# Final Report (October, 1993 - July, 1997)

## Title: Personality, Motivation and Cognitive Performance

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William Revelle and Kristen J. Anderson
Department of Psychology
Northwestern University
Evanston, Illinois 60208-2710

## Abstract:

This project examined the determinants of efficient cognitive performance. Specific questions addressed how environmental stressors combine with time of day and individual differences in personality to affect motivational variables that in turn affect components of information processing.

Our research addressed three separate objectives: 1) to do systematic taxonomic work on the relationship between personality traits, situational moderators, and activational states; 2) to develop and test models of stable individual differences and transient affective states as they affect the detection, encoding, storage, and processing of information; and 3) to test and revise our models of motivational effects upon complex cognitive performance.

Results showed that individual differences in temperament combine with a variety of stressors (e.g., time of day, exercise, stimulant drugs, feedback) to affect two components of motivational intensity, energetic arousal and tense arousal, and one of motivational direction. The two components of arousal have systematic effects on performance on a variety of simple and complex cognitive tasks. Cognitive performance measures examined included complex problem solving as well as attention, learning, memory and performance tasks. New techniques were developed that demonstrated the importance of within subject variation in energetic and tense arousal.

## Objectives and Overview:

Mistakes happen. Even with the best training and the best selection human performance rarely achieves optimal levels. Complex cognitive performance frequently falls far below normative values. Examples of inefficient performance range from the mundane (forgetting one's keys when leaving the house) to the catastrophic (following improper procedures while performing routine maintenance of nuclear reactors or failing to properly distinguish between commercial and hostile aircraft). Although serious mistakes are, thankfully, rare events, and are thus hard to study, less severe examples of inefficient performance are susceptible to detailed analysis.

Our research has examined the determinants of efficient cognitive performance in terms of the combination of personality, situational, and task variables. We have attempted to test and to develop further theoretical models of the interplay of individual differences in personality with situational constraints and task demands in order to be able to predict cognitive failures and decrements from optimal performance. Our basic research strategy has been theoretically driven with an emphasis upon systematic extensions of our earlier work.

We addressed three specific aims in our research:

1) To understand the role of the non-cognitive dimensions of personality as they interact with time of day and other sources of variation in arousal in affecting efficient performance on a variety of simple and complex cognitive tasks

2) To understand the role of non-cognitive dimensions of personality as they affect the detection, encoding, learning and retention of information*.* In particular, a) to understand the ways in which *arousal* affects the detection, encoding, and storage of new material; and b) to understand how impulsivity and anxiety interact with stimulus valence when learning new material.

3) To continue development of a formal model of the way in which personality variables affect the processing of stimuli, development of motivational states, and eventual effective expression of action tendencies.

Elucidation of the mechanisms through which arousal affects cognitive performance requires (a) theoretical and empirical attention to the distinctions between arousal and other motivational constructs, (b) research on the effects of arousal on specific aspects of information processing and on different aspects of performance efficiency, and (c) recognition of the role of personality variables on components of performance efficiency as well as their role in mediating the influence of situationally induced arousal on performance. The research described herein was designed to advance understanding of the impact of motivational states on cognitive performance through attention to each of these issues. An overriding goal was to develop a more precise theoretical model of the impact of motivational variables on information processing.

## Summary of Results

Studies addressed at each of the three specific aims were conducted in parallel. That is, experiments on the interactive effects of personality, time of day and other motivational manipulations on sustained performance, and immediate and delayed retrieval were conducted at the same time as other studies examining differences in detection and encoding of affectively valenced stimuli; theoretical modeling occured throughout. These were not completely independent paths, however, in that findings from one line of experiments were used in the other lines. Two of the specific aims involve empirical studies, the third addresses the need for a synthetic theory of personality, motivation, and cognitive performance.

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Prior results in our laboratory had shown that it is possible to produce large, replicable deficits in performance on high level cognitive tasks similar to the Graduate Record Examination. In our earlier research we had shown that the personality dimensions of impulsivity and neuroticism interact with time of day and caffeine to affect complex cognitive performance (Anderson and Revelle, 1982, 1983; Bowyer, Humphreys and Revelle, 1983; Revelle, Amaral, and Turriff, 1976; Revelle, Humphreys, Simon, and Gilliland, 1980). Integrating early motivational theories and models of individual differences we explained these results in terms of two motivational constructs (arousal and effort) and their effects upon different cognitive components (Humphreys and Revelle, 1984; Revelle, 1993; Revelle and Anderson, 1992). Our subsequent work has suggested that that the effects of arousal need to be analyzed in terms of two components of activation, energetic and tense arousal, which in turn affect performance outcome measures on a variety of attention and memory tasks.

That is, we analyzed decrements from optimal performance in terms of the effects of motivation.. This is a traditional approach (e.g., Anderson, 1990; Blodgett, 1929; Broadhurst, 1959; Hebb, 1955; Hockey, Gaillard & Coles, 1986; Humphreys and Revelle, 1984; Revelle, 1987, 1989, 1993; Sanders, 1983, 1986; Yerkes and Dodson, 1908) that unfortunately has been under-emphasized in much of the recent work on cognition (but see Matthews, 1998). Motivation is the vital link between knowing and doing, between thinking and action, between competence and performance. Theories of motivation explain why rats solve mazes faster when hungry than well fed, why bricklayers lay more bricks when given harder goals than easier ones, why assistant professors write more articles just before tenure review than after, and why people choose to be fighter pilots rather than dentists. How to motivate employees to produce more widgets and how to motivate oneself to do onerous tasks are the subjects of many management and self help courses.

Fundamental questions of motivation are concerned with the direction, intensity, and duration of behavior. Within each of these broad categories are sub-questions such as the distinctions between quality and quantity, effort and arousal, and latency and persistence. Cutting across all these questions are the relative contributions of individual differences and situational constraints to the level of motivation and of subsequent performance.

Individual differences in motivation and performance may be analyzed at multiple, loosely coupled, levels of generality (see Revelle, 1993, Figure 1). These levels reflect the time frame over which behavior is sampled. Over short time periods (e.g. the milliseconds of an evoked potential study), situational constraints are extremely important. As the sampling frame is increased (e.g., to the seconds of a reaction time study), energetic components of motivation as well as strategic tradeoffs of speed for accuracy become more important. At somewhat longer sampling frames (e.g. the tens of minutes of a typical psychology experiment), individual differences and situational demands for sustaining performance take precedence. At even longer intervals, differential sensitivities to positive and negative feedback affect task persistence and choice. At much longer intervals, individual differences in preference affect occupational choice and the allocation of time between alternative activities. At all of these levels it is possible to distinguish between effects related to resource availability and to resource allocation. Although an adequate theory of motivation and performance should explain behavior at all of these levels, motivational effects at intermediate time frames have been most frequently examined. In particular, the focus of much of our research for this project has been on those motivational effects that can affect the link between thinking and doing within periods of several minutes to several hours.

For psychologists concerned with linking cognition to action, it is essential to consider how motivational variables affect the competence-performance relationship. Ever since Blodgett's (1929) demonstration that well fed rats will learn mazes but that only hungry rats will show their knowledge by running rapidly through the maze, psychologists have been aware that competence is a necessary but not sufficient determinate of performance. An even more important study was Yerkes and Dodson's demonstration (1908) that motivational intensity (induced by foot shock) has a non-monotonic affect upon rates of learning a discrimination task and that task difficulty interacts with intensity.

Unfortunately many cognitive psychologists pay only lip service to the competence-performance distinction and will report that their subjects are well motivated and thus it is not necessary to worry about motivation. For such researchers, motivation is a nuisance variable that can be ignored by increasing sample size. The possibility that individual differences in personality might interact with situational manipulations in ways that can completely obscure important relationships is so foreign as not even to be considered.

Recognizing the complexity of the phenomena we have been trying to integrate, and sensitive to the possibility of over-interpreting our results, we followed the strategy of conceptual replication and extension of each of our studies. That is, in order to answer each of our specific questions we emphasized multiple studies using multiple manipulations in order to clarify the constructs of interest. We have long recognized that each manipulation and measure reflects some common, construct relevant, variance, as well as some specific, construct irrelevant variance (Anderson, 1990; Anderson and Revelle, 1994; Revelle & Anderson, 1992). By searching for consistencies across measures we have emphasized the consistent, construct relevant variance.

## 1) Taxonomic studies of personality and affect:

Descriptive taxonomies of individual differences have been a tradition in personality theories since Plato and Galen (see Revelle, 1995 for a review). Most taxonomic systems of cognitive and non-cognitive attributes are hierarchical: clustering similar behaviors into narrow traits, then clustering these into higher order traits, and eventually into a limited number of dimensional types (H. Eysenck 1991a). At any level of this hierarchy, behaviors and traits can be found that represent blends of separate dimensions, resisting any appearance of factorial simple structure and requiring a horizontal as well as a vertical structure (Goldberg 1993a,b). The problem for taxonomists thus becomes determining the optimal number of factors to describe these structures. Optimality means different things to different investigators, but includes being parsimonious, replicable, and useful. It is not surprising that there is not perfect agreement among all taxonomists given the many assumptions implicit to factor or principal components analysis.

There is strong agreement that the dimensions of extraversion/introversion and neuroticism/emotional stability are fundamental parts of any personality taxonomy. But proponents of what can be called “The Even Bigger 3” (EB3) suggest that openness is more of a cognitive than non-cognitive construct, and that agreeableness and conscientiousness are both parts of a higher order factor of Psychoticism (H. Eysenck 1990, 1991b), or Psychoticism-Impulsivity-Sensation Seeking (Zuckerman 1991, 1994).

Taxonomic studies of individual differences in mood have extended the earlier work of Tellegen (1985), Russell (1979); Thayer (1989), and Watson & Tellegen (1985) on identifying two independent dimensions of mood and emotion that are associated with positive and negative affect or energetic and tense arousal. These two dimensions of mood are, in turn, related to the EB3 and the B5. Extraversion is associated with measures of positive affect, neuroticism with measures of negative affect (Meyer & Shack 1989; Saucier 1992; Watson et al 1994).

While daily moods are commonly categorized as "good" or "bad" or given one of many specific labels, factor-analytic studies have consistently revealed that two major factors underlie the domain of self-reported emotional experience (Gotlib & Meyer, 1986; Meyer & Shack, 1989; Watson & Tellegen, 1985; Zevon & Tellegen, 1982; but see Matthews, 1998). Different labels have been attached to these dimensions, various rotations of them have been proposed, and there is still debate over which rotations are most appropriate (Feldman & Russell, 1998; Larsen & Diener, 1992; Russell, 1980). However, a strong theoretical argument for the utility of energetic-tired and tense-calm as fundamental mood dimensions has been presented (Thayer, 1989).

## Between Subjects analyses

We have clarified the taxonomic structure of arousal and affect by analyzing data aggregated from the many experimental studies we have conducted as part of this project. (Thus, the total number of subjects was > 2,500). In each of our cognitive studies (discussed below) we collected base line mood and motivation data using the Motivational State Questionnaire-Revised Form (MSQ-R; Revelle, 1994). The MSQ-R is a 72-item measure of mood that asks participants to rate their feelings on a four-point scale (Not At All, A Little, Moderately, Very Much).

The MSQ-R response format does not allow subjects to make noncommittal responses and has been found to be less biased than other formats (Meddis, 1972). The MSQ-R includes words that describe feelings or moods, such as "delighted" and "sociable". It includes the items from the PANAS (Watson, Clark, & Tellegen, 1988) and the Activation-Deactivation Adjective Check List (AD ACL; Thayer, 1988). It also contains adjectives which represent states directly opposite of high PA and NA, as suggested by Larsen and Diener (1992).

Factor analyses of the MSQ-R yield a very clear two factor structure of energetic and tense arousal although many of the words represent mixtures of these two constructs (Figure 1, Table 1). Measures of Energetic Arousal (EA) and Tense Arousal (TA) are very internally consistent (alphas >.9) and relatively independent (r=.1). We have developed short forms of eight items (two high and two low for EA and TA, table 2) that are also very reliable and independent.

Table1, Table 2, Figure 1

These two dimensions vary systematically across the day. By using the base line data from all of our cognitive studies we were able to show very clear diurnal patterns that differ as a function of personality. Emotionally stable subjects (Low neurotics) had much larger diurnal rhythms of Energetic arousal than did less stable individuals (High Neurotics) and much lower mean levels of Tense Arousal (Figures 2 & 3; Revelle, Anderson, Rogers, 1995; Rogers and Revelle, 1996). These self report data were in striking agreement with core body temperature data that we were able to analyze as part of another study (Baehr, Revelle, and Eastman, in press) in which we related impulsivity and morningness-eveningness to phase of the diurnal body temperature rhythm. The body temperature minimum for these subjects was roughly 12 hours different from the maximum of self report arousal and morning people were roughly two hours advanced in their rhythms compared to self described evening people. Impulsivity was related to body temperature phase, even when morningness-eveningness was removed.

Figure 2, Figure 3

## Within Subject analyses

It is clear that there are large variations across the day in EA and TA that seems to show a systematic rhythm. If these dimensions of arousal are to be useful to predict performance, it is necessary to show stability of the patterns in within subject variation in arousal. Thus, we have conducted several studies to examine the temporal coherence of arousal.

Study WS-1

The first of these studies (Rogers, 1996; Rogers and Revelle, submitted) was designed to test several hypotheses. First, we expected to replicate the links between extraversion and level of EA and neuroticism and level of NA. Second, we also expected to replicate the relation between morningness and acrophase of the energy rhythm. Third, we suspected that greater mood rhythm phase shifts might be associated with neuroticism. Fourth, we expected neurotic individuals to demonstrate disorganized energy rhythms relative to stables.

The participants were 82 Northwestern University freshmen who were fulfilling part of the laboratory requirement for a course in introductory psychology. Two groups with 41 participants each were selected: those with neuroticism scores in the lowest third (stables) and those with neuroticism scores in the highest third (neurotics) of the class distribution, based on data collected at a group testing session

In addition to our usual measures of impulsivity and neuroticism, we also measured Morningness-Evenness. Morningness was measured with a 13-item self-report instrument which combines items of the Horne and Östberg (1976) scale with the Torsvall and Åkerstedt (1980) scale to provide a brief but internally consistent measure of morningness (Smith, Reilly, & Midkiff, 1989).

Momentary mood assessment. A visual analogue scale (VAS) containing eight words was employed to assess momentary mood state (see Eastwood, Whitton, & Kramer, 1984, and Folstein & Luria, 1973, among others, for evidence of this method's utility). This method requires the individual to report the current intensities of feeling states by making vertical marks across 10-cm horizontal lines with the anchors "very little" and "very much" on each end.

Four of the words load highly on the energetic arousal factor (energetic, lively, sleep, tired) and four load highly on the tense arousal factor (tense, frustrated, calm, relaxed).[i]

The visual analogue method has been found to yield data that are Gaussian in their distribution and is desirable for use in repeated-measures experimental designs. It takes less than one minute to complete and is less likely to be completed in a habitual manner. The format has been found to discriminate depressed patients from normal controls and be sensitive to jet lag, diurnal variation, and voluntary seclusion (Monk, 1989). The VAS used contained blanks for reporting the day, date, time of completion, and activity immediately prior to completion.

Procedure Participants were given instructions for the two-week study, practice with the VAS, and trait measures of personality in a session in the laboratory. They were instructed to fill out the VAS as soon as possible after waking and as close as possible to every three hours thereafter until the participant had gone to bed. A Social Rhythm Metric was completed just before bedtime, if possible, or else the next day. At the end of the seventh day, Sunday, the participants completed the BDI and a weekly MSQ. Week 2 commenced exactly two weeks from the first Monday after week 1 and ended the following Sunday. The procedure for week 2 was identical to that for week 1.

Results: The hypotheses were tested through a multi-level data analytic strategy. The first level of this strategy involved scoring and transformation of the mood data that were collected from each subject on a daily basis. Each participant's daily energetic and tense arousal rhythms were quantified through a computer program that computed the mean, acrophase, and organization of each rhythm. Means were calculated in the typical way, but quantification of acrophase and organization of an individual's daily mood rhythm required cosine-fitting.

A series of sine-cosine functions with 24-hour periods were correlated with each participant's raw mood data until the best-fitting curve was found. This was done by iteratively adjusting the phase of the sine-cosine function until the correlation between the curve and the data was maximized. The time-of-day at which the function reached its peak was defined as the acrophase of that individual's mood rhythm. The degree to which the sine-cosine function correlated with the data was taken as an estimate of the organization of an individual's daily mood. (See Figure 4 for an example of the raw and fitted data).

Figure 4

The second level involved analyses of the relations between personality traits (i.e., extraversion, neuroticism, morningness) and mood rhythm parameters (i.e., mean, acrophase, organization) within each week. The third level involved predicting week 1-to-week 2 change in mood rhythm parameters and dysphoria. Pearson correlations and multiple regression analyses were utilized for these purposes.

Test-retest reliability. Energetic arousal (EA) mean and tense arousal (TA) mean both demonstrated high test-retest reliability, across subjects, from week 1 to week 2 ($r$'s = .67 and .72, respectively). The test-retest reliability of EA acrophase was moderately high ($r$ = .64), but that of TA acrophase was relatively weak ($r$ = .28). Test-retest reliability of EA and TA rhythm organization were moderate (both $r$'s = .56). Thus, the organization of mood rhythms and the time-of-day that energy peaks are, like intensity, temporally stable features of an individual's daily emotional experience.

Internal consistency. Based on data collected during the initial laboratory session, the between-subjects internal consistency of the visual analogue EA scale was moderately high (alpha = .67) as was the between-subjects internal consistency of the visual analogue TA scale (alpha = .66). More important than these estimates of internal consistency, however, were those derived from repeated assessment of a single subject. This method indicated higher reliability of the EA scale (average within-subjects alpha = .91) as well as higher reliability of the TA scale (average within-subjects alpha = .81). Thus, the four items on each momentary mood scale appear to demonstrate a high degree of covariance, especially at the level of the individual subject.

Study WS-2

The second of these studies was a conceptual replication of WS-1, with the addition of a simple and choice reaction time task performed at home once a day at five different times of day. EA and TA measures were conducted as in WS-1, but for one rather than for two weeks. 32 subjects were given pretests and instructions in the laboratory and then sent home with their materials. They were given a computer disk that had a reaction time task developed and used in our earlier studies. EA and TA were assessed both by using the VAS as well as a computerized version of the VAS.

Study WS-3

The third study in this sequence was another conceptual replication of WS-1, with the addition of a recognition memory task performed at home once a day at five different times of day. EA and TA measures were conducted as in WS-1, but for one rather than for two weeks. 28 Subjects were given pretests and instructions in the laboratory and then sent home with their materials. They were given a computer disk that had a recognition memory task modified from one used in our earlier studies. The computerized version of the VAS was used as well.

The EA and TA results from these further two studies confirmed the results from WS-1. EA and TA showed systematic rhythms that could be well fit by a cosine differing in acrophase Within subject correlations of EA and TA ranged from -.8 to +.8 across subjects uggesting that the interpretation of these self report states differs between subjects. The fitted EA and TA rhythms could be used to predict both Reaction Time and Memory Retrieval as a function of time of day.

## 2) Trait differences in sensitivity to environmental cues

Research from clinical psychology has suggested that predispositions to experience a certain class of affect may be related to cognitive processes. Depressed individuals are believed to consistently use cognitive structures, or schemata, that are negative in nature and lead them to process more negative information (Beck, 1967). In a review of this literature, Gotlib and McCabe (1992) concluded that depressed and non-depressed individuals clearly differ in their cognitive functioning. Typically, this difference is characterized by depressed individuals deploying greater attention to and more deeply processing negative-content stimul than do non-depressed individuals. However, the research suggests that cognitive functioning is influenced more by a depressed mood state than a trait-like propensity to become depressed.

There is ample evidence that normal mood states are associated with cognitive biases. Non-depressed individuals often demonstrate a bias toward positive information, which has been labeled a self-serving bias (see Alloy & Abramson, 1979). For example, Gotlib, McLachlan, & Katz (1988) found that nondepressed participants attended more to manic-content words than the depressed- or neutral-content words, while depressed participants attended equally to all types of words. Similarly, Isen and her colleagues have demonstrated that the effect of mood on schema activation is not specific to the affective and anxiety disorders (e.g. Isen, Shalker, Clark, & Karp, 1978). However, just as advocates of "depressive schemata" have yet to demonstrate that these constructs are stable across time, the role of stable individual differences in the relations between mood and processing of affective information has not been established.

Nevertheless, it is clear that traits can play a prominent role in the allocation of attention. MacLeod and Mathews (1988) measured trait anxiety by self-report, manipulated state anxiety by proximity to a major examination, and assessed allocation of attention by a probe-detection technique. Only trait anxious participants tended to shift attention towards threatening stimuli in both high and low state anxiety conditions, which supports the view that stable characteristics can influence cognitive processing. In addition, increased state anxiety was associated with increased attention to threatening stimuli in trait anxious participants and increased avoidance of such stimuli in participants with low trait anxiety. MacLeod and Mathews (1988) concluded that, in predicting the attentional response to threatening stimuli, trait and state anxiety should be considered to function interactively.

With this evidence and the demonstration of a shared personality/affective structure, research on cognitive biases should consider the relative contributions of and interactions between mood state and trait-like orientations to affect. The latter could be influenced by sensitivities to cues for reward and punishment. Thus, extraverts, who may be more sensitive to pleasant stimuli (cues for reward) than introverts, may show greater attention to and deeper processing of pleasant stimuli than introverts. Neurotics, who may be more sensitive to unpleasant stimuli (cues for punishment) than emotionally stable individuals, may show greater attention to and deeper processing of negative stimuli.

For the most part, these hypotheses have yet to be tested. However, the work of Derryberry, Reed, and their colleagues represents one beginning. Derryberry (1987) tested the cue-sensitivity model directly through an analysis of reaction times (RTs) and errors in responding to affective cues. Following signals of reward, extraverts responded more rapidly and with a higher error rate than introverts. Following signals of punishment, introverts responded more slowly than extraverts. Using a target detection task, Derryberry and Reed (1994) found that extraverts were slower to shift attention away from where a positive incentive cue had been located, whereas introverts were slower to shift from where a negative incentive cue had been located. These biases were found to be strongest in highly neurotic participants.

These results are important in three respects. First, they suggest that latency for shifting attention away from a stimulus should be considered as well as latency for shifting attention towards a stimulus. Second, they do not support a simple alignment of E with sensitivity to positive cues and N with sensitivity to negative cues. Rather, they support the notion that E relates to sensitivities to both types of cues and suggests that N amplifies E's effect on cognitive biases. Third, the effects were obtained in absence of a mood manipulation, suggesting that E and N may be related to individual differences in the processing of affective information. This assertion must remain tentative, however, as the investigators did not report participants' mood.

Individual differences in sensitivities to affect have also been found to relate to the tendency to group stimuli according to common affective valence (Weiler, 1992). Participants were asked to read three words (a triplet) and choose the two that were most strongly associated. The "pleasant affect" personality variables (e.g. Extraversion) were related to the tendency to form pleasant pairs, and the "unpleasant affect" personality variables (e.g. Neuroticism) were related to the tendency to form unpleasant pairs.

In four studies (Rogers and Revelle, 1998), we examined the relations between mood/personality and the evaluation of pleasant, unpleasant, and neutral word pairs. Specifically, we examined affectivity ratings, categorization, judgments of associative strength, and response latencies as a function of Extraversion and Neuroticism. Extraverts, as people who are sensitive to reward cues, were expected to be biased toward pleasant pairs relative to introverts. Similarly, bias toward unpleasant pairs was expected to depend on the individual's level of Neuroticism or sensitivity to punishment cues.

## 3) Arousal effects on cognitive processing

### Energetic Arousal effects on detection and on speed of processing

As part of the previous contract we completed three studies with a task that is sensitive to performance decrements within the first few minutes. Because of our interest in the dynamics of behavior, we examined performance as a function of time on task. The task we used (variable fore-period reaction time with an inter-stimulus interval of 1-11 seconds) lasts for just a few minutes (12-15) and is typical of the demands placed upon subjects doing many monotonous real world (or experimental) tasks. The subject’s task is to respond as rapidly as possible whenever a series of X's appears on the monitor of a computer. The targets remain until the subject responds. The fastest reaction times of our subjects tend to be of the order of 220-250 msec, with most responses being less than 400 msec. We discard all trials in which the subject takes more than 1000 msecs to respond, although we have observed at least one subject who was taking 7-8 seconds on some trials. That is, our task succeeds in putting some subjects to sleep. More objectively, self-reports of energetic arousal decay reliably across the 12 minutes of the task.

For this contract we have done several more studies with this task. We have continue to examine the effects of time of day, caffeine induced arousal, and monetary incentives. In addition, we have have examined changes in perormance on this task as a function of within subject variations in arousal as well as the earlier between subject analyses. Dependent measures were simple reaction time, as well as the change in reaction time as a function of trials.

When the results from all of these studies are compared they clearly show a difference between the effects of (caffeine induced or diurnally varying) arousal versus (monetary incentive induced) effort. Although both arousal and effort manipulations improve performance, only the arousal manipulation was able to sustain performance. The change across time clearly demonstrated the effects of arousal as well as impulsivity and neuroticism. Impulsivity was positively correlated with decay of RT in the morning but negatively in the evening, and high neurotics were unable to maintain their performance from the first to the last part of the experiment. These results bring to mind Broadbent's (1971) two levels of control. For although effort facilitated reaction time (Broadbent's lower level) arousal facilitated the long term maintenance of reaction time (Broadbent's higher level). We have made use of this task in our within-subject comparisons of performance across the day (Studies WS-2 and WS-3) and have found that RT and change in RT shows reliable relations with within-subject changes in Energetic Arousal.

## Energetic Arousal and Impulsivity effects on memory storage and retrieval

The central purpose of this study (Anderson and Revelle, 1994) was to clarify the relationship between impulsivity and arousal. Although a stable relationship between the trait of impulsivity and states of arousal had been rendered implausible by our previous research, questions remained regarding the relationship of this personality dimension to arousal states. The trait of impulsivity could be related to stable differences in rate of change in arousal states or, alternatively, to phase differences in diurnal arousal rhythms.

Our key finding was a four-way interaction between impulsivity, time of day, drug, and prior stimuli. The pattern of means indicates that (a) regardless of time of day, subjects given placebo recognized fewer words from longer lists and from later lists than subjects given caffeine and (b) in the absence of caffeine, recognition memory for these long or late lists was poorer the higher the impulsivity in the morning, but better the higher the impulsivity in the evening. This cross-over interaction between impulsivity and time of day contradicts the hypothesis that impulsivity is related to stable individual differences in either basal arousal levels or in rate of change in arousal states. Instead, this interaction is consistent with the alternative hypothesis that impulsivity is linked to phase differences in diurnal arousal rhythms, which in turn determine ability to sustain attention.

Relative to placebo, caffeine reliably facilitated recognition memory for long and late lists, as anticipated if arousal enhances sustained attention. Results of our manipulation check unexpectedly indicated that the placebo and caffeine subjects in the morning session did not differ reliably in self-reported activation states in the minutes immediately preceding the first memory task. Thus, it is possible that the beneficial effect of caffeine on later trials in the morning merely reflected an increase in the extent to which the drug had taken effect. It is worth noting, however, that the effects of caffeine on recognition memory across the four lists in the evening are similar to the effects observed in the morning, and data from the evening session indicated large, reliable differences in self-reported activation both before and after the memory task. It is thus difficult to attribute the observed effects of caffeine on the later lists solely to a delayed response to the drug during the morning.

## Energetic and Tense Arousal effects on working memory

Our earlier theoretical model of performance decrements had predicted that while arousal should facilitate attentional processes, it should harm working memory (Humphreys and Revelle, 1984; Revelle, 1993). Six studies examined the impact of energetic arousal on working memory (WM). Time of day, caffeine, and film clips were used to assure variation in energetic arousal, which ranges from feeling sleepy and tired to feeling lively and energetic. Both between-subjects and within-subjects data from two different WM tasks (verbal and computational) indicated that higher levels of energetic arousal were associated with better WM performance. This beneficial effect of heightened energetic arousal did not seem to be due to changes in attention, task strategy, or effort. Results from this series of studies thus converge to suggest that WM capacity is a positively asymptotic function of energetic arousal. In contrast, the effect of enhanced effort was more consistent with changes in resource allocation than changes in resource availability, and higher levels of tense arousal were occasionally, but not invariably, associated with poorer WM performance.

In summary, WM performance was found to vary systematically as a function of energetic arousal. Evidence in support of the hypothesis that WM capacity is a positively asymptotic function of energetic arousal derived from both verbal (Experiments 1, 2, and 3) and computational (Experiments 4 and 6) WM tasks, both between-subject (Experiments 1, 2, 4, and 6) and within-subject (Experiments 3 and 6) comparisons, and with experimental paradigms involving caffeine (Experiments 1, 2, and 4), time of day (Experiments 3, 4, and 6), and film clips (Experiment 6) as sources of variation in energetic arousal. Despite the use of conservative statistical strategies, only one of six studies failed to provide evidence in support of this hypothesis: A weak beneficial impact of energetic arousal fell short of standard levels of statistical significance in Experiment 5.

These effects of energetic arousal on WM performance are not readily attributable to either attentional mechanisms or strategic task trade-offs. Although it is possible that increases in energetic arousal may be associated with enhanced attentional processing, enhanced sustained attention, strategic shifts in the allocation of cognitive resources, or a combination of the above, the pattern of results across these studies is difficult to assimilate within attentional or strategic models. For one thing, the beneficial impact of energetic arousal on WM performance did not depend on time-on-task. Moreover, because items in the computational version of the WM task used in Experiments 4, 5, and 6 were scored as correct only if the simultaneous arithmetic verification task was completed perfectly, it is difficult to ascribe systematic variation in recall to inattention. Likewise, by requiring perfect arithmetic verification performance, results regarding recall from the computational WM task cannot be easily explained by a trade-off between the verification and memory tasks.

# 4) Theoretical models of personality, motivation, and cognitive performance

## Motivational states: Affective valence and intensity

A common assumption when studying human performance is that subjects are alert and optimally motivated. It is also assumed that the experimenter's task at hand is by far the most important thing the subject has to do at that time. Thus, although individual differences in cognitive ability are assumed to exist, differences in motivation are ignored. For compliant college students participating in one of only a few psychology experiments, this assumption might well be true. It is probably less true for psychiatric patients, oil platform workers at the end of their shift, deep sea divers under several hundred feet of water, or special forces troops waiting in ambush. Indeed, for almost any subject population of interest it is difficult to believe that the specific experimental task used has an equally powerful motivation effect upon all subjects. In fact, it is possible, even with college students, to show that variations in motivational state are important sources of between subject variation in performance.

Motivational states can be categorized in several different ways. Conventionally, it has been useful to distinguish between the affective direction and the energetic intensity of motivation (Humphreys and Revelle, 1984). More recent work on affective states, however, has suggested that direction may subdivided into positive and negative components (Watson and Tellegen, 1985) and that intensity should be considered in terms of energetic and tense arousal (Rogers and Revelle, submitted; Revelle, 1993; Thayer, 1989). How these four constructs interrelate is far from clear.

## Personality, motivation, and performance

Over the course of this project we have examined how personality traits combine with situational manipulations to produce motivational states that in turn affect cognitive performance. For organizational purposes, these effects can be conceived as affecting information processing at several different, possibly overlapping, stages (see Revelle, 1993 for a review). The conceptual stage model we use to organize these results is obviously derived from Broadbent's filter model (1958) and the latter distinctions between filtering and pigeonholing (1971) as well as Sanders' (1983) stage model of reaction time. We use it merely to distinguish between the types of demands placed upon the subject. Stimuli must first be detected, then encoded, before this new information is able to be stored in memory. Based upon the incoming stimuli, further information needs to be retrieved from memory, information needs to integrated, and some response needs to be executed. This is a continuous loop, in that as a consequence of each response, environmental feedback occurs that partly determine the next stimulus that is to be detected. Storage and retrieval processes are shown as arrows between the encoding, integrating, and memory systems.

Motivation affects each of these stages. In terms of tasks we have examined, we believe that vigilance-like tasks relate to the detection and response stages and are affected by variations in arousal; individual differences in the learning of affectively valenced material occur at the encoding stage and are related to differential sensitivities to rewards and punishments; memory storage and retrieval and the effect of retention interval are affected by variations in arousal: arousal facilitates storage but hinders retrieval; and the information integration stage is curvilinearly related to arousal because it reflects two components--a beneficial effect due to the speed of input and a detrimental effect due to unavailability of recent events.

On a larger time scale, as the information processing loop continues to be executed, resources vary in their availability and in their allocation. Knowledge structures in memory change, affective reactions to the outcomes bias expectancies of future reinforcement and strategic decision processes are used. The encoding of environmental demands reflect differences in biological sensitivities to cues for rewards and punishment (Gray, 1981; Zinbarg and Revelle, 1989) as well as the prior contents of memory. Emotional reactions to feedback reflect the interaction of expectancies and outcomes. Positive affective states result from reward following expectancies of reward or non-punishment following expectancies of punishment. Negative affective states result from punishment following expectancies of reward and from punishment following expectancies of punishment (Rolls,1990). Positive affect facilitates approach behavior, negative affect facilitates avoidance behavior. Approach and avoidance tendencies are mutually inhibitory. Increased arousal facilitates the detection and storage of information as well as the execution of the dominant response tendency. This leads to a much more complex model (Revelle, 1993, Figure 4), but one that is probably necessary if the interdependent effects of cognitive and affective processes are to be understood. This model is an attempt to sketch out the systems that are involved in actively processing valenced information in an ongoing system responding to environmental demands and environmental reinforcements.

## Motivation as a control process.

What complicates the relationship between stable measures of personality and performance across situations has been summarized by Rabbit "the human cognitive system is designed for flexibility, and can carry out any particular task in many different ways" (Rabbit, 1986, p 155). Indeed, not only do different people do the same task in different ways, the same people do the same task in different ways. Motivation can be seen as a control process, altering the parameters of the cognitive system so as to execute responses most efficiently. Individual differences reflect higher order rates of change in these parameter settings (see also Sanders, 1983,1986).

Consider the results from our various reaction time studies. All subjects could do the task most of the time. Increased incentive or caffeine induced arousal improved performance. As the task continued, although the fastest responses remained about the same, some responses were much slower, reflecting an occasional lapse of attention. High impulsives in the morning and high neurotics throughout the day were particularly sensitive to this loss of attention. Incentives were unable to inhibit the decay across time, but caffeine was able to inhibit the decay. We interpret this result as suggesting that while effort can improve immediate performance, effort alone is unable to sustain performance. That is, in a constrained situation, one is unable to will oneself awake. But at a higher level, effort can increase alertness. As anyone knows who has struggled to overcome jetlag, drive long distances, or write an overdue paper by staying up all night, given the proper incentives one chooses activities that lead to alertness (e.g., stands up, takes brisk walks, or consumes large doses of caffeine). Thus, we are forced to add a higher-level control process to the two proposed by Broadbent (1971) or the hierarchy of resource pools proposed by Mulder (1986) and Sanders (1983, 1986).

## Impulsivity and arousal

In confirming previous suggestions that (a) impulsivity, not sociability, is the personality dimension that mediates arousal-related performance effects and (b) impulsivity is related to phase differences in diurnal arousal rhythms, the results of this project raise serious difficulties for several theoretical interpretations of the individual difference dimension of impulsivity (Revelle, 1997). Models linking impulsivity to stable differences in basal arousal, stable differences in general rate of decay of arousal or habituation, or stable differences in general rate of increase in arousal or arousability are all inconsistent with the observed pattern of results. That is, any model positing a temporally consistent relationship between impulsivity and arousal states or between impulsivity and patterns of change in arousal states is questioned by these data.

Two particular models deserve attention here. First, these data obviously contradict our own previous arguments (e.g., Revelle et al., 1987; Revelle & Anderson, 1992) that impulsivity is linked to stable differences in rate of change in arousal states. Second, these findings disconfirm interpretation of impulsive behaviors in terms of states of arousal per se, thus creating substantial difficulties for Eysenck's (1967) theoretical explanation of impulsive behavior (cf. Revelle et al., 1987; Revelle & Anderson, 1992; Gray, 1981). Specifically, our data suggest that temporally consistent patterns of impulsive behavior cannot be attributed to efforts to compensate for either low basal arousal levels or stable tendencies toward low arousal levels. That is, if recognition memory in this supraspan paradigm does reflect the influence of arousal, then our data suggest that high impulsive subjects are (a) more (not less) aroused than low impulsives in the evening and (b) more (not less) able to sustain arousal than low impulsives in the evening. It is thus difficult to attribute impulsive behavior, which presumably occurs more frequently among high impulsives than low impulsives no matter what the time of day, to either low arousal or a greater rate of change in arousal. Instead, the direction of causality may be from impulsivity to arousal states, rather than from arousal states to impulsivity.

We cannot reject the possibility that impulsivity is related to differences in preferred arousal level, an issue that, as Gale (1981) noted, has received virtually no serious investigation. Similarly, Gray's (1981) hypothesis that impulsivity reflects sensitivity to signals of reward was not directly addressed by this project. Although this study did not offer a test of these models of impulsivity, the evidence for a link between impulsivity and diurnal arousal rhythms suggests that a complete understanding of this personality dimension will require some consideration of arousal states.

That impulsivity is arousal-related is strongly supported by the pattern of results from our studies of cognitive performance, which have yielded predictable and replicable interactions between impulsivity, arousal manipulations, and task characteristics. Moreover, as discussed earlier (e.g., Anderson and Revelle, 1994; Revelle & Anderson, 1992), the high-order interactions observed in these studies have eliminated a variety of alternative (i.e., non-arousal related) explanations for the performance effects. For example, although impulsivity is associated with a preference for speed over accuracy, such strategic differences can not explain the full pattern of results. (Note that the reversal of impulsivity differences from morning to evening in the present study likewise argues against a stable strategic explanation for the observed performance effects.) Similarly, hypotheses of differential sensitivity to caffeine or of performance disruption due to monitoring of unusual states of arousal are eliminated by interactions of impulsivity with time of day.

To summarize, our data suggest that impulsivity is linked to arousal and thereby to performance, but in a complex way: Susceptibility to lapses in attention is a function of arousal, with impulsivity bearing a consistent relationship not to basal arousal levels, and not to rate of change in arousal states, but rather to phase differences in diurnal arousal rhythms. Thus, high impulsive subjects are more susceptible to vigilance-like decrements than low impulsives in the morning, but less susceptible in the evening. This interaction of impulsivity with time of day contradicts hypotheses linking impulsivity to stable differences in basal arousal level (e.g., Eysenck, 1967) or in rate of change in arousal states (e.g., Revelle et al., 1987), and raise serious difficulties for any model proposing that individual differences in arousal states cause impulsive behavior. Instead, these findings strongly support an association between impulsivity and phase difference in diurnal arousal rhythms.

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**Invited presentations:**

Revelle, W. Personality: the temporal coherence of behavior. Invited address in honor of Hans Eysenck at the Experimental Psychology Society (of the UK), Oxford, March, 1997.

Revelle, W. (1996) Personality as melody: the temporal coherence of behavior. Department of Psychology Colloquium, University of Michigan, March, 1996.

**Conference presentations:**

Acton, G. S., and Revelle, W. (1996) *Testing for circumplex structure in the interpersonal circle and the structural analysis of social behavior*. Paper presented at the Midwestern Psychological Association annual meeting, Chicago, May, 1996.

Anderson, K. J. and Revelle, W. (1995) *The effects of activation states on performance on geometric analogies.* Paper presented at the 1995 meeting of the International Society for the Study of Individual Differences. Warsaw, Poland, July, 1995.

Billings, D. and Revelle, W. (1995) *An investigation into the proposed influence of personality on emotion sensitivity.* Paper presented at the annual meeting of the Midwestern Psychological Association, Chicago, May, 1995.

Billings, D. and Revelle, W. (1995) *Depression and the dimensions of mood regulation*. Paper presented at the annual meeting of the American Psychological Association, New York, August, 1995.

Born, W. and Revelle, W. (1996) *Motivational effects of stereotype-salience on performance of complex tasks* American Psychological Society, June, 1996.

Born, W. and Revelle, W. (1997) *Women, math, and stereotypes: What Helps and what Hurts* Midwestern Psychological Association, April, 1997

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Revelle, W. and Anderson, K. (1996) *Time of day and activation states: Interactions with impulsivity and neuroticism* . Paper presented at the European Association of Personality Psychologists, July, Ghent, Belgium

Revelle, W. and Anderson, K. J. (1995) *Traits, states, and time of day: Extraversion, neuroticism, and the dimensionality of affect and arousal*. Paper presented at the 1995 meeting of the International Society for the Study of Individual Differences. Warsaw, Poland, July, 1995.

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Rogers, G. M., & Revelle, W. (1997). *Personality predictors of daily mood rhythms.* Paper presented at the annual meeting of the Midwestern Psychological Association, May, Chicago, IL.

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## Summary of results with respect to previous research and hypotheses

Goal 1) To understand the role of the non-cognitive dimensions of personality as they interact with time of day and other sources of variation in arousal in affecting efficient performance on a variety of simple and complex cognitive tasks

Outcome: Impulsivity and Neuroticism affect mean level, phase, and amplitude of the diurnal arousal rhythms for energetic and tense arousal. Low neuroticism is associated with greater amplitude and higher mean values of Energetic Arousal and higher mean levels of Tense Arousal. Impulsivity and Neuroticims have interactive effects on the phase of the energetic arousal rhythm. Energetic Arousal increases working memory capacity. Tense Arousal seems to reduce working memory capacity.

Goal 2) To understand the role of non-cognitive dimensions of personality as they affect the <u>learning and retention of information</u>*.* In particular, a) to understand the ways in which *arousal* affects the detection, encoding, and storage of new material; and b) to understand how impulsivity and anxiety interact with stimulus valence when learning new material.

Outcome: Impulsivity interacts with time of day to affect the detection and subsequent retrieval of information. Impulsivity and neuroticism interact with the stimuls valence when processing new material.

Goal 3) To continue development of a <u>formal model</u> of the way in which personality variables affect the processing of stimuli, development of motivational states, and eventual effective expression of action tendencies.

Outcome: Our earlier model of efficient performance predicted that high levels of arousal (type unspecified) would reduce working memory capacity. This needs to be modified to reflect the beneficial effects of energetic arousal and the detrimental effects of tense arousal. Our earlier model also suggested that impulsivity related to the decay rate of energetic arousal. This needs to be modified to reflect our finding that impulsivity interacts with time of day to affect the decay rate of cognitive processes thought to reflect the benefits of energetic arousal.

However, in general, the formal model of the effects of individual differences, situational stressors, and cognitive task demands allows us to predict performance on simple attention and working memory tasks as a function of time of day, time on task, and affective valence of the input cues.

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Table 1: Items from the Motivational State Questionnaire sorted by angular location in the two space defined by Energetic Arousal and Tense Arousal. Factor loadings in this two space as well as item communalities are shown.

| Item (#) | EA/PA | TA/NA | angle | $h^2$ |
|---|---|---|---|---|
| energetic (55) | 0.84 | 0.01 | 1 | 0.71 |
| elated (22) | 0.73 | 0.02 | 2 | 0.53 |
| excited (41) | 0.78 | 0.08 | 6 | 0.61 |
| anxious (71) | 0.21 | 0.58 | 70 | 0.38 |
| tense (69) | 0.06 | 0.71 | 85 | 0.51 |
| distressed (62) | -0.04 | 0.75 | 93 | 0.56 |
| frustrated (65) | -0.10 | 0.75 | 98 | 0.57 |
| sad (16) | -0.14 | 0.69 | 101 | 0.50 |
| irritable (25) | -0.27 | 0.60 | 114 | 0.43 |
| sleepy (59) | -0.50 | 0.14 | 164 | 0.27 |
| tired (28) | -0.54 | 0.15 | 164 | 0.31 |
| inactive (49) | -0.50 | 0.03 | 177 | 0.25 |
| calm (50) | 0.21 | -0.39 | 298 | 0.20 |
| relaxed (8) | 0.35 | -0.46 | 307 | 0.33 |
| at ease (33) | 0.41 | -0.46 | 312 | 0.38 |
| attentive (63) | 0.71 | -0.04 | 357 | 0.51 |
| enthusiastic (14) | 0.80 | -0.03 | 358 | 0.64 |
| lively (20) | 0.85 | 0.00 | 360 | 0.72 |
| active (17) | 0.80 | 0.03 | 2 | 0.64 |
| vigorous (29) | 0.74 | 0.10 | 8 | 0.56 |
| aroused (21) | 0.70 | 0.11 | 9 | 0.50 |
| upset (48) | -0.13 | 0.74 | 100 | 0.56 |
| unhappy (19) | -0.23 | 0.70 | 108 | 0.54 |
| depressed (6) | -0.23 | 0.68 | 109 | 0.52 |
| content (68) | 0.62 | -0.35 | 331 | 0.51 |
| happy (61) | 0.75 | -0.23 | 343 | 0.62 |
| pleased (60) | 0.72 | -0.16 | 347 | 0.54 |
| cheerful (46) | 0.81 | -0.15 | 350 | 0.68 |
| wide awake (64) | 0.72 | -0.03 | 358 | 0.52 |
| full of pep (18) | 0.83 | -0.01 | 359 | 0.69 |
| alert (52) | 0.75 | 0.00 | 360 | 0.56 |
| strong (12) | 0.64 | 0.08 | 7 | 0.42 |
| inspired (53) | 0.67 | 0.17 | 14 | 0.48 |
| determined (40) | 0.66 | 0.23 | 19 | 0.49 |
| intense (11) | 0.44 | 0.46 | 46 | 0.41 |
| astonished (30) | 0.27 | 0.37 | 54 | 0.21 |
| jittery (3) | 0.22 | 0.47 | 65 | 0.27 |
| nervous (45) | 0.15 | 0.64 | 77 | 0.43 |

| | | | | |
|---|---|---|---|---|
| scared (13) | 0.08 | 0.65 | 83 | 0.43 |
| fearful (32) | 0.07 | 0.63 | 84 | 0.40 |
| afraid (35) | 0.07 | 0.64 | 84 | 0.41 |
| guilty (37) | 0.04 | 0.56 | 86 | 0.32 |
| clutched up (27) | 0.03 | 0.64 | 87 | 0.41 |
| ashamed (70) | -0.01 | 0.59 | 91 | 0.35 |
| sorry (58) | -0.02 | 0.64 | 92 | 0.41 |
| angry (44) | -0.07 | 0.67 | 96 | 0.45 |
| lonely (56) | -0.13 | 0.55 | 103 | 0.32 |
| hostile (4) | -0.15 | 0.56 | 105 | 0.34 |
| blue (10) | -0.19 | 0.67 | 106 | 0.49 |
| gloomy (42) | -0.29 | 0.64 | 114 | 0.49 |
| grouchy (47) | -0.32 | 0.56 | 120 | 0.42 |
| dull (31) | -0.48 | 0.23 | 154 | 0.28 |
| sluggish (5) | -0.54 | 0.17 | 163 | 0.32 |
| drowsy (51) | -0.50 | 0.13 | 165 | 0.27 |
| at rest (33) | 0.32 | -0.32 | 315 | 0.20 |
| satisfied (7) | 0.64 | -0.27 | 337 | 0.48 |
| confident (67) | 0.62 | -0.21 | 341 | 0.43 |
| warmhearted (9) | 0.64 | -0.18 | 344 | 0.44 |
| sociable (2) | 0.68 | -0.14 | 348 | 0.48 |
| delighted (1) | 0.66 | -0.09 | 352 | 0.44 |
| wakeful (23) | 0.70 | -0.06 | 355 | 0.49 |
| interested (34) | 0.66 | -0.05 | 356 | 0.44 |
| proud (15) | 0.64 | -0.02 | 358 | 0.41 |
| quiescent (38) | 0.10 | 0.04 | 22 | 0.01 |
| surprised (54) | 0.33 | 0.29 | 41 | 0.19 |
| bored (36) | -0.33 | 0.14 | 157 | 0.13 |
| quiet (57) | -0.24 | 0.06 | 166 | 0.06 |
| idle (72) | -0.24 | -0.01 | 182 | 0.06 |
| still (43) | -0.14 | -0.15 | 227 | 0.04 |
| placid (24) | -0.03 | -0.14 | 258 | 0.02 |
| tranquil (39) | 0.13 | -0.36 | 290 | 0.15 |
| serene (66) | 0.22 | -0.34 | 303 | 0.16 |

Table 2: Short Form of the Motivational State Questionnaire

| | Energetic | Lively | Sleepy | Tired | Tense | Frustratec | Calm | Relaxed |
|---|---|---|---|---|---|---|---|---|
| Energetic | 1.00 | | | | | | | |
| Lively | 0.75 | 1.00 | | | | | | |
| Sleepy | -0.42 | -0.38 | 1.00 | | | | | |
| Tired | -0.46 | -0.42 | 0.80 | 1.00 | | | | |
| Tense | 0.04 | 0.03 | 0.07 | 0.07 | 1.00 | | | |
| Frustrated | -0.07 | -0.07 | 0.16 | 0.16 | 0.54 | 1.0( | | |
| Calm | 0.13 | 0.14 | 0.00 | -0.03 | -0.30 | -0.2‹ | 1.00 | |
| Relaxed | 0.23 | 0.26 | -0.10 | -0.13 | -0.38 | -0.31 | 0.52 | 1.00 |

| | Energetic | Tense |
|---|---|---|
| Energetic Arousal | *0.82* | |
| Tense Arousal | -0.18 | *0.71* |

(Alphas reliabilities on diagonal)
Number of S's= 2679

Table 3

Correlations Between Week 1 and Week 2 Energetic Arousal (EA) and Tense Arousal (TA) Rhythm Parameters

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| | | | Week 1 | | | |
| 1. EA Mean | --- | -.33** | -.18 | .06 | .13 | .00 |
| 2. TA Mean | | --- | -.09 | -.09 | -.09 | .10 |
| 3. EA Acrophase | | | --- | .30** | -.13 | -.03 |
| 4. TA Acrophase | | | | --- | .14 | .18 |
| 5. EA Organization | | | | | --- | .43** |
| 6. TA Organization | | | | | | --- |
| | | | Week 2 | | | |
| 1. EA Mean | --- | -.43** | -.08 | -.35** | -.26* | -.14 |
| 2. TA Mean | | --- | .05 | .20 | .13 | .15 |
| 3. EA Acrophase | | | --- | .40** | -.05 | -.30** |
| 4. TA Acrophase | | | | --- | .20 | -.03 |
| 5. EA Organization | | | | | --- | .57** |
| 6. TA Organization | | | | | | --- |

Note. *p<.05, **p<.01

Figure Captions

Figure 1: Dimensional structure of affect. Adjectives taken from the Motivational State Questionnairre. .

Figure 2: Tense Arousal as a function of time of day (double plotted) and neuroticism.

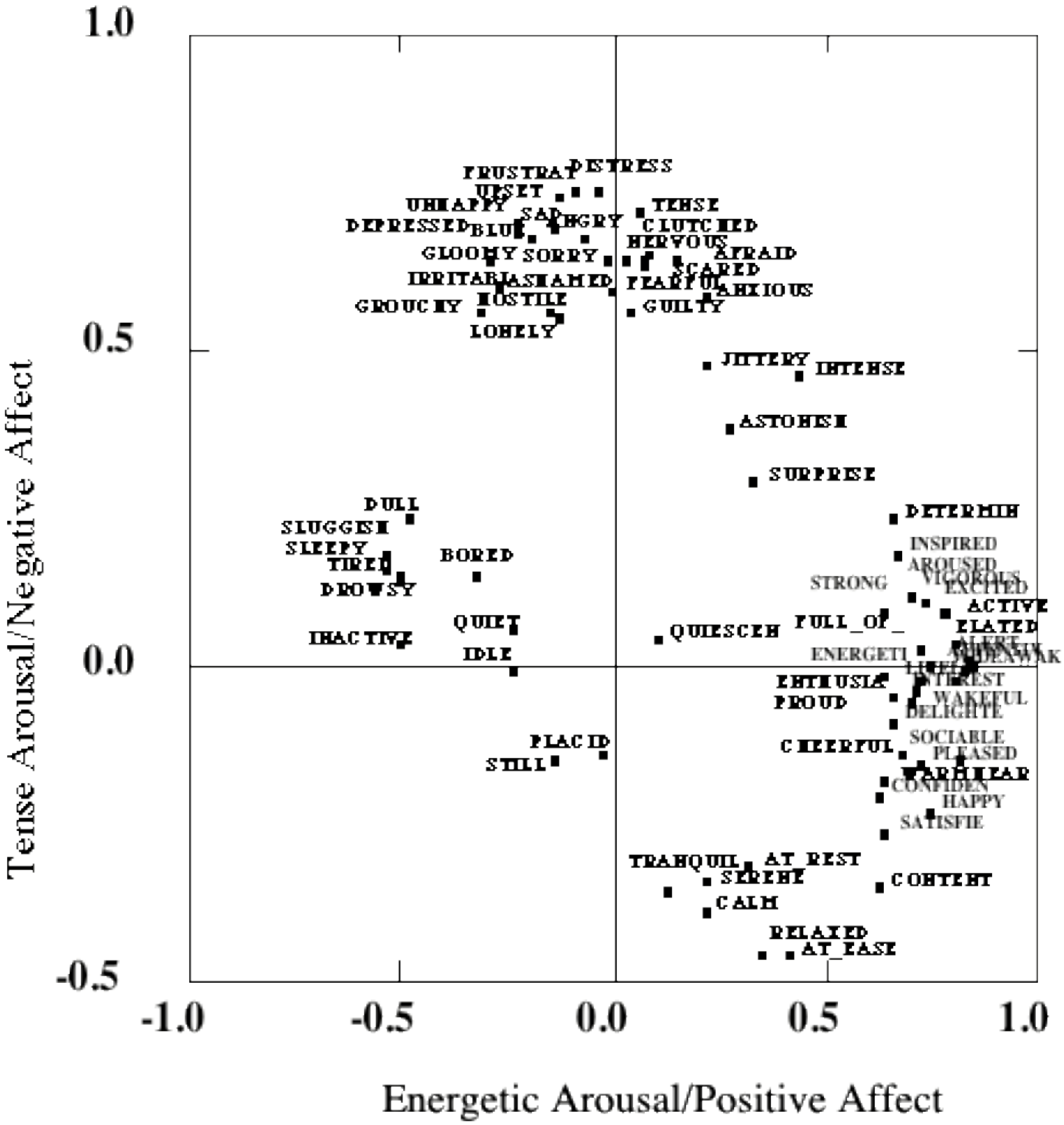
Figure 3: Energetic Arousal as a function of time of day (double plotted and neuroticism.

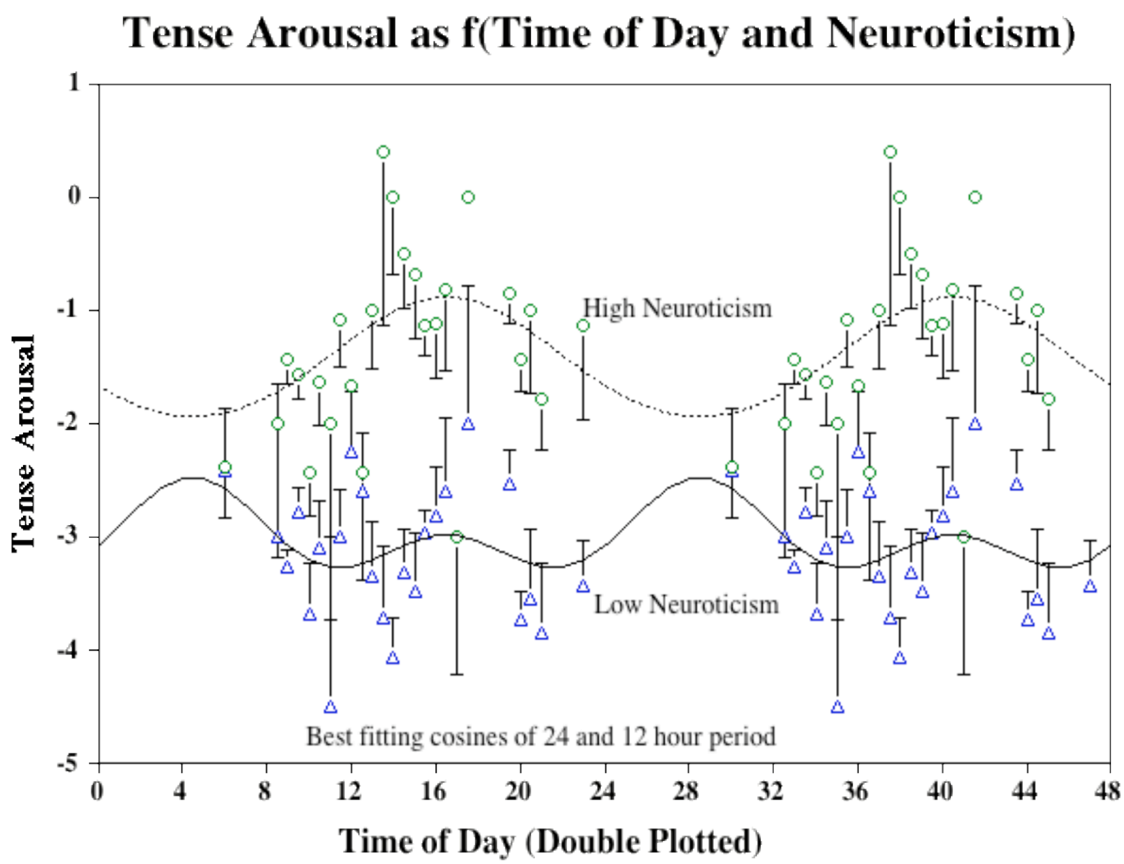
Figure 3. Week 1 energetic arousal rhythms of a nondysphoric participant (top panel) and a dysphoric participant (bottom panel).

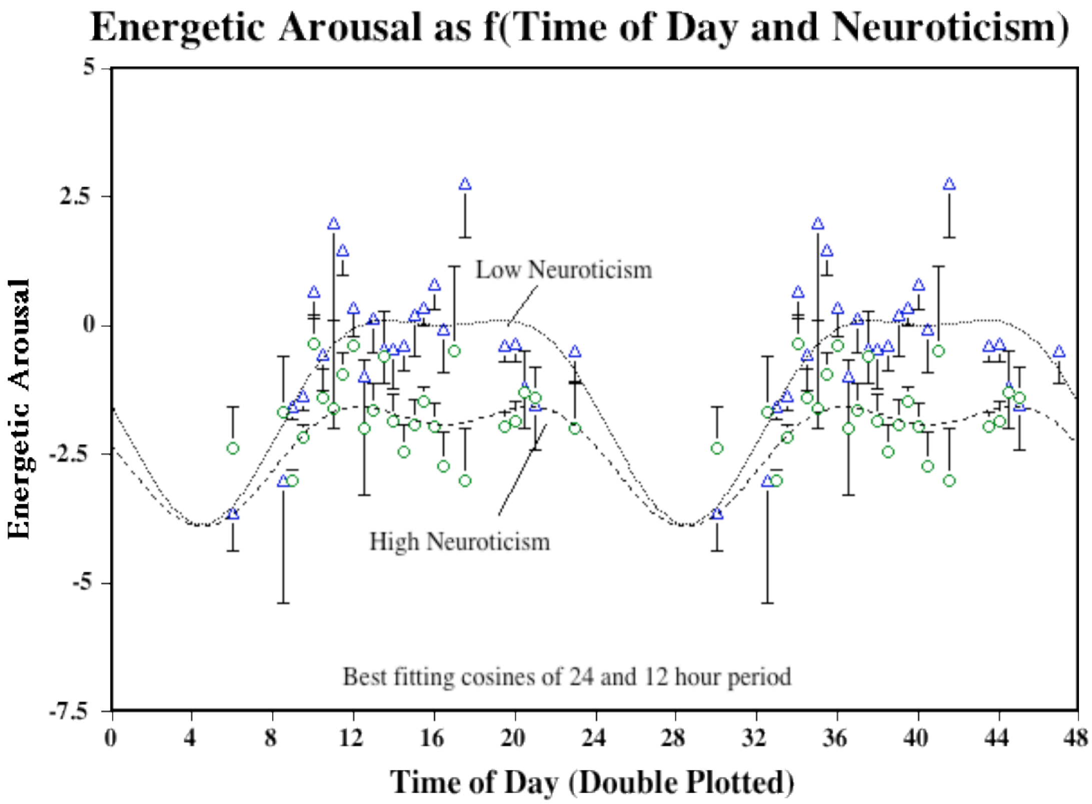
Figure 4. Week 1 negative affect (standardized) as a function of neuroticism and week 1 EA organization (standardized). Stables are represented by solid circles and solid line. Neurotics are represented by plus signs and dashed line.

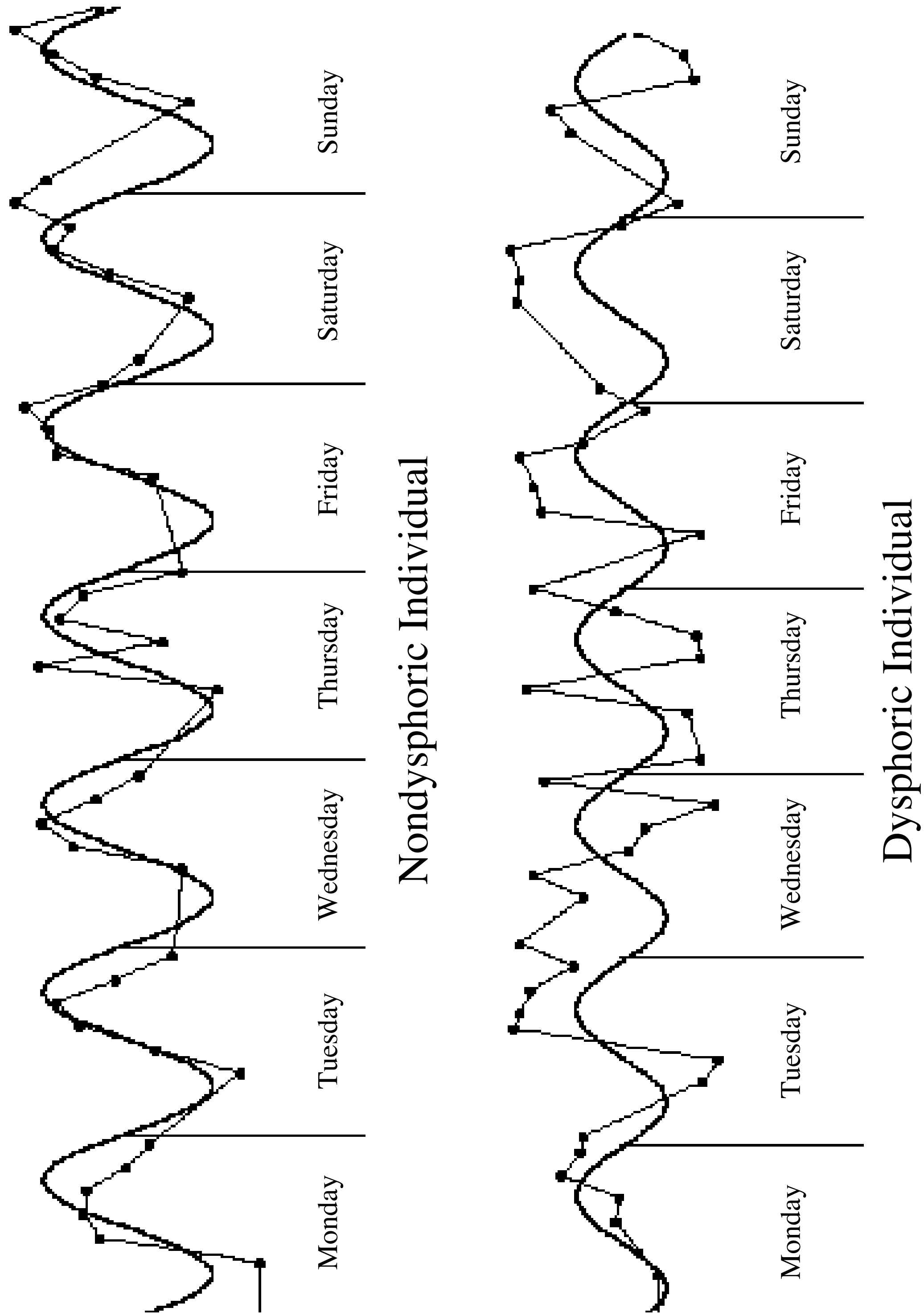
Figure 5. Residual change in standardized negative affect as a function of neuroticism and week 1 EA organization (standardized). Stables are represented by solid circles and solid line. Neurotics are represented by plus signs and dashed line.

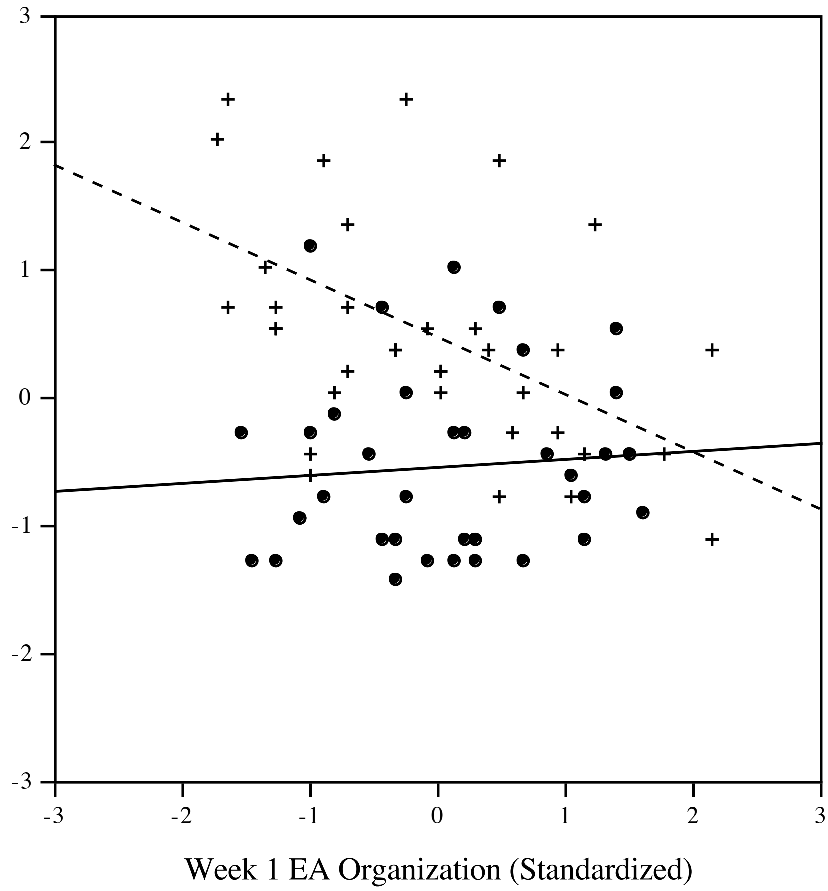
# Two dimensions of affective state:

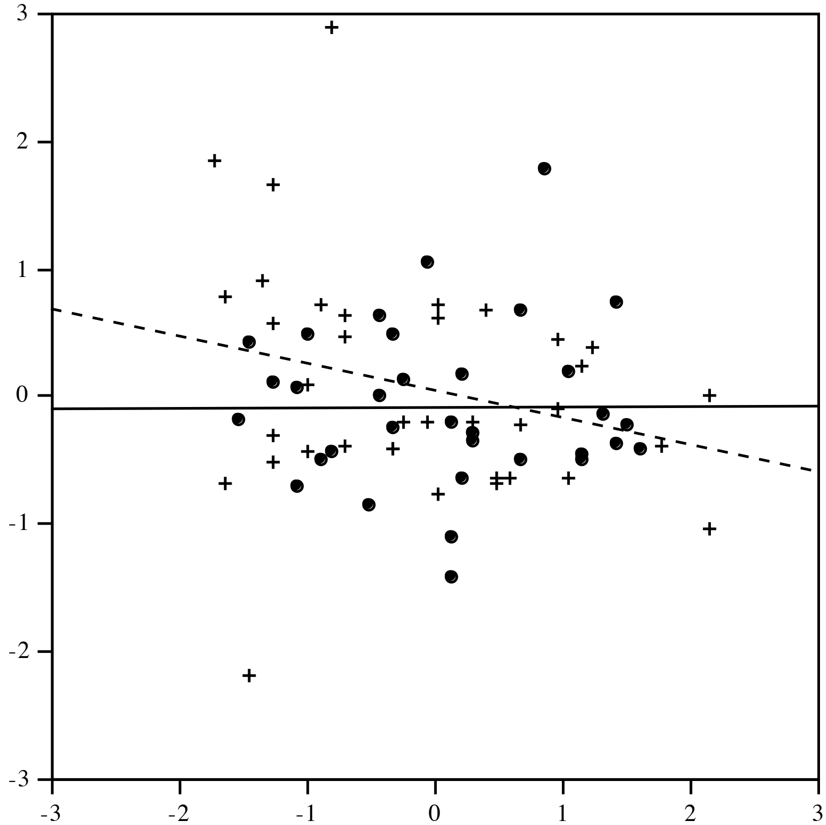



Tense Arousal as f(Time of Day and Neuroticism)
Tense Arousal
1
0
-1
-2
-3
-4
-5
High Neuroticism
Low Neuroticism
Best fitting cosines of 24 and 12 hour period
0
4
8
12
16
20
24
28
32
36
40
44
48
Time of Day (Double Plotted)


Energetic Arousal as f(Time of Day and Neuroticism)
Energetic Arousal
5
2.5
0
-2.5
-5
-7.5
Low Neuroticism
High Neuroticism
Best fitting cosines of 24 and 12 hour period
0
4
8
12
16
20
24
28
32
36
40
44
48
Time of Day (Double Plotted)


Nondysphoric Individual
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Dysphoric Individual
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday


3
2
1
0
-1
-2
-3
-3
-2
-1
0
1
2
3
Week 1 EA Organization (Standardized)




Week 1 EA Organization

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[i] Evidence that these descriptors load highly on the relevant factors comes from a large body of data collected in our lab and is consistent with factor analyses performed by Thayer (1986). Also see Zevon & Tellegen (1982) for evidence of the utility of a two-factor model of mood in studies involving repeated measures of mood for single subjects.