THOUSAND AVIATOR STUDY: NONVESTIBULAR CONTRIBUTIONS TO POSTURAL EQUILIBRIUM FUNCTIONS*

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SUMMARY PAGE

THE PROBLEM

To delineate other than vestibular sources of variance in postural equilibrium functioning, as defined by a new quantitative ataxia test battery, in a large group of middle-aged men, and to lay the groundwork for a longitudinal study of changes in such functioning in relation to chronological age and pathological processes.

FINDINGS

Twenty-eight of thirty-eight selected nonvestibular measures had significant relationships ($P < .05$) with one or another of three postural performance criteria. Implications of these and other findings for future research with the population studied as well as for vestibular and gerontological research are indicated.

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INTRODUCTION

The history of testing the vestibular "sense of balance" (postural equilibrium) by means of one or another clinical or laboratory procedure as exploited within the field of aviation medicine has been almost exclusively concerned traditionally with the selection or grounding of aviators. A broad, modified extension of this tradition evolved from challenging, vestibular-generated problems in the field of space medicine. In response to this challenge a new quantitative ataxia test battery was developed (15). Thus far several indications of its applicability in the field of space medicine have been demonstrated (7,8,13,15,16,19,27,28,34,48).

The present undertaking is an outgrowth of this postural test development. It is longitudinally concerned with the postural test capabilities of present and former Naval and Marine Corps aviators. The study has the general purpose of assessing the postural equilibrium test (PET) functioning of a group of middle-aged men so as to lay the groundwork for studying changes in this functioning as influenced by aging in juxtaposition with other influences complicated and uncomplicated by pathological processes.

Specific purposes of this preliminary inquiry were to: 1) delineate other than vestibular sources of PET variance; 2) compare predictability from single nonvestibular correlates (Pearson r's) with predictability from combined nonvestibular correlates of the criteria (multiple R's); 3) attempt separation of peripheral from more central influences which may be diagnostic or prognostic of postural disequilibrium, and from the postural measures determine postdictability of nonvestibular measures; 4) obtain normative performance standards on a large group of homogeneous middle-aged males whose medical status is well known; and 5) explore the utility of the new PET battery as a methodological tool for gerontological research.

PROCEDURE

SUBJECTS

Five hundred of a larger number (675) of medically re-examined survivors among a original group of 1056 men composed primarily of aviation cadets and including flight instructors in the Navy Flight Program in 1940-1941 (26,37) served as subjects during their most recent (1963-1965) evaluation (24,29,35-37). The surviving members of this longitudinal cardiovascular study, termed the "Thousand Aviator Study," had been previously re-evaluated in 1951 (17,39) and again in 1957 (20-22, 38).

The age range was 42-57 years, with 98.4 per cent in the range of 43-53 years and 95 per cent in the range of 43-50 years.

APPARATUS AND METHOD

Nonvestibular Measures

From a pool of over 100 major nonvestibular measures available, 38 were selected as being meaningful, prospective correlates of postural equilibrium functioning. These included age, fifteen anthropometric (body size and shape) measures, nine cardiovascular, eight laboratory, and five personal-social measures (Table I). Complete descriptions of these and all other measures constituting the Thousand Aviator Test Battery appear elsewhere (36,37).

Postural Equilibrium Test Battery

The new postural test procedures (15) have the combined advantages of brevity, objectivity, discriminative power over a wide age and ability range, multidimensionality, and normative standardization not apparent in traditional ataxia testing nor in more elaborate but cumbersome laboratory-experimental testing.

Following a combination of written and verbal instructions and pertinent demonstrations by the examiner, all subjects undertook the three distinct tests comprising the battery in the following sequence: 1) walking with eyes open (Walk H/T Test) on a $\frac{3}{4}$-inch by 8-foot rail, scored as number of steps (maximum of five steps per trial); 2) standing with eyes open (Stand E/O Test) on the $\frac{3}{4}$-inch-wide rail, scored to the nearest second (maximum of 60 seconds per trial); and 3) standing with eyes closed (Stand E/C Test) on a $2\frac{1}{4}$ by 30-inch rail, also scored to the nearest second with a maximum of 60 seconds per trial. The best three of five trials constituted the scoring of each test. Maximum scores obtainable were 15 (steps) on the Walk H/T, and 180 (seconds) on the Stand E/O and Stand E/C tests.

The body position required of all subjects was: a) body erect or nearly erect, b) arms folded against chest, and c) feet, shoes on, tandemly aligned heel-to-toe.

RESULTS

Zero-Order Correlations

Nineteen (50 per cent) of the nonvestibular measures had significant relationships ($P < .05$) with one or more of the three performance criteria (Table I). Ten such measures correlated significantly with all three postural tests. In descending ranked order of magnitude (of the average r's) these were: abdominal circumference, endomorphy, weight, bi-iliac diameter, lean body mass, age, cigarette years, heart rate immediately after exercise, body fat, and diastolic blood pressure supine basal. Three such measures correlated significantly with one or another pair of PET performances, these being weight standing, relative weight, and cigarette amount. The remaining six significant correlates were confined to single postural tests. These were: height sitting, mesomorphy, systolic blood pressure supine basal, heart rate, fundus, and alcohol amount.

Table 1

Correlations Between Thirty-Eight Selected Nonvestibular Measures from the "Thousand Aviator" Test Battery and the Postural Equilibrium Test Battery (N = 500)

Nonvestibular Variables	Walk H/T r*	Stand E/O r	Stand E/C r
Abdominal Circumference	-169	-174	-239
Calf Circumference	002	-020	-058
Bi-iliac Diameter	-108	-159	-171
Ankle Diameter	050	000	-055
Ponderal Index	029	024	021
Weight	-093	-150	-231
Relative Weight	-073	-099	-122
Body Fat	-110	-140	-122
Lean Body Mass	-091	-139	-204
Endomorphy	-196	-168	-189
Mesomorphy	146	063	036
Ectomorphy	-034	-001	-020
Height Standing	-060	-137	-236
Height Sitting	020	-068	-164
Dynamometer	013	036	-038
Systolic BP Supine Basal	-087	-119	-058
Diastolic BP Supine Basal	-125	-138	-097
Pulse Pressure Sitting	-054	-076	-028
Pulse Pressure Supine	-007	-042	010
Heart Rate	-113	-063	-007
Heart Rate Immediately after Exercise	-152	-128	-094
Arcus Senilis	009	048	080
Fundus	044	-080	-101
Coronary Heart Disease	039	-027	-042
Protein Bound Iodine	-027	000	000
Glucose 2-hour Post-Prandial	-014	-081	012
Cholesterol	045	-051	036
Calculated Triglycerides	-025	-035	015
Log Atherogenic Index	-005	-034	037
Uric Acid	-046	-039	-046
ST Depression, after Exercise	-065	-017	-035
EEG Interpretation	-011	055	043
Cigarette Amount	-094	-048	-106
Cigarette Years	-095	-093	-136
Alcohol Amount	-028	-050	-088
Military Status	-034	-019	-017
Flying Years	040	069	025
Age	-090	-132	-208
Postural Variables			
Walk H/T	---	294	257
Stand E/O	294	---	474
Stand E/C	257	474	---

*Absolute Value of Correlation:	.074	.088	.092	.104	.115	.138	.148
Two-Tailed Significance Level:	.10	.05	.04	.02	.01	.002	.001

Noteworthy was the finding that five anthropometric measures had greater significance than age, and that five cardiovascular measures and three personal-social measures (amount and duration of cigarette smoking, and amount of alcohol consumed) were nearly as significant correlates of postural performances as age. Also of interest was the finding that none of the eight laboratory measures proved to be significant correlates of the PET functioning of the middle-aged men sampled.

In terms of the frequency of the significant nonvestibular correlates, the Walk H/T and Stand E/O performances were virtually nondifferentiated from Stand E/C performance. Similarly, Walk H/T performance was virtually nondifferentiated from the two standing test performances. This result is somewhat surprising in view of the appreciable distinction of each postural test shown by their low to moderate intercorrelations (Table I). However, in terms of the greatest magnitude of the nonvestibular correlates, there was a slight tendency in favor of Stand E/C performance.

Of special interest was the finding that one of the postural measures, Stand E/C, shared with one nonvestibular measure, arcus senilis, the distinction of having the most statistically significant relationship with age. Arcus senilis is frequently present after age 50.

Even within a highly restricted age range, an increasing negative influence of age upon PET battery performances was evidenced (Table II). Walk H/T discontinuities were apparent at age 43, and again at age 52. Stand E/O discontinuities appeared at age 45 and at age 51, whereas Stand E/C discontinuities, reflecting the greater sensitivity of this test to age (Table I), were shown at ages 43, 44, and 50. The greater variability at all ages of Stand E/O performance over Walk H/T performance and of Stand E/C performance over Stand E/O performance reflects the imperfectly equated performance difficulty levels inherent with the apparatus used, the greater difficulty of visual standing over visual walking, and the still greater difficulty of nonvisual standing over visual standing. Variability thus appears related to the magnitude of the underlying vestibular contributions to these hierarchically differentiated performance tasks.

Multiple Regression Analysis

Multiple correlations (47) were obtained predicting each of the three performance criteria from the pool of thirty-eight selected independent variables (Table III).

With the Walk H/T criterion, seventeen correlates explained 13.25 per cent of the variance ($\underline{R}$ of .364). Nearly half of this variance was explained by only three variables--endomorphy, ectomorphy, and heart rate immediately after exercise. The additional predictors encompassed all of our classifications of measures, although these were predominantly anthropometric and cardiovascular.

Table II

Postural Equilibrium Test Battery Scores by Age in 500 "Thousand Aviators"

			Postural Equilibrium Test Battery					
		Percent of Total	Walk H/T Test		Stand E/O Test		Stand E/C Test	
Age	N	N	Mean	S.D.	Mean	S.D.	Mean	S.D.
42	4	0.8	12.3	2.95	21.8	7.36	121.0	53.17
43	23	4.6	10.7	2.51	25.0	21.83	78.6	63.47
44	55	11.0	10.8	2.74	22.2	18.20	60.6	45.09
45	73	14.6	10.8	2.81	18.4	12.41	50.0	39.45
46	95	19.0	9.8	3.31	19.1	14.40	54.9	49.30
47	80	16.0	10.2	3.17	18.7	10.72	51.2	47.92
48	63	12.6	10.9	3.14	17.6	8.00	43.3	31.35
49	64	12.8	10.0	3.35	17.6	10.43	45.9	42.64
50	22	4.4	10.1	2.61	17.7	12.79	39.2	42.60
51	10	2.0	9.8	3.87	12.5	3.75	26.4	17.44
52	2	0.4	7.5	6.50	23.0	10.00	24.0	1.00
53	5	1.0	8.6	2.24	10.6	1.74	19.8	6.11
54	1	0.2	12.0	---	22.0	---	24.0	---
55	2	0.4	5.5	2.50	11.0	1.00	13.5	0.50
56	0	---	---	---	---	---	---	---
57	1	0.2	5.0	---	27.0	---	23.0	---

Table III

Results of Wherry-Doolittle Regression Analysis for Prediction of PET Battery Performances From Nonvestibular Measures

Nonvestibular Correlates	Cumulative Multiple R	Z Score Weights
Walk H T Test Criterion		
Endomorphy	.196	-.089
Ectomorphy	.231	-.024
Heart Rate Immediately After Exercise	.255	-.090
Abdominal Circumference	.275	-.169
Chronological Age	.288	-.084
Height Sitting	.298	.143
ST Depression After Exercise	.306	-.101
Coronary Heart Disease	.315	.064
Cholesterol	.322	.084
Cigarette Years	.328	-.080
Diastolic BP Supine Basal	.334	-.089
Fundus	.343	.077
Ponderal Index	.349	-.139
Military Status	.353	-.057
Lean Body Mass	.357	-.139
Ankle Diameter	.361	.075
Mesomorphy	.364	.083
Stand E/O Test Criterion		
Abdominal Circumference	.174	-.039
Chronological Age	.211	-.121
Ponderal Index	.244	-.394
Heart Rate Immediately After Exercise	.267	-.129
Endomorphy	.282	-.106
Diastolic BP Supine Basal	.296	-.094
Relative Weight	.303	-.334
Glucose 2-hour Post-Prand.	.310	-.077
Cigarette Years	.317	-.067
EEG Interpretation	.321	.063
Heart Rate	.326	.093
Dynamometer	.331	.061
Calf Circumference	.334	.065
Bi-iliac Diameter	.337	-.059
Stand E/C Test Criterion		
Abdominal Circumference	.239	-.188
Chronological Age	.305	-.201
Height Standing	.362	-.252
Cigarette Years	.381	-.113
Endomorphy	.394	-.160
Body Fat	.409	.167
Ankle Diameter	.415	.083
Log Atherogenic Index	.420	.070
Fundus	.423	-.045
Heart Rate Immediately After Exercise	.426	-.133
Heart Rate	.433	.119
Alcohol Amount	.436	-.049

With the Stand E/O criterion, fourteen variables explained 11.36 per cent of the variance (R of .337). Over one-half (52 per cent) of explained variance was accounted for by only three measures--abdominal circumference, age, and ponderal index. Eight of the additional predictors represented anthropometric and cardiovascular measures.

The largest R, .436, was found with the Stand E/C criterion. Eleven measures explained 19 per cent of the variance. One-half (49 per cent) of this variance was explained by only two measures --abdominal circumference and age. Seven of nine additional predictors represented anthropometric and cardiovascular measures.

The five top-ranking multiple R predictors, i.e., measures selected as correlates of all three performance criteria, were, in descending order of magnitude: abdominal circumference, age, endomorphy, heart rate immediately after exercise, and cigarette years.

Notably, five laboratory measures were included as multiple R predictors: ST depression after exercise and cholesterol (of Walk H/T performance), glucose two-hour postprandial and EEG interpretation (of Stand E/O performance), and log atherogenic index (of Stand E/C performance).

DISCUSSION

Generally, the correlations obtained are underestimates of the true relationships, due primarily to the nonlinear distributions of the measures (24).

The best single nonvestibular correlate of postural test performance (r of -.239 between abdominal circumference and Stand E/C on a $2\frac{1}{4}$ -inch-wide rail) explains only 5.7 per cent of criterion variance. While this implies some practical significance, this relationship lacks utility in the individual case.* It was shown, however, that combinations of nonvestibular measures in multiple regression have considerable utility for postdictive explanation of PET functioning. Moreover, in conjunction with the longitudinal aspects of the Thousand Aviator Study, these nonvestibular measures show promise for prediction of future PET performances and of changes in these performances.

The finding that body size and shape measures, as peripheral influences, generally had greater influence than other measures upon postural performances dramatizes the interference of biomechanical handicaps, such as the displacement of the center of gravity in overweight individuals, in maintaining postural equilibrium. The additive interaction of certain cardiovascular measures with advancing age coupled with a long history of cigarette smoking (25 years or more) negatively exaggerates these handicapping influences (24,35,43).

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*However, by virtue of the large N, the practical significance of correlation coefficients at levels below .250 in an earlier evaluation of blood pressures in this group has been cogently demonstrated (21,38).

It would be most interesting to replicate the present study in a large group of young, including student, aviators in the age range of 18 to 27 wherein certain combined negative anthropometric, cardiovascular, and personal-social influences on PET functioning observed in the present group of older counterparts might have different hierarchical importance in relation to a comparable range of age and other laboratory measures.

More inclusive attempts than the present to validate specific test-defined postural equilibrium functioning-dysfunctioning in nonvestibular terms would entail comprehensive otoneurological and vestibular psychophysiological evaluations and careful accountability of physical activity levels documented in terms of the expenditure of bodily resources available (1,2,4,15,23,25,30,32,33,40,43,44,46).

Insofar as the postural equilibrium test battery performances may be considered to represent neuropsychological or behavioral indices, present results in terms of the negative influence of age and of cardiovascular variables are commensurate with the observations of other investigators (3-6, 41,42,44-46).

To the extent that the selected nonvestibular measures may be considered as diagnostic or prognostic indicators of "physiological aging," or functional age (4-6,30 , 31, 40,44-46), the present approach to the study of postural equilibrium holds promise of serving as a useful "physiological age index" with applicability in gerontological research.

Preliminary findings in middle-aged males indicate that individual differences in PET functioning are still largely attributable to vestibular psychophysiological test and behavioral measures, to quantifiable experimentally induced vestibular effects in vestibular normal individuals, and to clinical vestibular (otoneurological) signs rather than to single or analytically combined nonvestibular measures. In normals, the vestibular correlates found to date include: 1) bizarre vestibular stimulation effects of gravitoinertial force environments (12,13,15,16,19,34); 2) susceptibility to motion sickness (15); 3)threshold caloric response levels (14,15); 4) proficiency of trampoline performance (15); 5) experimentally induced positional alcohol nystagmus and blood alcohol levels (9,10); and 6) related clinical-type ataxia test responses (9-12,14,15,33). Clinically, individuals with varying amounts of vestibular defects have readily been differentiated from normals by their pronounced postural disequilibrium or ataxia (10-15,18,33).

Though it is valuable to investigate the hierarchical importance of interacting vestibular and nonvestibular influences on PET performances, the ultimate value of this approach lies in the diagnostic and prognostic information it provides about a complicated vestibular system interacting with a variety of observable and nonobservable body factors and processes.

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13. ABSTRACT

In a preliminary study of nonvestibular sources of variance in the postural equilibrium functioning of a group of middle-aged males, twenty-eight of thirty-eight selected measures have been shown to be related to one or another of three postural criteria. Outstanding among these, in descending order of magnitude, are: abdominal circumference, age, endomorphy, heart rate immediately after exercise, and duration of cigarette smoking. These and other findings are discussed in terms of their implications for vestibular and gerontological research.

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