PALMAR SWEATING AND PROBLEM SOLVING

by Joseph D. Kovatch

Thesis presented to the School of Psychology and Education of the University of Ottawa as partial fulfillment of the requirements for the degree of Doctor of Philosophy

Ottawa, Ontario, 1963

ACKNOWLEDGMENTS

This thesis was prepared under the supervision of William F. Barry, Ph.D., of the School of Psychology and Education of the University of Ottawa, and appreciation is herein expressed for his assistance and encouragement.

The writer's gratitude is also expressed to Mr. Thomas Mousseau for his technical and advisory assistance on the construction and evaluation of the apparatus.

The writer is also indebted to Dr. Albert C. Custance for his encouragement and assistance.

CURRICULUM STUDIORUM

Joseph D. Kovatch was born March 16, 1933, in Elizabeth, New Jersey. He received the Bachelor of Science degree in Economics from Villanova University, Villanova, Pennsylvania, in 1956. He received the Master of Arts degree in Psychology, from the University of Ottawa, Ottawa, Ontario, in 1961. The title of his thesis was Intra Cranial Pathology and the Negative After-Image Threshold.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURE

INTRODUCTION

Human palmar sweating and its occurrence during mental activities has been commonly observed. The question of differential mental activity and changes in palmar sweating has also been pondered and attempts have been made to study this possible relationship.

Controlled experimentation on this question has had little success and the lack of conclusive evidence can be traced to the usage of the galvanic skin resistance technique as the measure of palmar sweating rates. This technique suffers from being too sensitive and simultaneously responsive to more than one autonomic nervous system activity.

Direct measurements of sweating have been attempted but the efforts have been unsuccessful due to evaporation loss and non-continuous recordings throughout the experimental procedures.

Recently, a new apparatus was developed that determined the sweat rate indirectly by measuring the volume of air necessary to maintain a constant relative humidity within a sensing element enclosure covering a given portion of skin surface during the testing procedures. Thus, air volume was used as an indirect measure of sweating that occurred.

A prototype of this instrument was constructed and employed in this present study to test the theory that palmar sweating rates increase as mental activity increases. Palmar sweating was determined in the manner previously described and differential mental activity was considered to have been achieved as a function of solving problems of increasing difficulty.

This dissertation is divided into three chapters. Chapter I presents a brief review of the anatomical and physiological studies of human sweating followed by the psychophysiological studies and instruments employed. After this review, a summary and the hypothesis to be tested in this study is presented. Chapter II describes the experimental design, which includes the sample population employed, the physical conditions of the experiment, the psychological tool, and the techniques for data evaluation. Chapter III presents the results of the investigation, a discussion of them and some suggestions for further research.

CHAPTER I

REVIEW OF THE LITERATURE

This chapter presents a review of the experimental studies of human sweating and its relationship to activities at the cortical level. The sections are divided in the following manner: Section 1 presents a brief review of the anatomy and physiology of sweat glands. Section 2 describes the psychophysiological studies and discusses some of the techniques employed in the investigations. Section 3 is a short summary after which the hypothesis to be tested in this study is stated.

1. Anatomy and Physiology of Sweat Glands.

Studies conducted by Kuno[1] and his associates on the distribution of sweat glands in the human body revealed that the total number of sweat glands varied from two to five millions[2] and they were most dense in the palmar area[3], especially on the finger tips[4].

---

1 Yas Kuno, Human Perspiration, Thomas, Springfield, 1956, xvi-416 pp.

2 Ibid., p. 66.

3 Ibid., p. 68.

4 Ibid., p. 145.

Kuno classified the human sweat glands into three groups[5]: 1) the axillary apocrine glands; 2) the eccrine glands of the general body surface; and 3) the eccrine glands on the palms and soles. He labeled the eccrine glands, "...the thermal and the mental or emotional..."[6], because of the type of stimuli that evoked the sweating. He stated:

> Thermal sweating appears over the whole body surface, with the exception of the palms and soles. Mental or emotional sweating usually appears restrictedly on the palms, soles and axillae...[7].

These findings led to studies of the physiological innervation of the two areas.

Rothman[8] summarized many years of research on this question and stated that, "The innervation of eccrine glands although anatomically sympathetic, is physiologically and pharmacologically, "parasympathetic", ..."[9], and, "In contrast to all other postganglionic sympathetic fibers, which are adrenergic, sweat fibers liberate acetylcholine at their endings on stimulation..."[10]. Unfortunately, this exception

---

5 Ibid., p. 54.

6 Ibid., p. 98.

7 Idem.

8 Stephen Rothman, Physiology and Biochemistry of the Skin, University of Chicago Press, 1954, xii-741 pp.

9 Ibid., p. 162.

10 Ibid., p. 163.

to the general rule of autonomic innervation did not solve the problem of the functional differences between the "thermal" and "mental" sweating. Investigators then searched for the explanation in the central nervous system control.

Kuno[11] stated that a center in the cerebral cortex rostral to the center for thermal sweating controlled the palmar and solar sweating. The existence of two centers in the cortex could account for the independence of the two types of sweating. The view of separate centers appeared to be acceptable to other researchers[12,13,14].

This brief discussion of the anatomy and physiology of sweat glands indicated that palmar sweating in humans is complex but seems to be linked in some manner to activity at the cortical level. This aspect is reviewed in the next section.

---

11 Yas Kuno, Op. Cit., p. 93-94.

12 Harry J. Hurley Jr. and Herbert Mescon, "Localization of Specific Cholinesterase About Eccrine Sweat Glands of Human Volar Skin", in Proceedings of the Society for Experimental Biology and Medicine, Vol. 92, 1956, p. 103-106.

13 Harry J. Hurley Jr. and Walter B. Shelley, "Acquired Emotional Sweating in Transplants", in A.M.A. Archives of Dermatology, Vol. 75, 1957, p. 815-819.

14 T.M. Chalmers and C.A. Keele, "The Nervous and Chemical Control of Sweating", in The British Journal of Dermatology, February, 1952, No. 2, Vol. 64, p. 43-54.

2. Psychophysiological Studies of Human Sweating.

In 1920, Ikeuchi[15] noticed that the palmar sweat glands did not respond to a rise in room temperature. A few years later Jürgensen[16] observed that palmar sweating occurred when subject read a book, experienced pain and solved mental arithmetic problems. Five years later Kosaka[17] employed mental arithmetic problems as the stimuli and discovered that palmar and solar sweating acted as a unit.

As a follow up to these findings Kuno conducted a series of palmar sweating studies and concluded:

> Mental sweating has no latent period for its onset; it immediately attains a certain rate of secretion which corresponds to the intensity of the stimulation, remains as long as the stimulation lasts and subsides at once after it ends[18].

The conclusions that the latency period was short and secretion subsided soon after the stimulation was ended seemed justified. Unfortunately, experimental evidence to suggest that the rate of secretion corresponded to the intensity of the stimulation was lacking. The data indicated that the

---

15 K. Ikeuchi, (no reference), reported by Yas Kuno, Op. Cit., p. 104.

16 E. Jürgensen, (no reference), reported by Yas Kuno, Op. Cit., p. 104.

17 T. Kosaka, (no reference), reported by Yas Kuno, Op. Cit., p. 104.

18 Yas Kuno, Op. Cit., p. 104.

stimuli were of similar intensity or similar difficulty.

Sears[19] attempted to demonstrate the same proposition that changes in sweat rates varied with changes in problem difficulty but measured the sweat rates by means of the galvanic skin resistance apparatus. Technical difficulties of removing the sweat of previous trials and scoring analysis negated his efforts to validate his hypothesis. However, he did find that addition problems of abrupt increase in complexity were accompanied by a large rise in amplitude deflections as compared with the immediately preceding problem.

After he reviewed the studies of palmar sweating and galvanic skin resistance measures, Darrow[20] concluded that, "Any increase in prevailing alertness [...] is commonly accompanied by an increase in palmar secretory activity"[21], and further, "...in persons with intact nervous systems, palmar sweating is commonly associated with activity at a high cortical level"[22]. These conclusions and the partial findings of Sears and Kuno indicated that palmar sweating is related to

19 R. Sears, "Psychogalvanic Responses in Arithmetical Work: Effect of Experimental Changes in Addition", in Archives of Psychology, Vol. XXIV, March, 1933, No. 155, 62 pp.

20 Chester W. Darrow, "Neural Mechanisms Controlling the Palmar Galvanic Skin Reflex and Palmar Sweating: A Consideration of Available Literature", in Archives of Neurology and Psychiatry, Vol. 37, No. 3, March, 1937, p. 641-663.

21 Ibid., p. 642.

22 Idem.

cognitive activities. However, the question of differential sweating rates and increases in mental activity, has not been properly investigated.

Many of the problems encountered by past researchers regarding this possible relationship may be traced to the use of the galvanic skin resistance response as a measure of sweating rates. Darrow[23] criticized this technique in his study comparing sweating rates and galvanic skin resistance measures. He found that at high skin resistances a small amount of perspiration evoked a large galvanometer change; and at low skin resistance readings, large increases in sweating effected small changes in resistance readings. These findings seemed to indicate a serious defect in the usage of the galvanic skin resistance measures as an indicator of sweating rates.

McCleary[24], after he reviewed the literature, objected to the conclusions of past researchers who attributed the galvanic skin resistance measures, "...to any specific category of mental activity"[25]. He added that the galvanic skin resistance measure is correlated to a great extent to sweat

---

23 Chester W. Darrow, "The Significance of the Galvanic Skin Response in the Light of its Relation to Quantitative Measurements of Perspiration", in Psychological Bulletin, Vol. 31, No. 9, November, 1934, p. 697-698.

24 Robert A. McCleary, "The Nature of the Galvanic Skin Response", in Psychological Bulletin, Vol. 47, No. 2, March, 1950, p. 97-117.

25 Ibid., p. 97.

gland activity but at least two other important factors, muscular and vascular activity could simultaneously be responsible for the response. He also stated that, "...the variability and hypersensitivity of the response is often far too great to give the kind of results we need for good experiments"[26]. Lastly he concluded that the unit of measurement does not permit analysis of significant or non-significant measures.

Some of the studies since McCleary's review have attempted to improve the galvanic skin resistance apparatus to measure the sweating rates of individuals rather than an instrument to monitor the rates directly.

Past attempts to measure the sweating rates in this manner have had some success. Kuno[27] described these methods in great detail but found that none could overcome the difficulties of evaporation loss during the testing procedures or allow for a continuous measurement of secretion flow throughout the experiments.

---

26 Idem.

27 Yas Kuno, Op. Cit., p. 359-381.

The first apparatus to overcome these difficulties was devised by Custance[28,29] in 1960. His system bypassed the problem of evaporation loss by measuring the sweating rate indirectly and also allowed for a continuous measurement throughout the experimental procedure. The device recorded the amount of dry air necessary to maintain a constant relative humidity within a grid enclosure which covered a given portion of skin surface. The level of the relative humidity in the enclosure was continuously indicated by means of a Wheatstone Bridge. When the relative humidity in the enclosure was changed due to the presence of sweat, the resistance of the element was also changed and the Bridge became imbalanced. The signal which resulted from this imbalance was used to regulate the flow of dry air automatically in such a way to restore the relative humidity in the enclosure to its original level. The flow of dry air at any moment would be used to indicate the sweating rate.

The development of this system now allows for the testing of the theory that increases in mental activity are related to palmar sweating rates.

---

28 A.C. Custance, A New Technique for the Continuous Measurement and Automatic Recording of Sweating Rates, Defense Research Chemical Laboratories, Report No. 325, Defense Research Board of Canada, Ottawa, July, 1960, iii-23 pp.

29 Canadian Patent No. 633,692.

3. Summary and Hypothesis.

The survey of the literature has indicated that there is ample evidence to establish that palmar sweating is linked to activity at the cortical level. Studies were cited demonstrating that palmar sweating does occur when subjects were occupied in cognitive tasks, such as reading a book and solving problems. When these findings are linked to the evidence of a separate center in the cortex for palmar sweating the relationship between the two becomes strengthened.

Two studies attempted to test the theory, implicit in their experiments, that increases in mental activity are related to palmar sweating rates. One investigator employed an instrument which had technical and scoring difficulties inherent in its usage, and the other failed to demonstrate differential problem difficulty levels. Therefore, the theory has not been properly investigated and is the purpose of this present study.

In this investigation palmar sweating rates were determined indirectly by measuring the volume of air necessary to maintain a constant relative humidity within a grid enclosure during the solving of problems. Differential mental activity was considered to be achieved as a function of solving problems of increasing difficulty.

The problem is stated in the form of the null hypothesis: there are no significant differences between the mean air volume scores obtained during the solving of problems of three difficulty levels for men subjects.

The next chapter is devoted to the reporting of the experimental design of this study.

CHAPTER II

EXPERIMENTAL DESIGN

This chapter presents a description of the experimental design employed in this investigation. The sections are divided in the following manner: Section 1 describes the sample population. Section 2 is devoted to the testing conditions and facilities of the experimental situation. Section 3 presents the psychological tool and its construction procedures. Section 4 describes the psychophysiological instruments and their operation. Section 5 presents the experimental procedures of the investigation. Section 6 reports on the techniques for data evaluation, including the statistical formulas employed.

1. Sample Population.

The subjects of this study were twenty-two[1] men graduate student volunteers of the School of Psychology and Education, University of Ottawa. Their ages ranged from 21 to 39 with a mean of 27.1 years. All had some familiarity with the psychological tool employed in this investigation.

---

1 The records of three subjects were incomplete or invalid. One because his thumb was too small in relation to the grid housing opening and the other two because of apparatus component failures.

Women were not considered as subjects for this study because of the unknown effects extended usage of cosmetics and hand lotions may have had upon sweat gland functioning and the possibility their contaminating the sensing element surface.

2. Testing Conditions and Facilities.

The experiment was conducted in a classroom of an unused quiet wing of the main administration building at the University of Ottawa. The room was converted to accommodate the equipment and furniture necessary to conduct the experimental procedures.

The furniture was arranged to minimize distractions. In one corner of the room a single bed with an adjustable headrest and a table were placed against a common wall. When the subject sat on the bed he faced a black wall with his back to the table upon which the equipment was placed. A chair was positioned so that the experimentor was seated directly behind and above the subject's left shoulder. With this furniture arrangement he could manipulate the equipment and observe the subjects.

The room was illuminated by florescent lights and well ventilated. The average temperature during the testing procedures was 73.3 degrees with a range from 72 to 75 . The average relative humidity was 43.3 per cent with a range from 40 to 50 .

3. The Psychological Tool.

Items from four subtests of the Differential Aptitude Tests[2] hereafter referred to as DAT were selected to represent the three difficulty levels. These subtests were: Abstract Reasoning; Space Relations; Mechanical Reasoning; and Verbal Reasoning. Forty items were cut out of the respective test booklets and pasted to plain white 5" x 8" index cards.

The items were grouped in the following manner: Item number one of each subtest was used as a practice item to introduce the subtest. The next three items, second, third, and fourth, were labeled the Easy level. The middle three items of each subtest were considered to be the Medium difficulty category. The last three items of each subtest were called the Hard problems. The total test of this experiment therefore consisted of twelve items in each of the three difficulty levels of Easy, Medium and Hard.

2 George K. Bennett, et al, Differential Aptitude Tests, The Psychological Corporation, New York, 1947.

4. Psychophysiological Instruments.

An apparatus similar to the one devised by Custance[3] was constructed to measure palmar sweating rates. The rates were determined indirectly by measuring the volume of air necessary to maintain a constant relative humidity within a grid enclosure which covered a given portion of skin surface. The level of relative humidity was continuously indicated by means of a Wheatstone Bridge. When the relative humidity in the enclosure was changed due to the presence of moisture in the form of sweat the resistance of the element became imbalanced. The signal which resulted from this imbalance was used to regulate automatically the flow of dry air in such a way to restore the relative humidity in the enclosure to its original level. The flow of dry air was used to indicate the sweating rates.

A detailed description of the instruments are presented in three subsections. Subsection A presents the organization of the system to control the relative humidity in a sensing element enclosure. Subsection B considers the operation of the device and Subsection C describes the components of the apparatus in detail.

---

3 A.C. Custance, A New Technique for the Continuous Measurement of and Automatic Recording of Sweating Rates, Defense Research Chemical Laboratories, Report No. 325, Defence Research Board of Canada, Ottawa, July, 1960, iii-23 pp.

A. Relative Humidity Control in Element Enclosure.

A system was set up to maintain a constant value of relative humidity in a small enclosure which was constructed in such a manner that part of one wall was formed by the skin area of the right thumb. The basic organization of the system is illustrated in Figure 1, page 16.

The essential parts and their functions are: A humidity sensing element to detect changes in relative humidity which incorporated a comparator to provide an appropriate output when a change in relative humidity occurred. This comparator is the Wheatstone Type Bridge Circuit referred to previously. The comparator output was referred to as the error signal. An amplifier electrically amplified the error signal from the comparator and applied the amplified signal to a motor. The rotation direction of the motor depended upon the phase angle of the error signal which in turn was related to the sign change in relative humidity. The motor was used to operate a regulating valve which was coupled to the valve by means of a gear train, which increased the torque and reduced the speed of the motor. The regulating valve controlled the rate that dry air was supplied to the humidity sensing enclosure. Air was supplied to the valve at a constant pressure by means of a diaphragm pump. This air was taken from the room and passed through a drying tower before entering the pump. Air that passed through the sensor

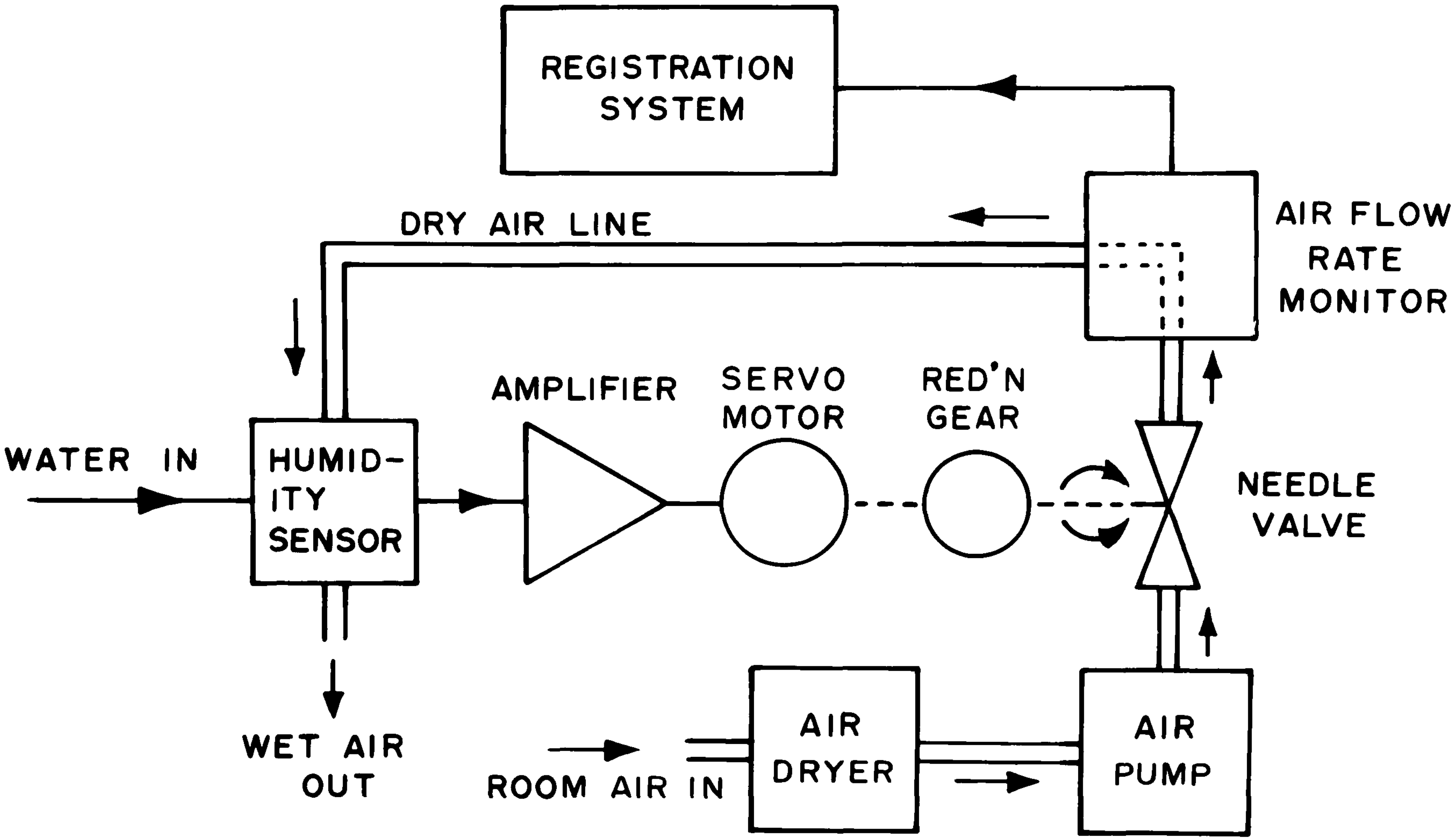

Figure 1

Schematic Diagram of Sweat Measurement System enclosure and accumulated moisture was exhausted to the room.

B. Operation of the Apparatus.

The apparatus was initiated into operation by bringing the bridge circuit to a null condition. Then a small adjustment was made to ensure that the system was always seeking a balance at a value of relative humidity slightly lower than the relative humidity of the dry air supply.

Any water entering the sensing enclosure caused an error signal of appropriate phase angle and of a magnitude related to the amount of water vapor introduced. This error signal initiated the flow of dry air through the enclosure until the pre-set null condition had been attained.

A device to measure the flow of dry air to the sensing unit was provided. This device had an electrical output which was related to the air flow rate. The relationship of the output voltage was determined by metering air through the flow measuring system by means of an aspirator bottle.

The output voltage from the flow measuring device was registered on a strip chart recorder. This information from the recorder was employed in the analysis of the sweating rates.

C. Description of Components.

The components of the instruments are described in detail in this subsection:

<u>The Humidity Sensing Element</u>:—The humidity sensing element manufactured by Photo-Crystals Inc., Geneva, Illinois, marketed by Allied Radio of Chicago, USA was used in the experiment. The units used were type HA Hygropak.

<u>The Bridge Circuit</u>:—An unequal arm AC bridge with Wagner ground and 5 volts AC power supply was used. The bridge output was fed to a Cathode follower which was one-half of a 12 AU7 with the filament operating at a reduced current.

<u>The Amplifier</u>:—The output from the Cathode follower was fed to the second half of the 12 AU7. The voltage gain of this stage was about ten times. A 12 AX7 was used with grid and plate limiting to give further gain and to drive a 6L6 type valve. R.C. coupling was used throughout. The overall gain of the system was adjusted by changing the Cathode resistor of the 6L6 valve. The gain was adjusted by trial and error until the amplifier output with a good bridge null was just equal to the starting voltage of the servo motor. Gain of the amplifier for a small signal was about 50,000 times the motor.

<u>The Motor</u>:—A Barber Coleman type DYAZ shaded pole motor was used with a no load speed of 3000 R.P.M.

<u>The Gear Train</u>:—The gear train had a reduction of 120:1 . This large ratio was necessary because of the air flow regulating valve employed.

<u>The Air Regulating Valve</u>:—A standard 1/8" Hoke needle valve was modified to give smooth control at low air flow rates.

<u>The Diaphragm Pump</u>:—A small aquarium air supply pump was used (Casco Star). Careful adjustment of the pump capacity control was necessary. The capacity of the pump as supplied was too high for the control system and regulation was on an "on-off" basis under low air demand conditions.

<u>The Drying System</u>:—A glass drying tower packed with magnesium perchlorate was used.

The Registration System:--Output of the air flow system was recorded with a Sefram R.F.5 strip chart recorder. Pen type 614 was used. Speed of paper was 5 m.m. per second.

The Flow Measuring System:--A thermistor bridge circuit was used. Two Fenwal GB32J2 thermistors with a 200 ohm potentiometer were used. The reference thermistor was located in a second hole drilled to the same diameter as the passage carrying the sensing thermistor. Bridge current with no air flowing was 30 mA. The output of the thermistor bridge was placed across a 5000 ohm potentiometer. The wiper was connected to the base of a 2N107 type transitor. The output of this simple amplifier was controlled by means of the 5000 ohm potentiometer. Linearity of the system was adequate. The potentiometer was adjusted to give four volts output at one volt bridge output.

5. The Experimental Procedures.

Prior to testing, the temperature and relative humidity were determined and written on the subject's record card. The apparatus was switched to ON and adjusted.

After these operations, the subject was escorted into the testing area. The experimentor carried on general conversation for a few minutes and then asked the subject to sit on the bed and to make himself comfortable.

While the subject rested in this position, the experimentor proceeded to clean the subject's right thumb with alcohol to remove any dirt or oils that might have been present. After the alcohol evaporated the grid housing was placed on the whorl of the right thumb and secured by three strips of adhesive tape. This procedure insured a stationary positioning of the grid housing throughout the experimental situation and prevented air leakage into the grid housing opening. During taping the subject was assured there would be no harmful stimuli administered throughout the procedures. He was told simply that he would solve a series of problems and his sweating rates were to be monitored.

As the operation of the apparatus was rechecked, the subject read the directions of the subtests. When he completed them, the testing situation began with the reading of the instructions: "You are to solve forty problems during this test, ten from each of the subtests. The first item, a sample problem, introduces the next nine items which are from the same subtest. You will have one full minute to solve each problem. In other words, no problem can be started until the full minute has elapsed. When you have the answer, say it out loud and I will write it on your record. When you have given me the answer hand me the card over your left shoulder and relax until I hand you the next problem. After each series of three items you shall have an extra minute to relax. When the subtest is completed I shall signal you so that you may move around, cough or clear your throat if you find it necessary. We shall then follow the same procedures for the next three subtests. Are there any questions?"

The order of items followed the same sequence as they were in the test booklets. The sequence of levels was from Easy to Medium to Hard. The subtest order was: <u>Mechanical Reasoning</u>; <u>Verbal Reasoning</u>; <u>Abstract Reasoning</u>; and <u>Space</u>

Relations.

During the test identifying marks were made on the pen recording paper to indicate: the one minute intervals; the moment the answer was given; the end of levels; and the end of subtests. Timing of the one minute intervals was achieved by means of a one second sweep hand stopwatch.

At the completion of the experiment, the purpose of the investigation was volunteered to the subject and he was shown his record. Proper identifying marks were made on the record to facilitate matching with the answer sheet at a later time.

6. Techniques for Data Evaluation.

The data analyzed in this experiment were the correcting of the DAT items and the determination of the air volume expended during the solving of the problems.

Correct answers of the items for the subtest were derived from the scoring keys of the DAT manual. Each item was scored either correct or incorrect.

Total incorrect frequencies were tabulated for each: difficulty level of subtests; and difficulty level regardless of subtest. The frequencies were converted to a percentage of failure. The results of these procedures are presented in the next chapter.

Air volume during problem solving was determined in the following manner. A linear relationship between air flow and a given area on the recording paper was established. Thus, air volume was directly convertible from measured areas.

To arrive at this score, the plane area within a polygon constructed from the movements of the tracer pen during a specified time period was measured with a compensating polar planimeter[4].

The measurement unit of the planimeter was a vernier unit which was directly related to square centimeters. Therefore, conversions from vernier units to areas to air volume could be made. Since nothing would be gained by multiplying the original unit of measure by a constant, the vernier unit was maintained for calculations. This area of measured figures was called an air volume score.

The limits of the figure on the recording paper were the subject's basal or resting level which when extended made a base line of six centimeters in length, and the irregular line drawn by the pen as a function of the amount of air passing through the flow measuring system. Parallel vertical lines were drawn at the one minute marks to circumscribe the figure.

---

4 Compensating Polar Planimeter 4236M, Keuffel and Esser Company, Hoboken, New Jersey.

The lowest deflection of the pen during the resting phases was considered to be a good estimate of the basal level. Thus, a measure of sweating only during problem solving, minus the resting rate, was achieved.

Each figure was measured three times with the planimeter and the average air volume score was employed as the best estimate of the area. The next chapter reports the accuracy of measurement from the usage of the planimeter.

After the calculation of air volume scores for every figure, the scores of each subtest were converted to standard scores in order that the results of the subtests could be combined and compared. Negative signs were eliminated by adding 500 to all standard scores and multiplying them by 100. This made the mean air volume score of each subtest 500 and the standard deviations 100.

Statistical tests of significance of correlated groups were undertaken between the mean air volume scores for each item within a difficulty level for the four subtests. For this analysis each problem within a difficulty level of the separate subtests was considered to be of equal difficulty.

The procedure was to calculate the significance of mean differences between the air volume scores of the: first and second items; the first and third items; and the second and third items, for each difficulty level on each subtest.

The following formulas were used to determine the statistical significance of the means[5]:

$$t = \frac{\text{Diff}}{\sigma_D}$$

where $$\sigma_{DM} = \sqrt{\sigma^2_{M_1} + \sigma^2_{M_2} - 2r_{12}\sigma_{M_1}\sigma_{M_2}}$$

and $$\sigma_M = \frac{\sigma}{\sqrt{N - 1}}$$

and $$r_{12} = \frac{N\Sigma XY - (\Sigma X)(\Sigma Y)}{\sqrt{[N\Sigma X^2 - (\Sigma X)^2][N\Sigma Y^2 - (\Sigma Y)^2]}}$$

The coefficients of correlation from this analysis were averaged by Fisher's z technique[6] to estimate the internal reliability of air volume scores. The results of these computations are presented in the next chapter.

---

5 Lawrence-T. Dayhaw, Manuel de Statistique, Editions de l'Université d'Ottawa, Ottawa, 1958, p. 355.

6 J.P. Guilford, Fundamental Statistics in Psychology and Education, 3rd Edition, McGraw-Hill, New York, 1956, p. 325-326.

The next step was the grouping of the individual scores according to the difficulty levels on each subtest. The air volume scores of the three items within a difficulty category on each subtest were averaged. This calculation resulted in each individual having one score for each level on each subtest.

The final grouping was the calculation of the average score for each level, regardless of subtest, which resulted in each subject having only three scores, one for each difficulty level.

Statistical tests of significance of correlated groups were undertaken between the mean air volume scores of the difficulty levels for each subtest and also between the difficulty levels, all subtest combined. The formulas described previously were used in this analysis.

The next chapter is devoted to the presentation and discussion of the results.

CHAPTER III

RESULTS AND DISCUSSION

This chapter presents the results of the experimental procedures and discusses them. The sections are divided in the following manner: Section 1 reports the accuracy of the planimeter measurements. Section 2 describes the grouped tabulations of incorrect frequency percentages of the test items according to difficulty levels. Section 3 is devoted to the consistency of air volume scores between items of the same difficulty level. Section 4 presents the results of the statistical tests comparing mean air volume scores of the difficulty levels. Section 5 discusses the results, considers explanations to account for them, and suggestions for further research are proposed.

1. Accuracy of Planimeter Measurements.

The accuracy of area measurements from usage of the planimeter was determined in the following manner. One figure from the sample population records was chosen and measured one hundred times. The mean of these measurements was 99.0 vernier units with a range from 97 to 101 and a standard error of the mean of .093 .

2. Problem Difficulty Level Analysis.

The incorrect answer percentage tabulations of subtest items were grouped according to the three difficulty levels and the results are presented in Table I, page 28.

Performance by the sample population indicated that the percentage of failure for items between difficulty levels increased on the four subtests. The comparison of subtests to each other indicated that the Space Relations subtest appeared to be more difficult than the other three.

3. Internal Consistency of Air Volume Scores.

The t tests of correlated groups were calculated between the mean air volume scores of the items within a difficulty level for the four subtests. No statistical differences were found, and the averaging of air volume scores within a difficulty level seemed justified.

An estimate of the internal reliability of air volume scores was determined by averaging the coefficients of correlation obtained from the preceding analysis. The procedures described in the previous chapter were employed and the average coefficient of correlation between the air volume scores was .88 .

Table I.-

Percent of Failure for Three Difficulty Levels of Items from Four Subtests and Average Totals for Levels. N = 22.

Subtest	Level: Easy	Medium	Hard
Mechanical Reasoning	3.0	18.2	36.4
Verbal Reasoning	9.1	21.2	36.4
Abstract Reasoning	4.5	16.7	63.7
Space Relations	25.8	60.6	87.4
Average Totals	10.8	26.7	60.0

4. Comparison of Difficulty Levels.

The *t* tests of significance between the means of correlated groups, all subtests combined and each subtest separately were undertaken using the formulas stated in the preceding chapter. This data is presented in Tables II to VI, pages 30 to 34.

No mean differences were found to be statistically significant. However, the mean differences in each case, with the exception of the reversal on Medium and Hard on Abstract Reasoning, Table II, page 30, were in the predicted direction.

5. Discussion.

The null hypothesis: there are no significant differences between the mean air volume scores obtained during the solving of problems of three difficulty levels for men subjects, was not rejected.

This conclusion necessitated an analysis of the experimental procedures to determine whether the lack of significance could be attributed to aspects of the experiment or the rationale of item difficulty and increased mental activity. These points were grouped into three subsections: A) The Size of the Sample; B) The Psychophysiological Apparatus; and, C) Difficulty Levels and Increases in Cortical Activity.

Table II.-

t Tests of the Mean Air Volume Score Differences Between Three Difficulty Levels of Problems from Abstract Reasoning. N = 22.

Level	M	σ	σ_M	r	Diff	σ_{DM}	t
Easy	490.0	76.33	16.67	.961	17.0	9.44	1.801
Medium	507.0	110.87	24.21				
Medium	507.0	110.87	24.21	.969	5.5	6.43	.855
Hard	501.5	95.74	20.90				
Easy	490.0	76.33	16.67	.961	11.5	6.77	1.699
Hard	501.5	95.74	20.90				

Table III.-

t Tests of the Mean Air Volume Score Differences Between Three Difficulty Levels of Problems from Space Relations. N = 22.

Level	M	σ	σ_M	r	Diff	σ_{DM}	**t**
Easy	497.9	83.68	18.27	.945	1.0	7.30	.137
Medium	498.9	98.27	21.46				
Medium	498.9	98.27	21.46	.918	6.8	8.60	.791
Hard	505.7	98.72	21.55				
Easy	497.9	83.68	18.27	.866	7.8	10.82	.721
Hard	505.7	98.72	21.55				

Table IV.-

t Tests of the Mean Air Volume Score Differences Between Three Difficulty Levels of Problems from *Verbal Reasoning*. N = 22.

Level	M	σ	σ_M	r	Diff	σ_D	*t*
Easy	494.0	90.20	19.69	.861	8.2	10.25	.800
Medium	502.2	86.68	18.93				
Medium	502.2	86.68	18.93	.958	--	6.23	--
Hard	502.2	98.23	21.45				
Easy	494.0	90.20	19.69	.851	8.2	11.39	.720
Hard	502.2	98.23	21.45				

Table V.-

t Tests of the Mean Air Volume Score Differences between Three Difficulty Levels of Problems from *Mechanical Reasoning*. N=22.

Level	M	σ	σ_M	r	Diff	σ_D	*t*
Easy	488.1	66.54	14.53	.596	17.1	20.09	.851
Medium	505.2	114.47	24.99				
Medium	505.2	114.47	24.99	.962	3.2	7.01	.457
Hard	508.4	108.19	23.19				
Easy	488.1	66.54	14.53	.599	20.3	18.90	1.074
Hard	508.4	108.19	23.62				

Table VI.-

t Tests of the Mean Air Volume Score Differences between Three Difficulty Levels of Problems from All Subtests Combined. N=22.

Level	M	σ	σ_M	r	Diff	σ_D	t
Easy	490.7	72.50	15.83	.961	10.3	7.11	1.449
Medium	501.0	95.04	20.75				
Medium	501.0	95.04	20.75	.971	3.5	4.06	.862
Hard	504.5	91.57	19.99				
Easy	490.7	72.50	15.83	.951	13.8	7.00	1.971
Hard	504.5	91.57	19.99				

A) The Size of the Sample.

The initial question considered was whether an increase in the number of subjects would have facilitated significant differences. From a statistical point of view this seemed plausible. However, a trend analysis of individual scores revealed that about forty-five per cent of the scores did not follow the expected pattern of air volume scores increasing as difficulty of items increased.

Therefore, a mere increase in the size of the sample, if the same trend occurred, probably would not result in significant differences between the mean air volume scores obtained during the solving of problems of increasing difficulty.

B) The Psychophysiological Apparatus.

Although there were some component failures of the apparatus, the rejection of its use to monitor sweating does not seem to be justified. Periodic checks indicated that the instrument was operating properly.

The high reliability coefficients between air volume scores within difficulty levels seemed to indicate that the measurement of sweating rates with this tool was consistent. This finding also lends support to the proper functioning of the apparatus during the testing procedures.

C) Difficulty Levels and Increases in Mental Activity.

In this experiment items of increasing difficulty were selected as adquate stimuli to evoke mental activity increases. The review of the literature indicated that this had been the procedure employed in the past. In view of the obtained results, there are two important questions to be considered regarding this assumption.

The first point is whether the traditional method of assessing item difficulty by correct or incorrect responses corresponds to the experienced difficulty of the individual for specific problems. The second is whether experienced difficulty of problems in itself can be considered as a sufficient condition to evoke increases in mental activity.

Prior to experimentation, the answer to either would have been positive, as there were no definite reasons to question the validity of the assumptions. However, during the testing procedures, various unrecorded performance observations were made which cast some doubt on the validity of the assumptions.

One of the observations was a pen amplitude reduction when some subjects successively failed a series of problems. These individuals seemed to exhibit a condition best described as boredom or non-involvement. This phenomenon seemed to indicate that the individuals did not experience difficulty with the problem because they may not have attempted a solution.

Another observation was the behavioral characteristics of some individuals who successfully passed all the items. High amplitudes of the pen were observed during problems with which they were highly involved and reduction deflections occurred when they seemed to arrive at solutions in a mechanical fashion.

These observations did not seem important during the testing procedures and were not properly recorded. However, they indicated that the theory of increased mental activity and increases of palmar sweating should be studied from another point of view.

Future experimental studies may be more fruitful if the mental activity is measured directly rather than employing the technique of this study. A measure of mental activity might be determined by monitoring various areas of the cortex with an EEG technique. In this manner, a direct relationship between quantitative and regional mental activity might be established with palmar sweating.

If a relationship can be established, palmar sweating rates then might be used as a criterion of mental activity. It may then be possible to determine whether individuals are involved in tasks and possibly to what degree.

Another area that should be investigated is the relationships between palmar sweating activity and other autonomic measures to determine if there are qualitative differences between them.

SUMMARY AND CONCLUSIONS

This dissertation reported on an investigation of the theory that differential mental activity is related to palmar sweating. Differential mental activity was considered to be achieved as a function of solving problems of increasing difficulty. Palmar sweating was determined indirectly by measuring the volume of air necessary to maintain a constant relative humidity within a grid enclosure during the solving of the problems.

The survey of the literature indicated there was ample evidence to establish that palmar sweating is linked to activity at the cortical level. Two studies were presented which attempted to test the theory and reasons why they were not successful were described.

Employing *t* tests of significance, the sweating rates of the sample population obtained during the solving of problems of increasing difficulty were compared to test the null hypothesis: "there are no significant differences between the mean air volume scores obtained during the solving of problems of three difficulty levels for men subjects". The null hypothesis was not rejected. No significant differences were found between the mean air volume scores of the three levels.

Three aspects of the design were discussed to account for the lack of obtained significance. The sample population and the instrument to measure the sweating rates were not considered as primary factors to account for the results. The other aspect of considering items of increasing difficulty to be adequate stimuli to evoke mental activity increases was discussed at length.

From observations during the testing conditions the assumption that some items were actually being experienced as more difficult than others could not be justified.

Suggestions for further research employing a more direct approach to the measurement of mental activity changes and the study of sweat rates in conjunction with other autonomic measures were made.

BIBLIOGRAPHY

Custance, A.C., *A New Technique for the Continuous Measurement and Automatic Recording of Sweating Rates,* Defense Research Chemical Laboratories, Report No. 325, Defense Research Board of Canada, Ottawa, 1960, iii-23 p.

This monograph presents a unique system of sweat measurement. Development of this system allowed the present study to be undertaken.

Darrow, Chester W., "Neural Mechanisms Controlling the Palmar Galvanic Skin Reflex and Palmar Sweating: A Consideration of Available Literature", in *Archives of Neurology and Psychiatry,* Vol. 37, No. 3, March, 1937, p. 641-663.

A review of the studies on the neuroanatomy of palmar sweat glands. He concludes that palmar sweating is related to activity at the cortical level.

--------, "The Significance of the Galvanic Skin Reflex in the Light of it Relation to Quantitative Measurements of Perspiration", in *Psychological Bulletin,* Vol. 31, No. 9, 1934, p. 697-698.

A study of relationships between palmar sweating and galvanic skin resistance measures. He concludes that the galvanic skin resistance measure is a poor technique to reflect sweating rates.

Kuno, Yas, *Human Perspiration,* Thomas, Springfield, 1956, xvi-416 p.

A summary of his thirty years work in the area of human sweating. The text contains a review of past investigations by others but bibliographic references are not always present. A necessity before studying aspects of human sweating.

McCleary, Robert A., "The Nature of the Galvanic Skin Response", in *Psychological Bulletin,* Vol. 47, No. 2, March, 1950, p. 97-117.

A comprehensive review of galvanic skin resistance measure studies. He questions the validity of the technique to measure sweat gland activity. He found that two other aspects, vascular and muscular activity, could simultaneously be responsible for the response.

Rothman, Stephen, Physiology and Biochemistry of the Skin, University of Chicago Press, 1954, xiii-741 p.

Chapter six of this text is a review of his own as well as the works of others on the anatomy and physiology of sweat gland activity. He concludes that eccrine sweat glands are an exception to the general rule of automatic innervation.

Sears, R., "Psychogalvanic Responses in Arithmetical Work: Effect of Experimental Changes in Addition", in Archives of Psychology, Vol. XXIV, March, 1933, No. 155, 62 p.

An early investigation of the relationships between palmar resistance measures and solving of problems of increasing difficulty. Very comprehensive and detailed demonstration of problem difficulty increases but apparatus measures much too variable for clear conclusions to be drawn.

APPENDIX 1

ABSTRACT OF

Palmar Sweating and Problem Solving[1]

Past investigations reveal that palmar sweating is linked to cortical activity. Two studies attempted to test the theory that increases in mental activity is related to palmar sweating rates but were not successful due to instrumentation and stimulus deficiencies.

In this study, differential mental activity was considered to be achieved as a function of solving problems of increasing difficulty. Palmar sweating was determined indirectly by measuring the volume of air necessary to maintain a constant relative humidity within a grid enclosure during the solving of the problems.

The null hypothesis: "there are no significant differences between the mean air volume scores obtained during the solving of problems of three difficulty levels for men subjects", was not rejected. No significant differences were found between the mean air volume scores of the three levels.

Three elements of the design were considered to account for the lack of obtained significances. One, differential

---

1 Joseph D. Kovatch, doctoral thesis presented to the School of Psychology and Education, University of Ottawa, Ontario, 1963, viii-43 p.

mental activity achieved as a function of item difficulty increases, was considered to be important.

Observations during the testing procedures indicated that items ranked as more difficult may not have been experienced by some subjects as such. Some individuals, after successive failures, did not seem to attempt solutions and their sweating rates diminished. Others who successfully passed most of the items exhibited an increase in sweating with problems they were involved with and a fall in sweating when they arrived at solutions in a mechanical fashion.

Suggestion proposed for future study were to measure mental activity directly with an EEG technique to determine whether palmar sweating rates are related to quantitative or regional mental activity, and also the relationships of palmar sweating to other autonomic measures to determine if qualitative differences could be established.