Undersea Biomedical Research, Vol. 5, No. 3, September 1978

Diver adaptability during a nitrox saturation dive at 7 ATA

B. B. WEYBREW

Naval Submarine Medical Research Laboratory, Naval Submarine Base New London, Groton, CT 06340

Weybrew, B. B. 1978. Diver adaptability during a nitrox saturation dive at 7 ATA. Undersea Biomed. Res. 5(3):259–273.—The major objective of this study was to demonstrate the advantages of transforming raw scores to ipsative form (deviation scores calculated around each subject's mean), particularly in diver research characteristically involving small subject samples in a self-control design. Measures of reaction time, response accuracy, anxiety, hostility, and depression were obtained from three U.S. Navy divers (Ss) during a nitrox saturation dive at 7 ATA (bottom time 7 days). It was argued and to some extent demonstrated that normative (interindividual) statistics obscure individual differences which are clearly delineated with the scores in ipsative form. Further, this score transformation allowed for meaningful between-Ss (same measure) and between-measures (same S) comparisons. These relationships could not be demonstrated with the scores in normative form. Application of P-technique of factor analysis within each S's arrays of data suggested that the characteristic adaptive patterns of two Ss in this study reacted to the pressure-stress by directing affect inward; for the third S, affect was directed outward. However, none of the 20 scales from the Minnesota Multiphasic Personality Inventory clearly discriminated among the three adaptive types.

measurement methods
diver performance
hyperbaric
psychological factors
adaptation
factor analysis
ipsative scores
normative scores

Two studies, one by the U.S. Navy (Kiessling and Maag 1960) and the other by the British Navy (Barnard, Hempleman, and Trotter 1962), provided substantial support for the 30-year-old finding that mental efficiency is impaired by exposure to air at 3–6 ATA (Shilling and Willgrube 1937). Although perhaps less severe, behavioral changes have also been reported in pressurized heliox mixtures (Seki and Hugon 1976). Measures of mental processes varying from arithmetical tasks and card sorting in the above studies to measures of simple reaction time, two-hand coordination, and spiral-induced illusions (Adolfson 1965; Weybrew and Parker 1968) have been used to assess the effects of exposure to these hyperbaric conditions. In addition, subjective symptomatology indicative of subjects' mood, fatigue states, and localized pain and discomfort has been collected by means of diving logs, diaries, and standardized symptom scales of various kinds (Radloff and Helmreich 1968).

While the techniques of data collection used in the present study are not new, the approach to analyzing the data, insofar as is known, has not appeared in the diving literature to date. The

impetus for the methodological approaches used in this experiment stemmed from the observation that many, perhaps most, of the psychological studies in the diving literature are normative in nature. That is to say, they derive their conclusions from the divers' average responses based upon between-individual differences obtained from subject samples varying in size from two to six or occasionally more subjects. In approximate agreement with Allport (1961), it is assumed for the purpose of this study that normative studies involving group statistics of this kind are quite restricted in terms of providing an understanding of a specific individual's unique adaptation to the environment. An examination of almost any study involving human subjects in the diving literature generally reveals group means (n = 2–5, generally) plotted against exposure time in an exotic gaseous and/or hyperbaric environment compared (in the typical ABA or self-control design) with means computed from the pre- and postexperimental control data. However, inspection of individual profiles shows that the means are atypical insofar as a specific subject is concerned. Seldom does any one subject's value fall on the mean. Calculated in this manner, the average provides at best a statistical compromise which may be of limited value in attempts to assess a given subject's unique reaction to the imposed stress.

Of perhaps hundreds available, one example of an excellent study of heliox effects at 16.1 ATA demonstrated that the means calculated for selected psychomotor, memory, and cognitive tests changed significantly as a function of pressure (O'Reilly 1974).[1] An analytical technique occasionally found in the diving literature was used in the above study, namely, plotting line graphs with data points consisting of mean percent of control values (n = 5 or 6). Plotted in this manner, the means for all measures dropped sharply during the hyperbaric phase of the experiment. However, with no indication of the variability at a given data point it is impossible to determine whether the percentage changes were positive for one or more of the subjects during the experimental conditions. While percentages based upon small samples tend to be quite unreliable and the calculation of means from these percentage changes tends to compound the unreliability, this analytical technique nonetheless does to an extent provide between-measure and between-person comparability at a given point in the experiment.

One recent study was methodologically focussed in the same direction as the present paper (Seki and Hugon 1976). Mean fatigue symptoms and other measures were calculated not between persons (n = 2), as is commonly done, but for each subject's data array during the control and experimental phases of the experiment. Further, correlation matrices were calculated singly for each subject from covariance patterns between measures obtained over the 27-day experiment.

The present study extends the methodology of the Seki and Hugon (1976) experiment in two ways. First, the raw scores for each measure are expressed in deviation form around each subject's mean. Second, the intraperson correlation matrices derived by Seki and Hugon (1976) were also calculated in this study; however, these matrices were subsequently factor-analyzed to delineate individualistic, adaptive patterns for each of the experimental subjects.

In sum, the major methodological objective of this paper was to demonstrate an analytical approach aimed at identifying unique, individualistic adaptive patterns in subjects participating in diving studies and in similarly designed experiments in other fields. A secondary objective was to conduct a preliminary search for personality trait configurations usefully predictive of these adaptive patterns after these had been identified.

[1] Any number of studies employing normative methodology might have been cited.

METHODS

This experiment was conducted in a decompression chamber located at the Naval Submarine Medical Research Laboratory, Groton, Connecticut. The saturation depth was 60.4 msw equivalent pressure. The oxygen concentration was maintained between 3.15 and 4.42%. The bottom time was about seven days and was followed by a decompression schedule requiring approximately the same amount of time.[2] The study involved the familiar ABA or self-control design typically used in diver experimentation with small subject samples.

Subjects

The three volunteers for this experiment were U.S. Navy divers first-class, married, in their early or mid-thirties, and in excellent health.[3] Each had made at least 300 dives (both wet and simulated) and had a history of from seven to 13 years' hard-hat experience. Further, two of the three men had from 10 to 20 years' scuba experience and one (Diver B) had more than four years' saturation diving experience. Diver C had no history of any pressure-related symptomatology, while the other two divers each reported one instance of treatment for "pain-only" bends.

As in previous hyperbaric experiments conducted at this Laboratory, considerable dependence was placed upon the Minnesota Multiphasic Personality Inventory (MMPI) profiles of the diver-volunteers as a means of identifying any psychopathological trends. In addition, the MMPI profiles for each of the divers provided an initial data base for a search for personality trait patterns systematically related to individual differences in the adaptive responses of the divers to the experimental conditions. Table 1 contains the individual MMPI profiles as well as normative data obtained from an independent sample of 30 USN divers.

A brief descriptive statement for each of the MMPI subtests included in Table 1 follows (see Welsh and Dahlstrom 1956): L, F, and K scales measure test-taking attitudes; Hs, overconcern about one's own health; D, depressive trends; Hy, somatization defenses; Pd, tendency toward dyssocial conduct; Mf, sex role identification; Pa, suspiciousness; Pt, trait anxiety; Sc, degree of reality contact; Ma, level of psychic energy; Si, social withdrawal; A, situational anxiety; R, suppressive tendencies; Cn, impulse control; Es, ego resiliency; Dy, dependency needs; Re, dependability; and Do, coping capacity.

At the outset, the profiles in Table 1 clearly demonstrate the high degree of similarity between MMPI score patterns for each of the three divers used as subjects in this study and mean MMPI profiles for a sample of 30 U.S. Navy divers reported elsewhere (Weybrew 1974). Application of a ranking method for testing the significance of the differences in the MMPI subtest patterns of the three divers compared to the normative data ($n=30$) indicated no overall differences at the 5% confidence level (Friedman 1937). Thus, as discussed in some detail in Weybrew (1974), the MMPI profiles in Table 1 as a whole appear to describe a psychologically healthy segment of the U.S. Navy population. The same statistical technique applied to the MMPI profiles for the three divers alone demonstrated significant individual differences for the 10 diagnostic scales (5% level), but only a trend (9% level) for the seven experimental subtests. The nature and extent of these profile differences will be examined in more detail later in the context of a search for personality correlates of different adaptive responses to the experimental conditions.

[2]The detailed dive profile may be obtained from the author by written request.

[3]All three divers were processed through the Longitudinal Health Study procedure, a comprehensive, day-long medical examination included as part of a research project going on at the time of this study.

TABLE 1
COMPARISON OF MMPI PROFILES OF THREE DIVER-SUBJECTS WITH MEAN MMPI PROFILE OF 30 USN DIVERS

MMPI Subtests†	Mean T-score, (n=30 divers)*	T-scores, subject A	B	C
Validity Scales				
L-Scale	49	53	50	50
F-Scale	54	58	55	55
K-Scale	56	61	61	64
Diagnostic Scales				
Hypochondriasis (Hs)	51	47	52	54
Depression (D)	52	58	48	53
Hysteria (Hy)	55	49	55	53
Psychopathic Deviate (Pd)	62	60	55	67
Masculinity-Feminity (Mf)	56	53	51	55
Paranoia (Pa)	54	56	47	44
Psychasthenia (Pt)	51	48	56	52
Schizophrenia (Sc)	52	55	57	53
Hypomania (Ma)	59	65	70	65
Social Introversion (Si)	47	40	49	40
Experimental Scales				
Factor A (A)	44	43	50	33
Factor R (R)	51	49	28	53
Control (Cn)	58	55	61	43
Ego Strength (Es)	59	67	59	66
Dependency (Dy)	45	43	50	33
Social Responsibility (Re)	47	40	45	52
Dominance (Do)	56	48	56	59

*These and other normative data are presented in Weybrew (1974).
†See text for a brief descriptive statement for each MMPI subtest. Duckworth and Duckworth (1975) contains a brief but succinct discussion of each of these scales.

Measurement techniques

The rationale for the choice of the psychological measures obtained twice daily during the two-week experiment was based upon three considerations: 1) the scores had some demonstrated validity for assessing subtle psychological changes during hyperbaric stress; 2) the measurement sessions were brief and unobtrusive; and 3) the measurement procedures had high face-validity for the diver subjects. Some brief statements describing these measures are contained in Table 2.

The Sequential Reaction Time (SRT) and SRT-error scores are at once measures of reaction time, visual discrimination, eye-hand coordination, aiming skills, and hand tremor. These measures have been shown to be sensitive to hyperbaric conditions (Weybrew and Parker 1968) and to long exposure to loud sonar "beeps" (Weybrew and Noddin 1971).

The Multiple Affect Adjective Checklist (MAACL) measures the affective components of emotional responses to a given set of environmental circumstances. As indicated in Table 2, scores are obtained simply by summing a prescribed pattern of adjectives which are or are not checked by the respondent. Examples of the adjectives included in the three MAACL subtests

TABLE 2
MEASUREMENT TECHNIQUES

Measures	Test Content	Administration and Scoring Procedures
Sequential reaction time (SRT)	Upper case "Cs" are randomly interspersed with "Os". Thirty different forms with approximately 80 responses per form were used	Instructions were to put a line through all of the Cs on the form as rapidly as possible. Reaction time = total time (s) divided by number of responses. Type I errors included cancelling "Os" while Type II errors were failing to cancel Cs. The test was administered twice daily at taps and reveille.
Multiple Affect Adjective Checklist (MAACL)*	The MAACL consisted of 132 adjectives factor analytically validated to form 3 item clusters purported to measure *Anxiety*, *Depression*, and *Hostility*	A prescribed pattern of adjectives checked as well as another pattern not checked are summed to obtain scores for each of the three dimensions of the MAACL. It was administered twice daily at reveille and at taps.

*The MAACL was constructed by M. Zuckerman and B. Lubin and is published by Educational and Industrial Testing Service, San Diego, Calif.

may serve to clarify their content: for *Anxiety* (21 words in all), examples of inclusion words are afraid, desperate, and nervous. Exclusion words for *Anxiety* are joyful, secure, and calm. For *Hostility* (28 words), examples of inclusion words are angry, unsociable, and disagreeable, while exclusion words were kindly, understanding, and friendly. For *Depression* (40 words), examples of inclusion words were miserable, hopeless, and sad, and exclusion words were enthusiastic, merry, and interested.

Data analytical techniques

Methodologically, this study may be described as an idiographic experiment rather than a nomothetic one; that is, intra-individual variation, rather than interindividual differences, is emphasized (Meehl 1954; Allport 1961). Thus, all of the raw scores for each of the measures for each of the three divers were converted to ipsative[4] form by the following formula

$$IS_i = \left[(X_i - M_i)/SD_i\right] 10 + 50$$

where IS_i = the ipsative score for each individual for each measure, X_i is the raw score for each subject, M_i is each subject's mean calculated over his array of repeated measures, and SD_i is the standard deviation of the same intraperson distribution. Multiplying by 10 and adding 50 transforms the deviation or z-scores to T-scores (sometimes called McCall scores) (McCall 1922), which were used in this case to avoid negative z-scores.

[4]For a comprehensive discussion of the rationale underlying the concept of ipsative scores, see Cattell (1944).

It is the thesis of this paper that this ipsative score conversion is desirable, in fact necessary, to assess the crucial intra-individual covariance patterns meaningfully. This is particularly true for subjective data such as that obtained with the MAACL (Table 2). This bias is in approximate agreement with at least one recognized authority on personality assessment, who has stated flatly, "Introspective data can only be expressed in ipsative units, if any" (Cattell 1952, p. 327).

Reliability of differences between control and experimental data within each subject's arrays of measures over time was estimated by the median test (Mood 1950), while the between-person differences in distribution statistics were examined by means of the F- and t-ratios. Similar to a P-technique of factor analysis applied to a group of incarcerated submariners (Weybrew 1955), the intra-individual factor analysis conducted for each of the three subjects in this experiment involved a centroid technique (Thurstone 1947). The reference axes were rotated orthogonally (axes vertical) by means of a simple geometric procedure (Fruchter 1954).

RESULTS

To reiterate, the major methodological assumption underlying this study is that the score distributions for each of the five variables taken over the intra-individual arrays for each of the three diver-subjects constitute the most meaningful sources of variance describing an individual's unique adaptability to imposed experimental conditions. Table 3 presents these distribution statistics calculated from the raw scores obtained for the five measures for each subject.

There are two important dimensions of the intraperson arrays, namely level, as indicated by the means, and scatter, as indicated by the variance or its square root, the standard deviation of the distribution. Accordingly, the between-person variances are all significant at the 1% level (F-ratio) for all five measures. This finding indicates that the divers do indeed differ in terms of scatter or variance on all of the five measures. Similarly, though not shown in Table 3, the t-ratios calculated between the means of each measure for each diver were significant (1% level or less) for all subject-pairs except for Subjects A and B on SRT and A and C on SRT-errors (>5% level).

TABLE 3
MEANS AND SDS DERIVED FROM WITHIN-PERSON-OVER-TIME ARRAYS OF RAW SCORES FOR THE THREE SUBJECTS

Subjects	SRT (n=32)	SRT-errors (n=32)	*Anxiety* (n=27)	*Hostility* (n=27)	*Depression* (n=27)
A	0.96 (0.24)	4.2 (3.2)	9.5 (0.9)	12.0 (1.1)	17.8 (1.9)
B	0.87 (0.15)	1.0 (1.0)	4.6 (2.1)	5.7 (1.7)	9.8 (1.9)
C	1.26 (0.37)	2.8 (2.5)	7.5 (1.6)	9.3 (0.8)	8.5 (1.3)
P of F-ratios	<.01 df:2/93	<0.01 df:2/93	<0.01 df:2/78	<0.01 df:2/78	<0.01 df:2/78

Values are means ± SD (in parentheses).

To summarize the data in Table 3, it may be argued that in view of the nonrandom differences between the intraperson arrays, the meaningfulness of the between-person averages commonly calculated at selected points along the time continuum can at least be questioned. A related and perhaps more serious limitation in the interpretation of data of this kind in raw score form has to do with making meaningful comparisons either between measures for a given person or between persons for a given measure at a given phase of the experiment. The crux of the measurement problem underlying the limited use of raw data in this context is the nonequivalence of scores between measures and between persons. Clearly, a common denominator for these raw scores is required before data of this kind can be meaningfully analyzed. One possible common denominator is the standard deviation calculated over each person's score array taken over time.

Thus, it is argued that both of these limitations are eliminated by converting the raw score arrays for each measure and subject to ipsative form by the computational procedure described in the METHODS section. The ipsative score profiles for each of the three subjects for the five measures are presented in Figs. 1 and 2. In addition, the reliabilities of changes at selected points during the experiment are indicated by the probabilities shown in Table 4.

Considering first the profiles as a whole for the dive measures in Figs. 1 and 2, it is possible, since the scores are in comparable units, to make several direct observations.[5] For example, by far the greatest initial effect of reaching saturation depth was an increase in SRT (Fig. 1) amounting to about two SDs for all three divers. These changes were significant at the 1%

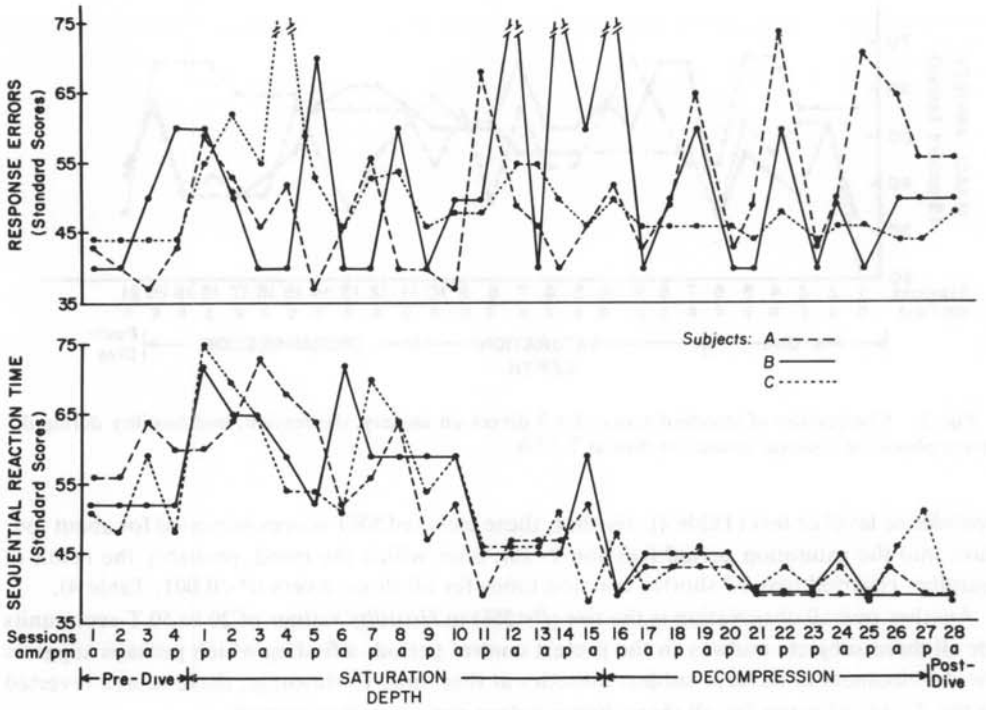

Fig. 1. Comparison of standard scores for 3 divers on sequential reaction time and response errors during different phases of a nitrox saturation dive at 7 ATA.

[5]All of the within-person-over-time profiles in Figs. 1 and 2 have an approximate mean of 50 and an SD of 10 T-score units.

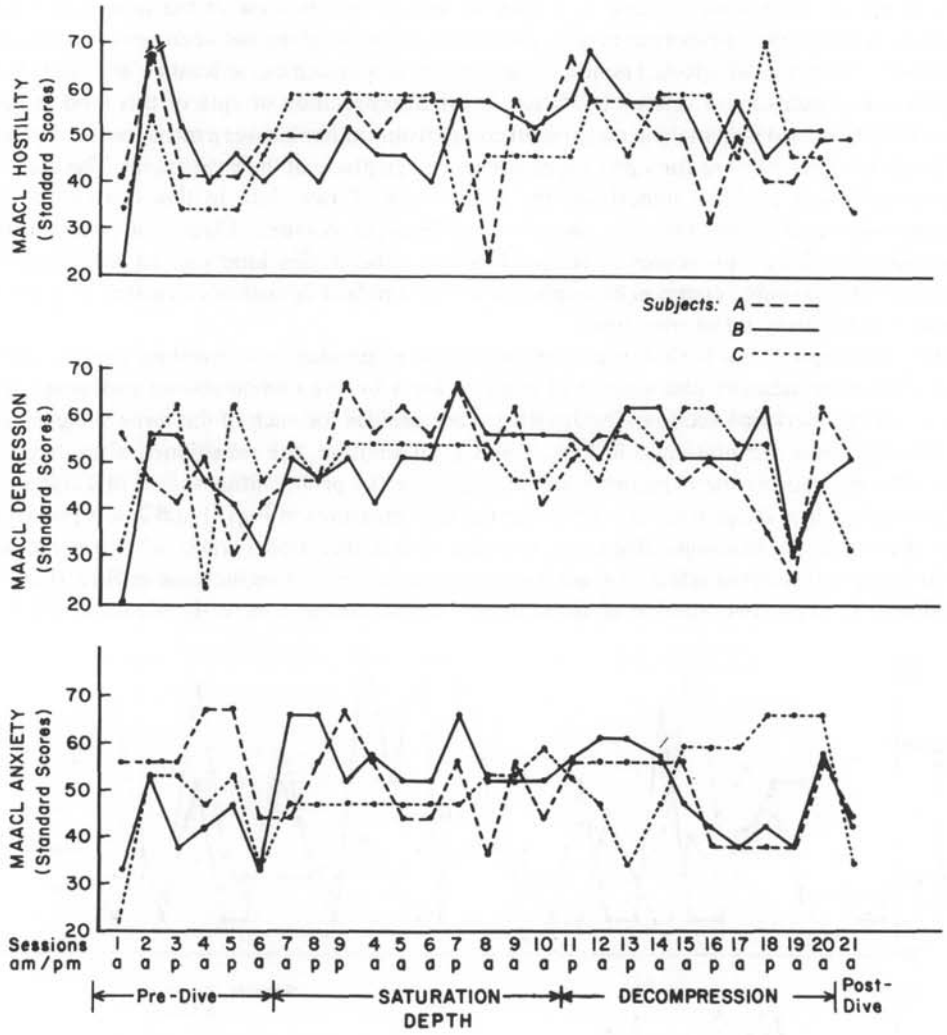

Fig. 2. Comparison of standard scores for 3 divers on anxiety, depression, and hostility during different phases of a nitrox saturation dive at 7 ATA.

confidence level or less (Table 4). Further, these elevated SRT scores persisted for about four days into the saturation period (session 9–10), after which the trend, probably the result of learning, reverted toward shorter reaction times for all three divers ($P<0.001$, Table 4).

Another overall observation is the rise ($P<5\%$) in *Hostility* ratings of 20 to 50 T-score units for all three subjects midway in the pretest control period, a finding which perhaps suggests the development of adverse subject attitudes at that time. Fortunately, these scores reverted to the T=35–45 range for all three divers before pressurization started.

As for SRT-errors (upper polygon in Fig. 1), much more variability over time is seen for all divers than appeared for SRT. However, only divers B and C showed error scores in excess of T=70 on the second day at depth. Parenthetically, these increases in error scores may have been a concomitant of the moderately severe nausea and vomiting observed in Subjects B and C (but not A) starting three hours after reaching saturation depth and ending 41 h later.

TABLE 4
DIRECTION AND RELIABILITY OF IPSATIVE SCORE CHANGES FOR FIVE MEASURES FOR EACH SUBJECT

Subjects	Time Segment	SRT	SRT-errors	*Anxiety*	*Hostility*	*Depression*
A	Predive/Dive*	(+) $P<0.01$‡	(+) $P=0.01$	NS	(−) $P=0.05$	NS
	1st/2nd Half†	(−) $P<0.001$	NS	NS	NS	NS
	Dive/Decomp.	(−) $P<0.001$	NS	NS	NS	NS
B	Predive/Dive	(+) $P<0.001$	NS	(+) $P=0.01$	(−) $P=0.01$	NS
	1st/2nd Half	(−) $P<0.001$	NS	NS	NS	NS
	Dive/Decomp.	(−) $P<0.001$	NS	NS	NS	NS
C	Predive/Dive	(+) $P<0.001$	(+) $P=0.01$	NS	(−) $P=0.05$	NS
	1st/2nd Half	(−) $P<0.001$	(−) $P=0.003$	NS	NS	NS
	Dive/Decomp.	(−) $P<0.001$	NS	NS	NS	NS

*Predive sessions compared with an equal number of trials at outset of pressure phase; plus (+) refers to an increase, minus (−) to a decrease. †First half of experimental sessions compared with last half. ‡Null probability by Median Test (Mood 1950); NS = not significant, $P>5\%$.

At this point in the discussion of the graphs in Figs. 1 and 2, it may be argued that the between-person differences in reactions to the experimental conditions at a given time are meaningful only because the test scores are in comparable units, that is, in ipsative score form. The necessity for unit comparability would seem to be true also for the between-measure comparisons for a given diver at selected points during the experiment. Examination of these important interrelationships using either the raw scores themselves or normative (interindividual) statistics calculated from them would seem to be less meaningful, if indeed possible at all.

The unit comparability of ipsative scores also allows for a meaningful cross-comparison between measures either for a given person or between subjects for a given measure at any of a number of points in time. For example, diver B showed a rise of about 20 T-score units in SRT ($P<0.001$) and a 35-unit increase in *Anxiety* ($P=0.01$) (Fig. 2) the first few hours on the bottom. This covariation pattern was not seen in either of the remaining two subjects. Again, these cross-measure comparisons, either within a given subject or between subjects, would appear to have been of limited value with the plots in raw score form.

Another related advantage of having repeated-measurement data in ipsative rather than raw score form has to do with the ability to pinpoint deviant or extreme data points for a given subject during a given time. Thus, with standard scores plotted against time, as in Figs. 1 and 2, a rough estimate of the likelihood of a given deviation point for any subject can be obtained directly from the plots. For example, the SRT for all three subjects increased by 2 to 2.5 SDs during the first four measurement sessions during the pressurization phase. Further, for divers B and C, the divers who became nauseous, the same magnitude of change in SRT scores occurred during the sixth and seventh sessions after the onset of pressurization (Fig. 1). Depending upon the symmetry of the intrasubject distributions, deviations in this direction and of this magnitude would be expected to occur by chance at less than 2% of the data points. Even more significant ($P=0.1\%$) are increases in response errors for Subjects B and C early in the pressure phase and for B just before and after the onset of decompression (upper graph, Fig. 1). Similar probability estimates can be made for any selected point, both high and low, on the three polygons for the MAACL data in Fig. 2.

Characteristic adaptive profiles (CAPs)

It has been argued throughout this paper that much of the diving literature has been methodologically deficient in the sense that the usual normative statistics have failed to elucidate meaningful information pertaining to a given diver's unique pattern(s) of adaptive response to a variety of stressful environmental conditions. Based upon covariance patterns between repeated measures over time, P-technique of factor analysis applied to data from a single individual (Cattell 1943) will yield, it is proposed, trend or fluctuation factors meaningfully related to these individualistic adaptive processes. Table 5 contains the results of this technique applied separately to the 5 × 5 matrices calculated for each of the three divers.

Looking first at the matrices of Pearson product-moment correlation coefficients in Table 5, it is seen that the number of nonchance (5% confidence level) coefficients varied between subjects, with two, three, and five for the matrices for Subjects C, A, and B, respectively. Simply stated, this finding suggests that the amount of between-measure covariance is lowest for Subject C and highest for B. In the language of the personality psychologist, Subject B's characteristic adaptive pattern (CAP) stands out from those of the other two divers largely by high intercorrelation of his *Depression* score with the two performance measures and with the other two measures of affectivity. While this finding may be only coincidental, it is at least interesting and possibly heuristic that Subject B reported the most acute and prolonged symptoms of nausea the first 41 h of the saturation phase of the experiment.

A logical extension of correlational procedures, factor analysis yields empirically defined dimensions called factors, which are sometimes viewed as hypothetical constructs (Fruchter

TABLE 5
CORRELATION MATRICES AND ROTATED FACTOR LOADINGS FOR THREE DIVER-SUBJECTS

Subject		Correlation Matrices					Rotated Factor Matrices		
A	Measures	I	II	III	IV	V	F_1	F_2	h^2
	I SRT						00	80	64
	II SRT-errors	−28					−08	36	14
	III *Anxiety*	36	−16				56	48	54
	IV *Hostility*	−58	21	34			42	82	85
	V *Depression*	15	−12	31	50		68	18	49
B	Measures	I	II	III	IV	V	F_1	F_2	h^2
	I SRT						70	16	52
	II SRT-errors	−27					68	68	92
	III *Anxiety*	41	25				63	−42	57
	IV *Hostility*	−31	21	27			58	00	34
	V *Depression*	56	−87	42	42		99	01	98
C	Measures	I	II	III	IV	V	F_1	F_2	h^2
	I SRT						−12	64	42
	II SRT-errors	30					−12	60	37
	III *Anxiety*	−17	−19				−14	88	79
	IV *Hostility*	38	34	19			14	68	48
	V *Depression*	14	16	82	31		18	98	99

Decimals are omitted. With $n = 27–32$ measurement sessions, a product-moment correlation coefficient of 0.36 is significant at the 5% level.

1954). These factors are thus based solely upon the variable interactions depicted by the correlation matrices in Table 5. It is noted at the outset that only two factors were extracted from each subject's correlation matrix. This limited number of factors resulted from the application of a formula developed by Thurstone (1947), showing that with only five variables included in the correlation matrix, no more than two factors can be meaningfully delineated.

As the term implies, a communality (h^2 in Table 5) derived for a given test or measure indicates the amount of variance or individual differences common to the other variables included in the matrix. Also, h^2 may be considered a useful estimate of the reliability of the individual tests or measures involved, in this study the 2 SRT and the 3 MAACL scores. Accordingly, the one variable which had the highest reliability and accounted for the most variance for Subjects B and C (but not A) is the MAACL measure of *Depression* (Table 5). Empirical validation studies, for example that of Zuckerman, Lubin, and Robins (1965), tend to support the notion that the MAACL *Depression* score measures state anxiety (mood) as opposed to trait or characterological anxiety (Spielberger 1972). Therefore, the high communalities for the depression scores for Subjects B and C in Table 5 suggest that the mood fluctuations for these two divers were probably reactions to the experimental conditions and quite possibly reflected the effects of the distressing nausea reported by these two men during the first part of the saturation phase.

While there are similarities between the CAPs of Subjects B and C, there are also differences. Thus, rotating the reference axes orthogonally[6] toward the *Depression* scale resulted in the emergence of a general factor for both Subjects B and C, factor 1 (F_1) for B, and F_2 for C in Table 5. But the remaining factor for Diver C, F_1, has no structure, i.e., it has no significant factor loadings or weights. This is not true, however, of the rotated factor matrix for Subject B, which shows a second factor (F_2) marked by positive loadings on SRT-errors and negative loadings on *Anxiety*. In sum, the adaptive styles of both Divers B and C are characterized by strong emotional responses, mainly anxiety and depression, to the imposed stress. Only for Subject B, however, is the affect sufficiently intense to "spill over" and influence performance as measured by the SRT procedure.

What of the CAP of Diver A, who reported no nausea during the early saturation phase? At the outset, it is seen that the most reliable (highest h^2) measure for Diver A is the MAACL scale *Hostility* (Table 5). Thus the rotated solution for Diver A resulted in two factors, namely F_2, the most substantive factor identified by SRT and *Hostility*, and F_1, a unique affective factor delineated by all three MAACL subtests. To summarize the CAP of Diver A, hostile attitudes tended to be sustained at a moderately elevated level (Table 3 and Fig. 2), and to covary with SRT (F_2 in Table 5). Parenthetically, a symptom of this underlying hostility may be inferred from an incident recorded in the diving log. During the first 30 h into the decompression phase the *Hostility* ratings for Diver A rose significantly ($P = 0.05$, Fig. 2). At that time, an altercation of sorts occurred between Subjects A and C. Precipitated in part by a disagreement over the choice of a movie, the incident, while minor, nonetheless suggested that the hostility trait as measured by the MAACL may have been in fact indicative of underlying interpersonal hostility.

Personality correlates of CAPs

Assuming that the factor structures defining the CAPs of the three divers depicted in Table 5 are relatively stable, one might also assume that essentially the same reaction patterns would

[6]The centroid method of factor analysis involves representation of tests as hypothetical vectors in hyperspheric space bounded by reference axes. These perpendicular (orthogonal) axes are rotated geometrically through test clusters to identify the factors (Thurstone 1947).

emerge under a variety of stress-inducing situations. Based upon this assumption, a related question arises. What configuration of personality traits is found in persons who demonstrate each of the two or perhaps three adaptive patterns represented by the factor matrices in Table 5?

It may be recalled that the MMPI profiles of the three experimental subjects were not systematically different (5% level) from the normative data based upon a sample of 30 Navy divers (Table 1). But it may also be recalled that there was a difference (5% level) among the MMPI profiles of the three divers on the 10 diagnostic subtests. However, a closer examination of the between-diver differences in the conventional MMPI patterns indicative of exaggerated emotional or characterological trends (Welsh and Dahlstrom 1956) failed to yield any statistically significant findings—and this despite the fact that the overall diagnostic profiles were different for the three subjects. Nevertheless, Diver A stands out as a different adaptive type than Divers B and C, shown not only by the divergent factor patterns in Table 5 but also by the different systemic reactions to pressure, one specific indicant being the total absence of the severe nausea and vomiting observed in the latter two divers. In the absence of an unequivocal physiological explanation for these differences in symptomatology (insufficient oxygen, for example), etiological factors in the realm of psychology or psychophysiology remain a possibility. Based largely upon the high communality (h^2) for *Hostility* (Table 5), Diver A apparently copes with stress by projecting his affect outward upon the environment. Conversely, and again based upon an elevated h^2, but this time for *Depression*, both Divers B and C characteristically direct their affect inwards, the result being more intense somatic response, one example of which may have been the nausea reported by these two divers.

There are at least four bodies of psychophysiological data which have been interpreted as supportive of similar dichotomous response patterns, namely affect-in/affect-out types (Ax 1953; Schachter 1957; Funkenstein, King, and Drolette 1957; Weybrew 1962). Insofar as is known, however, the use of P-technique of factor analysis to identify these hypothetical types has not appeared in the literature to date.[7]

DISCUSSION

The central argument of this paper has been that one of the most cogent data sources lies in the intra- rather than interindividual subject variation over time. This is particularly true if the experiment involves a self-control design and a small subject sample and if the major objective is to assess the quality of a specific individual's adaptation to a set of environmental circumstances. In standard score form, ipsative units allow for meaningful comparisons between measures for a given person as well as between-person scores (same measure) at any point in the experiment.

But the five dependent variables in this study, sequential reaction time, response errors, and the three affectivity self-ratings, were quite restricted in terms of content and, as a result, the substantive findings of the study were somewhat limited. However, the methodological possibilities for use of ipsative measures in this context remain forceful. Suppose, for example, measures as diverse as indices of adrenogenic hormone levels, serum sodium or potassium levels, respiratory tidal volume, selected indices of EKG and EEG dysrhythmia, electrodermal conductance, self- and peer ratings, and a number of other measures had been collected from the three subjects sequentially 25 to 30 times during the present experiment. In ipsative

[7]There is no presumption that this typology is other than hypothetical. The intent is rather to demonstrate the methodological possibilities of P-technique of factor analysis in this context.

score form, individual profiles as well as the P-technique factor structure delineated for each subject would conceivably have shed light on such diverse but important questions as the biochemical correlates of mood, interrelationships of cardiovascular and respiratory dynamics, and the relation of peripheral autonomic indices of emotionality to peer choices—to name some possibilities.

The nature of the descriptive findings related to the effects of the experimental conditions that can be obtained from a direct examination of ipsative scores plotted against time (Figs. 1 and 2) attests to the essential simplicity of this methodology. For example, it was seen (Figs. 1 and 2, and Table 4), that the SRT for all three divers increased upon reaching saturation depth but decreased thereafter. Also, hostility decreased at the outset of the dive for all subjects, but anxiety increased only for Subject B during the same interim. Also, hostility as measured by the MAACL first increased for all subjects during the base-line phase but reverted to below average (T-score = 50) level at the onset of the dive (Fig. 2). Anxiety increased only for Subject B during the same interim, and so on. Thus, with raw scores in ipsative form it is possible not only to pinpoint in time any number of extreme fluctuations of a specific measure, but also to estimate the reliability of that change for a given subject directly from the data plots.

With unit comparability, ipsative scores also serve an hypothesis-generating function when intercorrelated over time for a given person. For example, the factor matrices derived by P-technique of factor analysis for each of the three subjects suggested different "characteristic adaptive patterns" (CAPs) which, in part, accounted for individual differences in the quality of the divers' adaptation to the experimental conditions. The types of hypothetical questions emanating from this methodological approach have to do with prediction of individual differences in the ability of persons with different CAPs to adapt to a variety of environmental conditions. A specific example from this experiment might have been to investigate the differential adaptive ability of Diver A, whose CAP suggested an "affect-out" style, compared to that of B and C (affect-in types) in terms of the quality of their adaptation to prolonged sleep deprivation, sustained isolation or confinement, or other stresses. Differences in the performance degradation of persons with different CAPs exposed to a variety of stressors would be yet another possible research focus.

Except in a negative sense, little light was shed on the important problem of identifying meaningful correlates of different CAPs derived from divers exposed to the stresses inherent in this study. That is, none of the trait patterns composed of the 20 MMPI subtests (Table 1) clearly discriminated among the three adaptive styles delineated by the P-technique factor analyses. These negative findings may have resulted from the fact that the MMPI, as an objective personality test, measures traits, the structural and functional constancies of personality. Instead, the need is for measures of the dynamic (in place of static) characteristics of personality, for example, measures of autonomic nervous system resiliency in stress situations (Weybrew 1965) and mood fluctuations occurring under a variety of environmental conditions (Nowlis and Nowlis 1956). These measures should correlate with the trend or fluctuation factors delineated by the P-technique procedure demonstrated in this study.

There is at least one, and possibly serious, limitation resulting from the manner in which the ipsative transformations were made in this study. That is, the standard scores for each subject were calculated from means and SDs based upon the intraperson arrays taken over the pre-experimental, experimental, and postexperimental distributions combined. This was necessary because it was logistically impossible in this experiment to obtain more than four to six base-line data points, too few to provide a data base for calculating these statistics meaningfully. Ipsative scores calculated from means and SDs obtained from a base line of 20–30 data

points would be ideal and might avoid some unnecessary confounding between the experimental and control conditions. However, the counter-argument to this ideal situation is that the concept of CAP is based upon an inference from the reaction patterns characterizing a person's adaptive "style" day-in-and-day-out, during stressful as well as nonstressful periods. The raw data converted to ipsative form allow one to make deductions about the magnitude and duration of the reactions to the introduction of environmental stressors relative to a person's CAP—this is the central methodological point of this paper.

The ipsative score concept is particularly appropriate for measurement of affective processes in humans exposed to stresses similar to those found in diving experimentation. Psychologists involved in these kinds of investigations might be well advised to reconsider the statement made by the late Gordon Allport some 35 years ago (Allport 1942) ". . . psychological causation is always *personal and never actuarial* . . . ." (italicized in original, p. 156).

The assertions or opinions which appear in this paper are those of the author and are not to be construed as the official views of the U.S. Navy Medical Department.—*Manuscript received for publication November 1977; revision received April 1978.*

Weybrew, B. B. 1978. Etude méthodologique de l'adaptation chez le plongeur au cours d'une plongée à saturation à 7 ATA en mélange azote-oxygène. Undersea Biomed. Res. 5(3):259–273.— Notre but a été de démontrer les avantages de la transformation des résultats en formes ipsatives (écart calculé autour du moyen pour chaque sujet), surtout pour les études sur la plongée où il s'agit d'échantillons très restreints et d'un protocole contrôlé par le sujet. On a mesuré le delai de réaction, l'exactitude des réponses, l'anxiété, l'hostilité, et la dépression chez 3 plongeurs de la Marine americaine au cours d'une plongée fictive à saturation en azote-oxygène à 7 ATA (temps au fond, 7 jours). Nous avons pensé, et démontré jusqu'à un certain dégré, que la statistique normative (pour plusieurs individus) obscurcit les différences entre les sujets, lesquelles sont plus clairement exprimées quand les résultats individuels sont présentés en forme ipsative. De plus, cette transformation des résultats nous permet de faire des comparaisons significatives entre sujets (du même paramètre) et entre paramètres (chez un seul sujet). Il serait impossible de mettre an évidence ces relations si les résultats restaient en forme normative. L'application de technique P de l'analyse factorielle aux résultats pour chaque sujet suggère que deux sujets avaient réagi au stress de la pression en dirigeant vers l'intérieur l'affect, tandis que le troisième l'avait dirigé vers l'extérieur. Aucun des 16 échelles du MMPI n'a cependant distingué entre les trois genres d'adaptation.

méthodologie des déterminations
performance du plongeur
hyperbare
facteurs psychologiques
adaptation
analyse factorielle
valeurs en forme ipsative

REFERENCES

Adolfson, J. 1965. Deterioration of mental and motor functions in hyperbaric air. Scand. J. Psychol. 6: 26–32.
Allport, G. W. 1942. The use of personal documents in psychological science. S.S.R.C. Bulletin No. 49.
Allport, G. W. 1961. Pattern and growth in personality, Holt, New York.
Ax, A. F. 1953. The physiological differentiation between fear and anger in humans. Psychosom. Med. 15: 433–442.
Barnard, E. E. P., H. V. Hempleman, and C. Trotter. 1962. Mixture breathing and nitrogen narcosis. R.N. Physiological Laboratory Report, Alverstoke, Hants, U.K.
Cattell, R. B. 1943. The description of personality: I. Foundations of trait measurement. Psychol. Rev. 50: 559–92.

Cattell, R. B. 1944. Psychological measurement: normative, ipsative, interactive. Psychol. Rev. 51: 292–303.
Cattell, R. B. 1952. Factor analysis: an introduction and manual for the psychologist and social scientist. Harper and Brothers, N.Y.
Duckworth, J., and E. Duckworth. 1975. MMPI interpretation manual for counselors and clinicians. Accelerated Development Inc., Muncie, Ind.
Friedman, M. 1937. The use of ranks to avoid the assumption of normality. J. Am. Stat. Assoc. 32: 675–701.
Fruchter, B. 1954. Introduction to factor analysis. Van Nostrand, N.Y.
Funkenstein, D. H., S. H. King, and M. E. Drolette. 1957. Mastery of stress. Harvard University Press, Cambridge, Mass.
Kiessling, R. J., and C. H. Maag. 1960. Performance impairment as a function of nitrogen narcosis. U.S. Navy Exp. Diving Unit Report No. 3.
McCall, W. A. 1922. How to measure in education. Macmillan, London, U.K.
Meehl, P. E. 1954. Clinical versus statistical prediction: a theoretical analysis and a review of the evidence. Univ. of Minnesota Press, Minn.
Mood, A. M. 1950. Introduction to the theory of statistics. McGraw-Hill, N.Y., p. 394.
Nowlis, V., and H. H. Nowlis. 1956. The description and analysis of mood. Ann. N.Y. Acad. Sci. 65: 345–355.
O'Reilly, J. P. 1974. Performance decrements under hyperbaric He–O_2. Undersea Biomed. Res. 1(4): 353–361.
Radloff, R., and R. Helmreich. 1968. Groups under stress: psychological research in SEALAB II. Appleton-Century-Crofts, New York, N.Y.
Schachter, S. 1957. Pain, fear, and anger in hypertensives and normotensives: a psychophysiologic study. Psychosom. Med. 19: 17–29.
Seki, K., and M. Hugon. 1976. Critical flicker frequency (CFF) and subjective fatigue during an oxyhelium saturation dive at 62 ATA. Undersea Biomed. Res. 3: 235–247.
Shilling, C. W., and W. W. Willgrube. 1937. Quantitative study of mental and neuromuscular reactions as influenced by increased air pressure. USN Med. Bull. 35: 373–380.
Spielberger, C. D. 1972. Anxiety as an emotional state. *In* C. D. Spielberger, Ed. Anxiety: current trends in theory and research. Academic Press, N.Y.
Thurstone, L. L. 1947. Multiple factor analysis; a development and expansion of the vectors of mind. University of Chicago Press, Chicago.
Welsh, G. S., and W. C. Dahlstrom. 1956. Basic readings on the MMPI in psychology and medicine. University of Minnesota Press, Minneapolis.
Weybrew, B. B. 1955. Predicting adjustment to long periods of confinement: a study in factor analytic methodology. Doctoral dissertation. Univ. of Colorado, Boulder.
Weybrew, B. B. 1962. Behavioral energetics: I. A factor analytical study of individual differences in modes of energy discharge resulting from experimentally-induced frustration. Nav. Sub. Med. Res. Lab. Rpt. No. 378.
Weybrew, B. B. 1965. Selection of men for hazardous duty from indices of autonomic nervous system reactivity. Nav. Sub. Res. Lab. Memo Rpt. No. 65-1.
Weybrew, B. B. 1974. Shallow habitat air dive (SHAD-I): II. Psychological screening of divers as subjects for long duration saturation experimentation. Nav. Sub. Res. Lab. Rpt. No. 776.
Weybrew, B. B., and J. W. Parker. 1968. Performance effects of increased ambient pressure. I. Helium-oxygen saturation and excursion dive to a simulated depth of 900 feet. Nav. Sub. Res. Lab. Rpt. No. 556.
Weybrew, B. B., and E. M. Noddin. 1971. Psychological effects of prolonged exposure to sonar signals at an elevated intensity: II. Twenty-four days' exposure to signals at 85 dB. Nav. Sub. Res. Lab. Rpt. No. 691.
Zuckerman, M., B. Lubin, and S. Robins. 1965. Validation of the Multiple Affect Adjective Checklist in clinical situations. J. Consult. Psychol. 29: 594–605.