial correlations (sr^2inc) for each step, indicating the amount by which R^2 was increased by addition of the new block of variables to the equation. R was significantly different from zero after each step. After step 1, the equation including Task, Noise, and Volume as predictors accounted for a significant 12% of the variability in CPT omissions. After step 2, with pretest Anxiety added to the equation, an additional 2% of variability was explained. On step 3, the two- and three-way interactions of the manipulated variables were entered, and contributed to a significant increase in prediction of 7% of variability. Addition of the two-way interactions of pretest Anxiety with Task, Noise, and Volume did not add significantly to prediction of omission errors. Entry of the final block of variables, including the three- and four-way interactions of pretest anxiety-state with the manipulated variables added to prediction of another 5% of variability.

Prediction of CPT Commission Errors (False Alarms)

In a second analysis, the same set of predictors was regressed on recoded CPT false alarm errors. After entry of all predictor variables in a standard regression equation, neither the combination of IVs nor individual variables contributed significantly to prediction of number of CPT false alarms, $R = 0.2560$, $F(15,147) = 0.6873$, $p > .05$. Hierarchical analysis therefore was not conducted.

Prediction of Anxiety State Change

A third standard multiple regression was conducted to assess the contributions of the independent variables to prediction of the change in

Table 2. Hierarchical Multiple Regression of Task Difficulty (Task), Type of Noise (Noise), Volume Level (Volume), Anxiety State (Anxiety), and Interaction Terms on CPT Errors of Omission.

	Predictors	R	R^2	$Adj. R^2$	sr^2inc	*Finc (df)*	p
1	Task Noise Volume	0.3458	0.1196	0.103	0.1196	7.198 (3,159)	.00
2	Anxiety	0.374	0.1398	0.118	0.0203	3.721 (4,158)	.05
3	T × N T × V N × V T × N × V	0.4613	0.2128	0.1719	0.073	3.569 (8,154)	.01
4	A × T A × V A × N	0.4876	0.2377	0.1822	0.025	1.647 (11,151)	.18
5	A × T × N A × T × V A × N × V A × T × N × V	0.5329	0.284	0.2109	0.0463	2.374 (15,147)	.05

Note. Interaction terms were formed by multiplication of the factors Task (T), Noise (N), Volume (V), and Anxiety (A).

anxiety state from pretest to posttest. After entry of all predictor variables in a standard regression equation, Multiple R was significantly different from zero, $R = 0.5128$, $F(15,147) = 3.497$, $p < .0001$. Significant unique contributions to the prediction of anxiety-change were made by coefficients of pretest Anxiety ($sr^2 = 0.0323$, $F = 6.552$, $p = .01$), Noise ($sr^2 = 0.0198$, $F = 3.947$, $p = .05$), Anxiety × Noise ($sr^2 = 0.0323$, $F = 6.448$, $p = .01$), and Anxiety × Task × Noise × Volume ($sr^2 = 0.0196$, $F = 3.905$, $p = .05$). These four variables contributed 10.46% in unique variability. All IVs in combination contributed an additional 15.84% in shared variability.

Again because of the correlations among IVs, hierarchical regression analysis was conducted to determine the additional prediction of anxiety-change offered by pretest anxiety-state and interaction terms, after accounting for effects of manipulated variables. Table 3 displays the results. R was significantly different from zero after each step. After step 1, the equation including Task, Noise, and Volume as predictors accounted for 12% of the variability in anxiety change-scores. After step 2, pretest Anxiety contributed to prediction of an additional 4% of the variability in anxiety-change scores. Addition of the interaction terms of Task, Noise, and Volume in the third block did not add significantly to prediction, nor did addition of the two-way anxiety-state interactions in the fourth block. However, the fifth block of variables, which included the three- and four-way interactions of manipulated variables with pretest anxiety-state, significantly contributed to prediction of an additional 5.94% of the variability in anxiety-change.

MANOVA Results

To aid in interpretation of the regression results, and to facilitate comparison of CPT error scores and anxiety-state changes of high- and low-anxiety students, subjects were divided into two groups on the basis of a median split of pretest state anxiety. The mean omission errors, mean commission errors, and mean anxiety-change scores were compared for subjects in cells formed by the factors of task difficulty (Task), noise type (Noise), noise volume (Volume), and the median split of pretest anxiety-state scores

Table 3. Hierarchical Multiple Regression of Task Difficulty (Task), Type of Noise (Noise), Volume Level (Volume), Anxiety State (Anxiety), and Interaction Terms on Pretest to Posttest Change in Anxiety-State.

	Predictors	R	R^2	$Adj.R^2$	sr^2inc	*Finc (df)*	p
1	Task Noise Volume	0.3482	0.1213	0.1047	0.1213	7.313 (3,159)	.00
2	Anxiety	0.4067	0.1654	0.1443	0.0442	8.360 (4,158)	.00
3	T × N T × V N × V T × N × V	0.424	0.1798	0.1372	0.0144	.674 (8,154)	.61
4	A × T A × V A × N	0.4512	0.2036	0.1456	0.0238	1.504 (11,151)	.22
5	A × T × N A × T × V A × N × V A × T × N × V	0.5128	0.263	0.1878	0.0594	2.964 (15,147)	.02

Note. Interaction terms were formed by multiplication of the factors Task (T), Noise (N), Volume (V), and Anxiety (A).

(Anxiety). Differences between means were evaluated via SPSS-PC MANOVA, with results comparable to regression analysis using the continuous variable pretest anxiety-state. Because dependent variables were correlated, Roy-Bargmann Stepdown *F*-tests were used to assess univariate effects for each DV while controlling for overlap with higher-priority variables (Tabachnick & Fidell, 1989). Multivariate and stepdown univariate *F*-values are reported in Table 4, which shows that significant multivariate effects were found for Task, Anxiety, Anxiety × Volume, and Anxiety × Task × Volume. These results were due primarily to univariate effects on CPT omissions and anxiety-change, while CPT false alarms were not affected by any main or interaction terms. Additional univariate effects on omission errors were found for Task × Noise × Volume, Noise × Volume, and Task × Volume. Evaluation of the differences between cell means was conducted via Tukey's Honestly Significant Difference Test.

Effects of Task Difficulty

As expected, significantly more omission errors were made in the "difficult" task (M = 1.90) than in the "easy" task (M = 0.37). In contrast, false alarm errors were not affected by task difficulty. Not surprisingly, level of anxiety-state increased significantly more for subjects performing the difficult task (M = 8.22) than the easy task (M = 1.72).

Effects of Noise Type and Volume

No significant multivariate or univariate main effects were found for either the volume or the quality of the white noise background. However, both factors contributed to interaction effects on the recoded number of CPT omission errors. As illustrated in Figure 1, the Task × Volume interaction produced significantly more omission errors in the difficult/quiet condition than in all other conditions (HSD > 1.256, $p < .05$). Similarly, the interaction of Noise × Volume, shown in Figure 2, led to significantly more omissions in conditions of quiet surf-like noise than in the

Table 4. MANOVA Results: Multivariate *F* and Stepdown Univariate *F* values Showing Effects of Task, Noise, Volume, Anxiety, and Their Interaction Terms on Recoded CPT Errors of Omission (CPT-OM), False Alarm Errors (CPT-FA), and Changes in Anxiety-State (AS-CHNG)

		Stepdown Univariate F-values		
Effect	Multivariate (df = 3,145)	CPT-OM (df = 1,147)	CPT-FA (df = 1,146)	AS-CHNG (df = 1,145)
Task	11.021**	21.015**	1.439	9.271*
Noise	2.113	0.531	0.295	5.491
Volume	1.324	3.192	0.047	0.76
Anxiety	4.135*	2.441	0.06	9.77*
T × N	0.363	0.513	0.309	0.274
T × V	1.624	4.343+	0.348	0.216
N × V	2.252	5.437+	0.652	0.693
T × N × V	2.528	4.3+	0.292	2.951
A × T	0.497	1.183	0.297	0.027
A × N	1.72	1.826	0.172	3.141
A × V	2.675+	4.482+	2.776	0.726
A × T × N	1.304	3.362	0.205	0.378
A × T × V	3.765+	3.022	0.584	7.536*
A × N × V	1.273	0.12	0.021	3.678
A × T × N × V	0.785	0.006	1.229	1.119

Note. Interaction terms were formed from two levels each of the factors Task (T), Noise (N), Volume (V), and Anxiety (A).
+$p < .05$, * $p < .01$, ** $p < .001$.

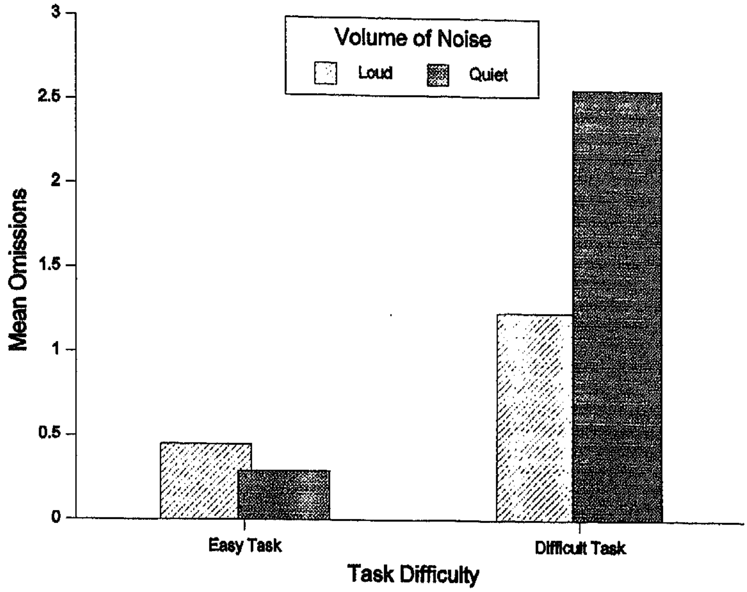

Fig. 1. Interaction effect of Task × Volume on Continuous Performance Task (CPT) omission errors. Mean number of omissions was significantly greater on the difficult task performed in quiet noise ($M = 2.58$) than on the difficult task performed in loud noise ($M = 1.24$) or on the easy task performed in either quiet ($M = 0.29$) or loud noise ($M = 0.45$).

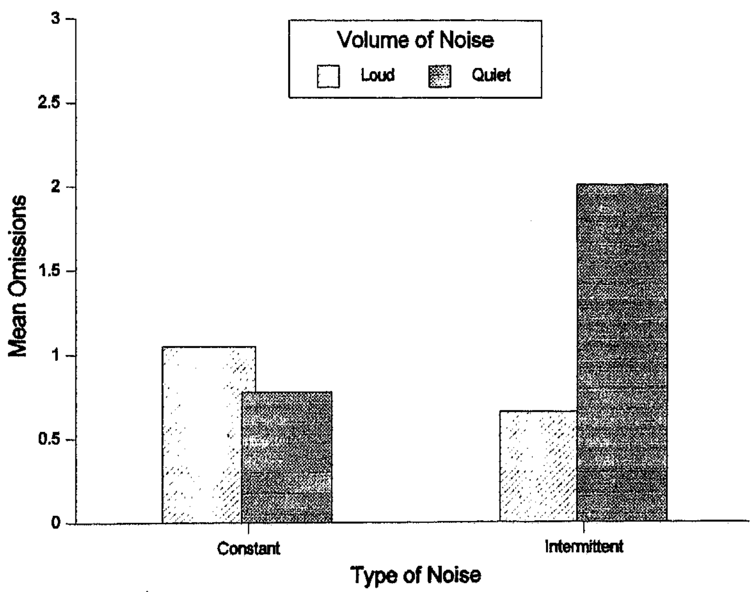

Fig. 2. Interaction effect of Noise × Volume on Continuous Performance Task (CPT) omissions. Mean number of omissions was significantly greater in quiet intermittent ($M = 2.02$) than in loud intermittent ($M = 0.66$), quiet constant ($M = 0.78$), or loud constant noise ($M = 1.05$).

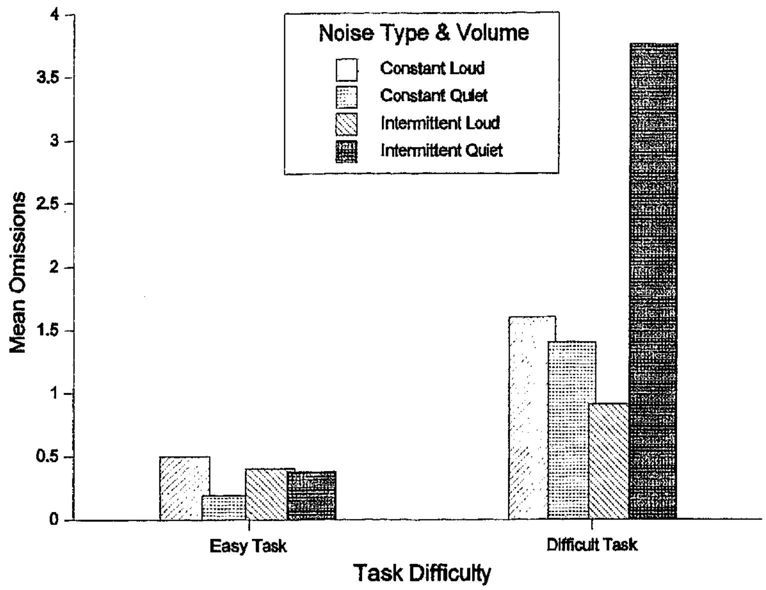

Fig. 3. Interaction effect of Task × Noise × Volume on Continuous Performance Task (CPT) omission errors. Mean number of omissions was significantly greater on the difficult task in intermittent quiet noise ($M = 3.75$) than on the difficult task in constant quiet ($M = 1.40$), constant loud ($M = 1.60$), or intermittent loud noise ($M = 0.91$), or on the easy task in intermittent quiet ($M = 0.38$), intermittent loud ($M = 0.40$), constant quiet ($M = 0.19$), or constant loud noise ($M = 0.50$).

loud/surf condition, which produced the lowest mean error score ($HSD < 2.0995$, $p < .05$). Finally, the three-way Task × Noise × Volume interaction, illustrated in Figure 3, yielded more omissions on the difficult task in conditions of quiet surf than in all other conditions ($HSD > 2.0995$, $p < .05$).

Effects of Subject Anxiety

High- and low-anxious subjects demonstrated no difference in errors of commission, but a trend toward fewer errors of omission by low-anxious subjects was observed $p < .10$). However, high-anxious subjects were significantly more affected by volume level than were low-anxious subjects. The Anxiety × Volume interaction is illustrated in Figure 4, which shows that high-anxious subjects made more omission errors in conditions of quiet noise than in conditions of loud noise or than low-anxious subjects in either condition ($HSD > 1.256$, $p < .05$).

In addition, increases in anxiety were significantly greater for persons with low pretest anxiety scores ($M = 6.89$) than for persons with high pretest anxiety scores ($M = 2.94$). The interaction effect of Anxiety × Task × Volume, shown in Figure 5, produced significantly greater increases in state anxiety for low-anxious subjects in the difficult/quiet condition than for low-anxious subjects in the easy/quiet condition or for high-anxious subjects in the easy/loud or the easy/quiet conditions ($HSD > 9.066$, $p < .05$). High-anxious subjects actually showed a mean decrease in anxiety state in the easy/loud condition, which differed significantly from low-anxious subjects in either the difficult/loud or the difficult/quiet conditions ($HSD > 9.066$, $p < .05$).

Summary

Effects of manipulated variables and subject anxiety level varied for the two types of errors on the vigilance (CPT) task. Commission errors (false alarms) were not significantly affected by any factors or interaction terms. In contrast, omission errors (misses) were significantly

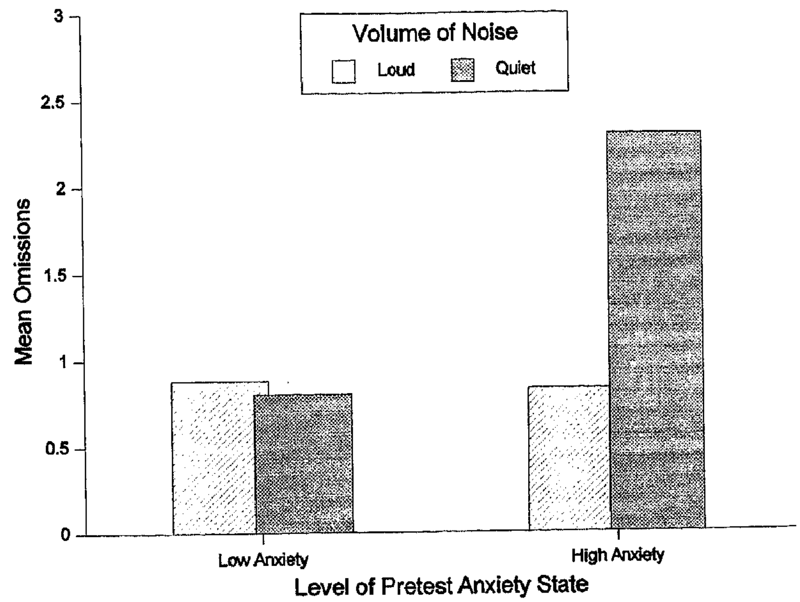

Fig. 4. Interaction effect of Anxiety × Volume on Continuous Performance Task (CPT) omission errors. Mean omissions were significantly greater for subjects with greater pretest anxiety levels performing in quiet noise ($M = 2.30$) than for high-anxious subjects in loud noise ($M = 0.83$) or for low-anxious subjects in either quiet ($M = 0.80$) or loud noise ($M = 0.88$).

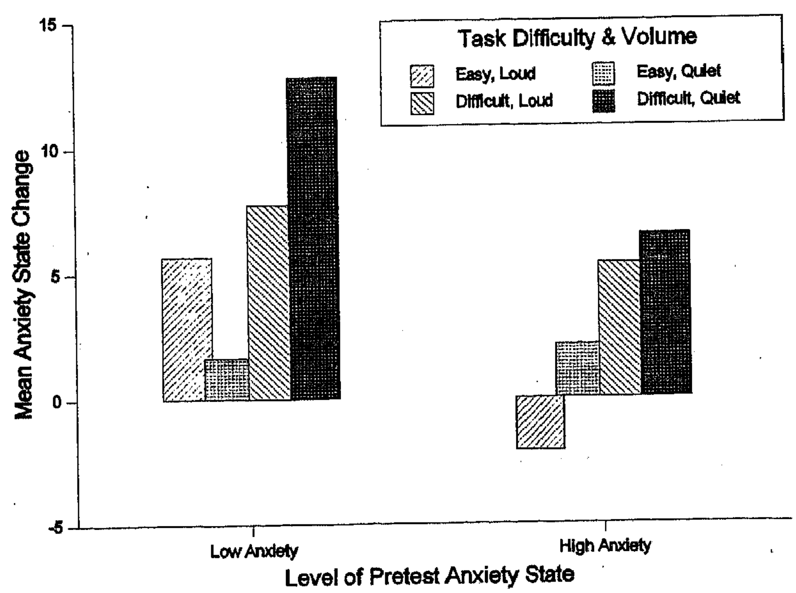

Fig. 5. Interaction effect of Anxiety × Task × Volume on anxiety state change. Mean anxiety state level was significantly increased for subjects with lower pretest anxiety performing the difficult task in quiet noise ($M = +12.79$), while anxiety level was significantly decreased only for subjects with higher pretest anxiety performing the easy task in loud noise ($M = -2.10$).

greater on the difficult than on the easy task. Main effects of noise type and volume on omissions were not significant, but each contributed to interaction effects. Specifically, omissions were significantly greater on the difficult task when performed in quiet noise than when performed in loud noise. Similarly, omissions were greater when surf-like noise was quiet rather than loud. These effects varied further when task difficulty, noise type, and volume were taken into account together, with significantly more omission errors in the hard/quiet/surf condition. Pretest level of anxiety added to prediction of omission errors in several ways, with somewhat more errors made by high-anxious than by low-anxious persons, and significantly more when high-anxious persons performed the difficult task in quiet noise.

Changes in anxiety-state from pretest to posttest also were affected by several factors and interaction terms. Increased anxiety was strongly associated with performance of the difficult task and with lower pretest levels of anxiety. In addition, anxiety increases tended to be greater for high-anxious persons in quiet than in loud conditions, while low-anxious persons showed similar increases in both quiet and loud conditions. The greatest anxiety increases were demonstrated by persons with low pretest anxiety who performed the difficult task in conditions of quiet noise. In contrast, decreases in anxiety state were seen for high-anxious persons performing the easy task in conditions of loud noise.

DISCUSSION

The results of the present study raise several questions regarding the effects of environmental stimuli, task demand, and subject characteristics on performance of vigilance tasks. Both the current results and those of prior research suggest complicated relationships between these factors. In addition, some aspects of these data indicate a need to examine assumptions about the nature of the CPT vigilance task and the commonly derived performance measures.

Consistent with predictions and with prior findings, increased task difficulty led to more CPT omission errors and greater anxiety increases. By increasing the number of computer screens to be monitored, the manipulation also increased the background event rate, decreased the signal to noise ratio, and increased the need for memory and sequencing skill, all of which diminished vigilance performance in prior studies.

Also as predicted, complicated effects on performance of CPT tasks were produced by the interactions of test environment, task parameters, and subject characteristics. These complex interactions may help to explain the sometimes conflicting results of prior studies, particularly those of the effects of noise on human performance, in which interactions were not evaluated. In the present study, the effects of noise volume depended both on type of noise and on task difficulty, with the greatest omission error rate produced by the combination of hard task, quiet volume, and surf-like noise. This effect was most pronounced for the subjects with high pretest anxiety. In the same difficult/quiet/surf condition, low-anxious subjects showed the greatest anxiety increases. Although only white noise was tested in the current study, future studies may show that equally complex interactions are produced by different volume levels and types of variable noise, such as music or voices.

It is noteworthy that only CPT omission errors were affected by main and interactive factors. In contrast, commission errors were not significantly different across conditions. These dissimilar patterns of effects suggest that the two commonly derived measures represent different aspects of the cognitive capabilities underlying the capacity to "sustain attention." Furthermore, the cognitive substrates associated with the two types of errors may be differentially affected by task and environmental factors. For researchers using the vigilance task, the analysis of omissions and commissions in a single combined "error rate" is likely to distort effects. Instead, research is needed to explore and explain the differences in effects of various factors on omission and false alarm error rates.

Implications of the current findings include support for the view of attention as a multifaceted construct, with numerous underlying substrates and with equally numerous possibilities for measurement. Most models of attention are inadequate to explain these effects, largely because the observed effects must be interpreted in terms of hypothetical constructs. The present finding that the difficult/quiet/surf condition yielded the highest rate of CPT omissions, as well as the greatest increases in self-reported anxiety, suggests that increased "arousal" impairs performance. However, without corroboration of "arousal level" by independent physiological measures, even a neurologically based arousal theory cannot account for all observed effects on vigilance performance (Hockey, 1984).

The variety of factors affecting CPT performance has important implications for clinical and educational practice. Most importantly, caution in the assessment of attention deficits should be the rule. Specifically, diagnosis of Attention Deficit Hyperactivity Disorder cannot be based legitimately on poor performance during a single administration of a vigilance task. Attributions about the performance of a subject on a single vigilance task necessarily will be complicated, given that performance on such tasks clearly is affected by a host of environmental factors and task parameters, as well as by a variety of individual subject differences, including anxiety. Poor CPT scores by clinic patients suggest only a need for further evaluation of subject characteristics and environmental stressors that may be affecting performance.

It may be useful to employ such tasks as the CPT in clinical practice to make general predictions about the individual subject's ability to perform certain types of work under certain environmental conditions. Such assessment may prove to be a useful adjunct to vocational aptitude evaluation and counseling. Some support for the accuracy of such predictive use of vigilance tasks is found in prior studies showing that vigilance performance is associated with school readiness and later academic achievement (Campbell, D'Amato, Raggio, & Stephens, 1991; Edley & Knopf, 1987). These associations most likely are due to similarity in the cognitive abilities required for both vigilance performance and sustained classroom performance. In using such tasks to assess performance capability in general, as well as performance in specific environmental conditions, it is likely that certain environmental stimuli will depress performance more than others. However, individuals may respond differently to different sets of stimuli, depending on the personal characteristics that they bring to the situation. These individual differences in responses to environmental factors should be taken into account in educational placement decisions, curriculum planning, and job assignments. Although this is not a new idea, it is one that often is ignored, particularly in planning for learning-disabled students.

Limitations of the present study include the difficulty of generalizing results from the performance of normal undergraduate students to the general population or to clinical groups. A second concern relates to the non-normal distributions of CPT error scores on both the "easy" and the "difficult" task, even after recoding to reduce the effect of outliers. Such distributions are problematic in many studies utilizing the CPT, since normal subjects often perform without error. Finally, anxiety change scores must be interpreted with caution, given the correlation with initial status and the possibility that effects are obscured by scores that vary in both positive and negative directions. In addition, low-anxious subjects were overrepresented in conditions that included "quiet" noise in the present study. The tendency of low-anxious subjects to show greater anxiety increases may have inflated the apparent effect of noise on anxiety change. In future studies, more direct control will be useful in assigning subjects with high- and low-anxiety characteristics to experimental conditions.

Nevertheless, in the context of prior research, the findings of the present study suggest several avenues of future inquiry. First, the design of the present study should be extended to include other types of environmental noise. Including more than two levels of each manipulated factor will help to evaluate the possibility of non-monotonic effects. Research designs could be employed to examine effects of different types of noise commonly present in work environments.

Second, additional analysis of omission and false alarm error patterns is needed. The work of Halperin and associates (Halperin et al., 1992; Halperin, Newcorn, Matier, Sharma, McKay, & Schwartz, 1993; Halperin et al., 1990; Halperin, Sharma, Greenblatt, & Schwartz, 1991; Halperin, Wolf, et al., 1991; Halperin et al., 1988; Matier et al., 1992) provides additional indication that false alarm error analysis should include consideration of the type of commission errors observed. Similarly, Mirsky and associates (1991) demonstrated different patterns of errors on CPT tasks by patients with different seizure types. In addition, Barkley et al. (1990) found comparable omission rates for Attention-Deficit with Hyperactivity (ADD+H) and Attention-Deficit without Hyperactivity (ADD-H) groups, but more commission errors for the ADD+H group.

Third, analysis of additional performance measures will be useful. The current study focused on error rates, as is often the case in research employing the CPT version of vigilance tasks. However, other characteristics of performance, such as reaction time, may be differentially affected by task parameters, environmental factors, and/or subject variables. Further research is needed to determine the utility of classifying subjects' performance on the basis of multivariate outcome measures.

Fourth, additional investigation is needed to explore the contribution of subject variables to the interactions observed in the present study. Of particular interest for both educators and child psychologists is the possibility of developmental changes in the effects of anxiety. In such research, both the direct effects of anxiety (or other clinically relevant symptoms) and the interactive effects of anxiety, task demand, and environmental characteristics will be important aspects of study. Comparison of clinical populations of anxious persons with normals and with other clinical groups (e.g., depressed) may help to determine whether the effects of anxiety are specific, or whether the effects observed in this study reflect the influence of *any* clinically relevant symptom.

Finally, additional investigation is warranted to evaluate the usefulness of the current findings for applied settings. Specifically, studies in both school and industrial settings may help to determine the usefulness of vigilance tasks for prediction of performance in particular environments by individuals with certain characteristics.

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