J. Soc. Cosmetic Chemists, **17**, 749–767 (1966)

A New and Realistic Electronic Approach to the Evaluation of Antiperspirant Activity

R. J. JAMES, B.S.*

Presented May 10, 1966, New York City

Synopsis—A new method for the evaluation of antiperspirant activity eliminates many of the problems inherent in other proposed methods. The use of electronic equipment gives fast results. The use of phosphorus pentoxide cells minimizes the problem of temperature control. Simultaneous measurements are recorded on an X-Y recorder instead of the strip chart recorder usually used. The method described illustrates the measurement of the dynamic changes in rates of perspiration.

Introduction

Many systems have been devised to measure perspiration in order to evaluate antiperspirant materials. Generally, they can be divided into three classifications. The simplest of these detect perspiration by visual observation of color effects with dyes, starch iodide paper, or specially prepared plastic films (1–4). The next are gravimetric in nature and require the collection of sufficient perspiration to be weighed (5–7). These may either absorb perspiration in pre-weighed pads and absorption cups or freeze it from a gas stream into convenient traps. Finally, there are those methods which sense and record perspiration electronically (8–14). Only these are suitable for continuously recording the changes in perspiration rates during a test period. The method to be described is of the last type.

* Shulton, Inc., Clifton, N. J. 07015.

The manner in which data are handled, either as they are obtained by the equipment or later treated by the investigator, is very important. To date, all of the methods devised have erred in one fundamental detail. Those methods which rely on the gravimetric determination of perspiration automatically carry the error into the data. Where electronic recording has been used, the error has been unavoidably, though unknowingly, included in the results. The error is essentially the averaging of test results at various perspiration rates to produce a *single point* ratio for a series of determinations made on a control area as compared to those made on a test area. This situation has occurred because too much time would be required for a single product evaluation if the other methods were to produce a sufficient number of points to assure the *constant nature* of the ratio for different rates of perspiration. The method described in this paper resolves the problem by continually recording the ratio itself. Before describing the procedure, the principles of obtaining perspiration ratios must be reviewed.

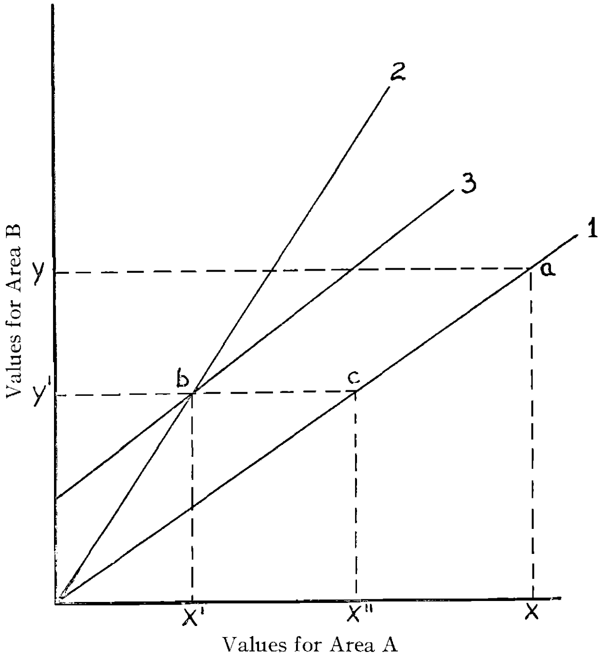

Figure 1. Idealized plot of the perspiration output of area A *vs.* area B. Without product (line 1) and with product applied to area A only (line 2)

Mathematical Considerations

When one wishes to compare the effectiveness of antiperspirant materials, it is obvious that tests must be performed directly on human subjects. However, people perspire for many reasons other than too high a temperature or humidity. Many other factors, such as emotion, temperament, and other psychological stimuli, state of health, variation of diet, etc., also influence the degree of perspiration (15). Control of all these variables simultaneously and from test to test is totally impossible. For this reason a single x to x' comparison, in which the output of per-

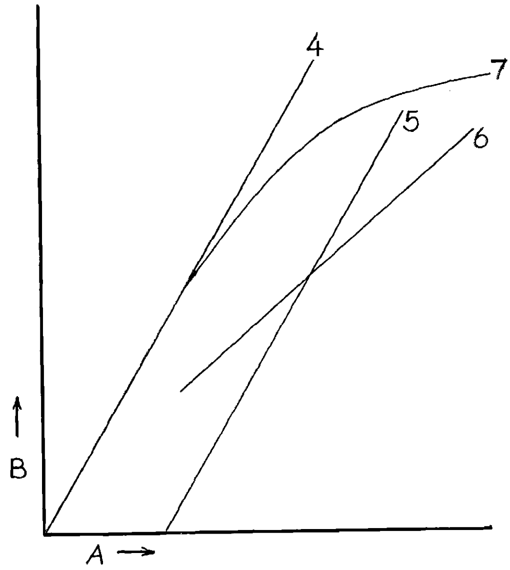

Figure 2. Plots of perspiration output of area A *vs.* area B for different types of control tests

spiration, x, from one area, A, of the body is compared to x' from the same area of the body after a product has been applied, cannot be made with accuracy. There is no way of knowing how much of an influence these variables may have had on the change in the value of x to x' as opposed to the influence of the test product coincidentally applied.

In order to obtain a value for x' which represents an antiperspirant effect free of these variables, it has become standard practice to measure the output from another area, B, simultaneously with that from area A, as originally proposed by Fredell and Read (5). The ratio of perspiration between the two areas may be defined as x/y, where x is the value obtained from area A and y is the value from area B. This test is done once with no product applied to either area. The ratio itself becomes the control.

In a second test an antiperspirant material is applied to area A, leaving area B untreated. If the material is effective, a lower perspiration rate will be obtained from area A, to which a new value x' is assigned. The output from area B may increase or decrease, but rarely will it be the same as that of the first test, because of the influence of the uncontrollable variables. The value y' is assigned to it.

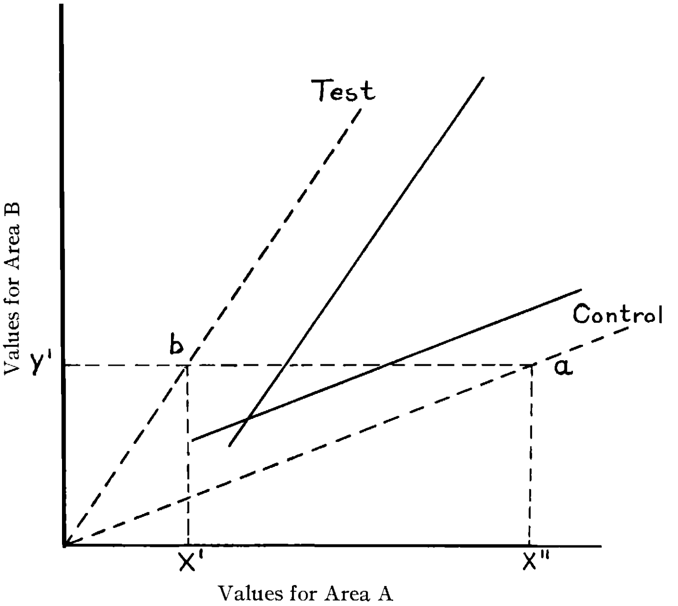

Figure 3. Practical plot of the output of perspiration from area A & B under control and test conditions. The dotted lines represent the corrected test lines for a valid comparison

The result of the second test is a new ratio of perspiration from the two areas for the condition where a product is applied to one side only. It is expressed as x'/y'. However, x' includes both the effects of the product and those of the uncontrollable factors which caused y to change to y'. Thus the following inequality results:

$$\frac{x'}{y'} \neq \frac{x}{y}.$$

A new value of x from area A, which does not include the effects of the product when y' is the value for area B, is now required. It may be calculated as x'' from the previously determined values x, y, and y' in the following expression:

$$\frac{x''}{y'} = \frac{x}{y} \text{ or } x'' = \frac{xy'}{y} \quad (1)$$

If the uncontrollable factors cause y' to be less than y in the control area, then x'' will be less than x. If the converse is the result, then x'' will be larger than x (see Fig. 1).

If the antiperspirant applied has been effective, the calculated value x'' from area A, representing the condition of *no product applied,* will always be larger than x', the value determined from area A representing the condition of *a product applied.* The following calculation will give the *per cent depression* of perspiration caused by the product:

$$\frac{x'' - x'}{x''} \cdot 100 = \text{per cent depression} \quad (2)$$

This is the mathematics used in previous work to obtain the desired information from antiperspirant test data. However, these calculations were based on the tacit assumption that the ratio of the rates of perspiration from two areas on a human body remained constant at *all levels of perspiration.* Previous work has taken for granted that this assumption is valid; however, no direct proof has yet been offered. It is known that human subjects perspire in erratic ways and from many causes other than exercise, heat, and humidity (15). Thus, the constant nature of this ratio becomes of prime importance. If proven to be false, then all previous work becomes quite inconclusive.

In part this paper will *prove* the *validity* of the original assumption and that previous work, based on the calculations just discussed, has contained unexpected errors which have compromised the results. A graphic representation of these calculations compared to the graphic treatment of data by the proposed procedure will clarify these errors and demonstrate a means for separating them from the desired information.

The graph in Fig. 1 presents the relationship of the perspiration values obtained from area A as plotted against those from area B. Point a is the specific ratio, x/y, obtained for the values x and y derived from the simultaneous test of areas A and B respectively. Because the perspiration rates from the right and left axilla of a given individual are rarely equal, these values will seldom be the same. Line 1 drawn through point a to the origin of the graph represents, as assumed, a set of equal ratios for the values obtained from areas A and B for *various rates of perspiration* in the condition where *no product is applied* to either area.

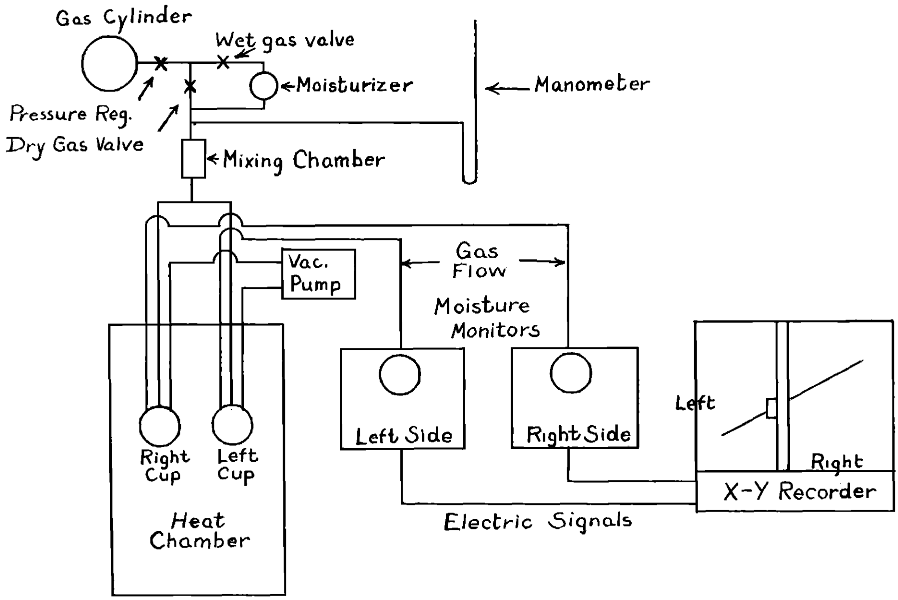

Figure 4. Diagram of equipment organization

Point b, the ratio x'/y', represents the new ratio obtained from a second test in the condition where a *product is applied* to area A only. Similarly, line 2 through point b to the origin of the graph is a new set of equal ratios, but in the second condition. The value x'' is obtained by extending a horizontal line from point y' through b to the intersection c on line 1 and dropping a perpendicular from c to the x-axis. Now two perspiration rates, x' *with product* and x'' *without product,* have been established for area A while the value for area B is unchanged, i.e., equal to y'. These two values of x may now be used to calculate the per cent depression of perspiration as described previously (eq. 2).

This treatment of data, whether graphic or calculated, is valid only if the ratios in each set are constant at different perspiration rates, i.e., the lines on the graph representing them pass through the origin. Assume that point b had fallen instead on a line such as 3, not passing through the origin. With this *single point* there is no way of knowing which way the ratio line is directed. As a result, the value calculated for x'' would be incorrect, because it would be based on one of the many ratios found on line 3, and the ratios along line 3 vary.

In their effort to save time, or to produce a practical number of tests economically, previous methods have erred by relying on a single point

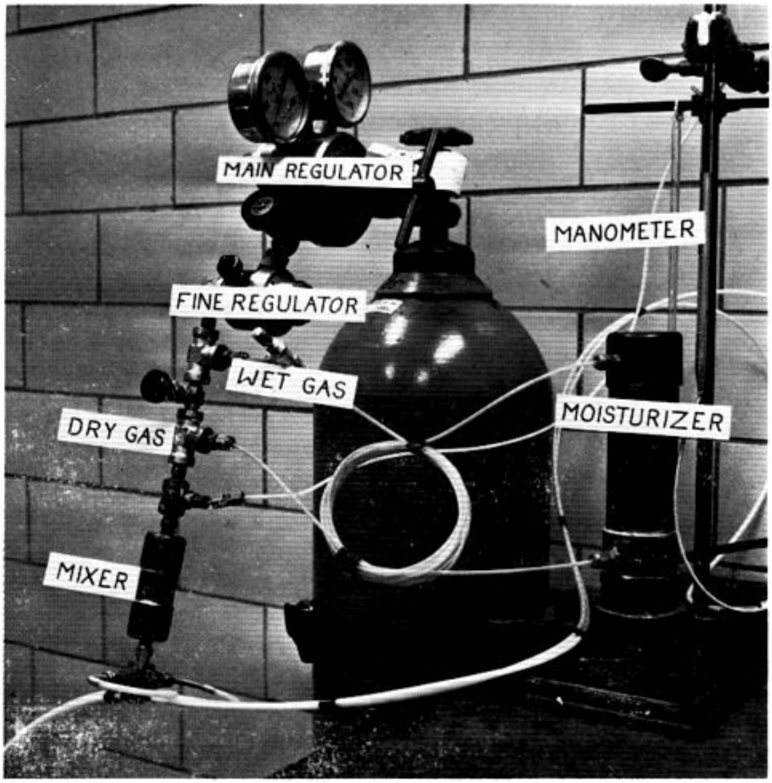

Figure 5. Gas supply and regulating system

determination of the ratios concerned. In a sense they have been forced to do this by the time required to collect sufficient perspiration for an accurate weight to be made or sufficient data to produce the single point by averaging. The constancy of the ratios cannot be determined by this type of data treatment. The ratio line or constancy of the ratio can be determined conveniently only by the continuous recording of the ratio itself rather than its components.

The procedure described in this paper continuously records the ratio changes which result directly in a ratio line rather than a single point. A consequence of this precision is the discovery of several forms of error or deviations from the ideal ratio line. The analysis of these deviations and the understanding of their operation has led to the determination and application of the necessary corrections to obtain valid results.

Four types of tests are represented by the lines in Fig. 2. Line 4, *passing through the origin*, is the ideal test along which the ratios of the

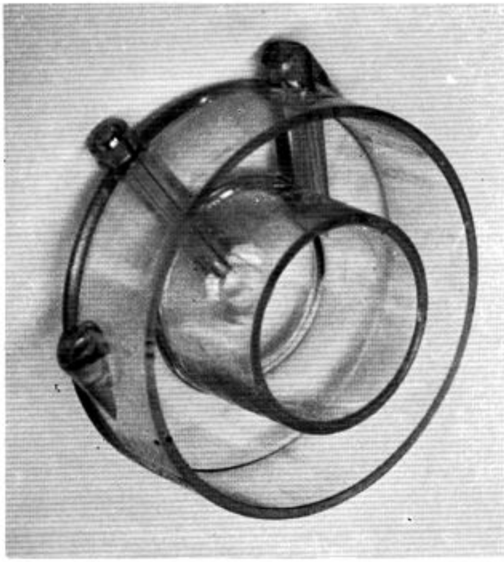

Figure 6. Absorption cup. The outer concentric space uses a vacuum to hold the cup to the subject. Moisture is picked up in the center section

values from area A to those of area B are equal. This test, however, is quite rare. Line 5, ***not passing through the origin***, represents the more common form of test. It may be displaced to one side or the other of the ideal line. The ratios along this line are not equal. Line 6, another form of test, has the same properties as line 5 but a starting point also above the origin. Again the ratios are not constant along this line. Line 7 is quite rare and represents the only specific case of an individual with different perspiration ratios at different rates. It can also be displaced from the origin.

The important observation to be made here is that the perspiration ratios of most subjects change along a linear function as illustrated by lines 5 and 6. This fact has been repeatedly demonstrated by the procedure to be described. The fact that the ratios along these lines are not constant is due to an additive factor, the source of which will be explained later. If this additive factor is eliminated, the lines will pass through the origin and become ideal lines. Consequently, the original assumption, that two areas on an individual would retain a constant ratio at different perspiration rates, has been proven correct. The problem has remained with the elimination of experimental errors.

The device used to refine these displacements or errors from the desired information is based on the realization that the *slopes* of the ratio lines obtained from the tests are the factors to be compared. The slope of the line is independent of its placement on the graph.

Figure 3 illustrates how this comparison may be accomplished graphically. One draws new lines respectively parallel to the test lines and

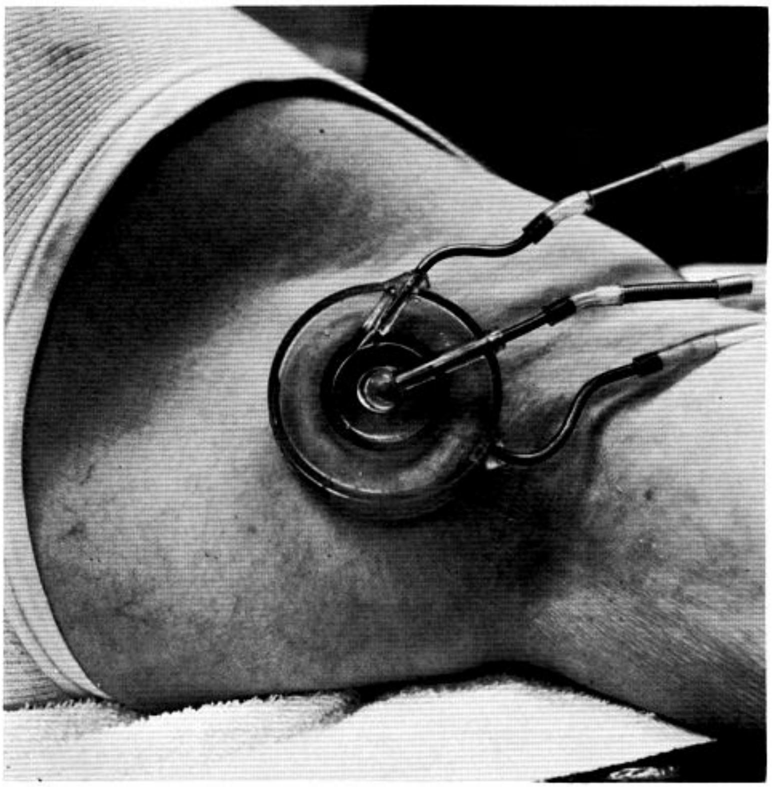

Figure 7. Absorption cup in place

passing through the origin. The change in ratio from point a on the parallel to the control ratio line to that of point b on the parallel to the test ratio line may immediately be read. Perspiration rate x'' has been reduced to x' by the application of a product to site A. Values x'' and x' taken from Fig. 3 may now be used to calculate the absolute reduction of perspiration, as in equation 2.

The causes of these additive shifts in position of perspiration ratio lines are not easily defined. Tentative data suggest that variations in the initial wetness of the skin during the test may be the cause. It is surprising how long it takes to dry wet skin even with a very dry gas stream. Capillary creepage of liquid moisture from the wet side to the dry side under the edge of the separation in the cup may be another cause. If this is so, then any method utilizing absorption cups will be subject to this error. Applying grease to the cup can possibly eliminate

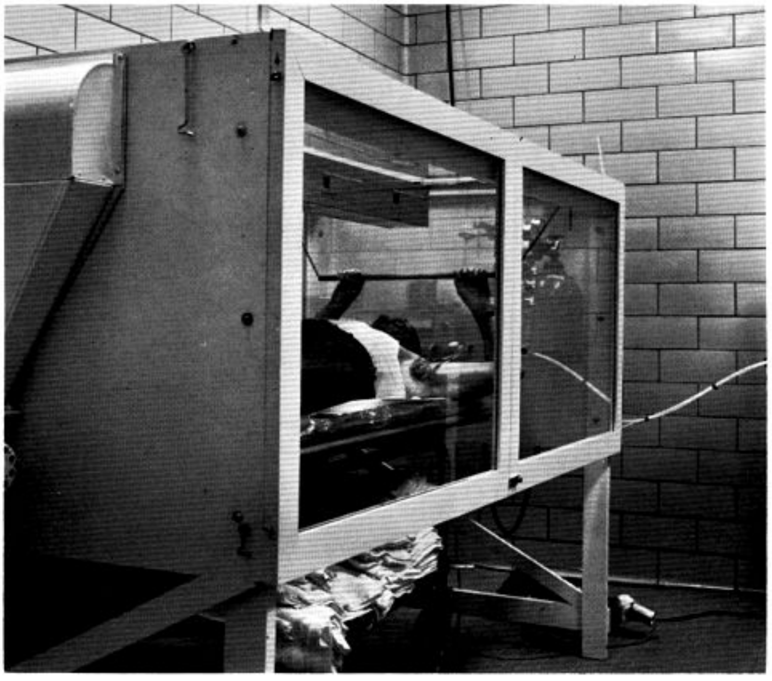

Figure 8 Heating chamber

this creepage, but great care must be used not to smear the test area with it or the results will be compromised.

The additive error becomes considerably more serious as the test period is reduced or as the rate of perspiration utilized for the test is decreased. However, if the test period is lengthened, one loses the ability to follow the relative change in product effectiveness with time. If heavy perspiration rates are used, a washing away of the active material renders the test inaccurate. Since the procedure to be described can separate the error from the desired data, a short test period does not impair the results. Consequently, this procedure can both follow a product effect with time and measure, if any, a wash-out effect as well.

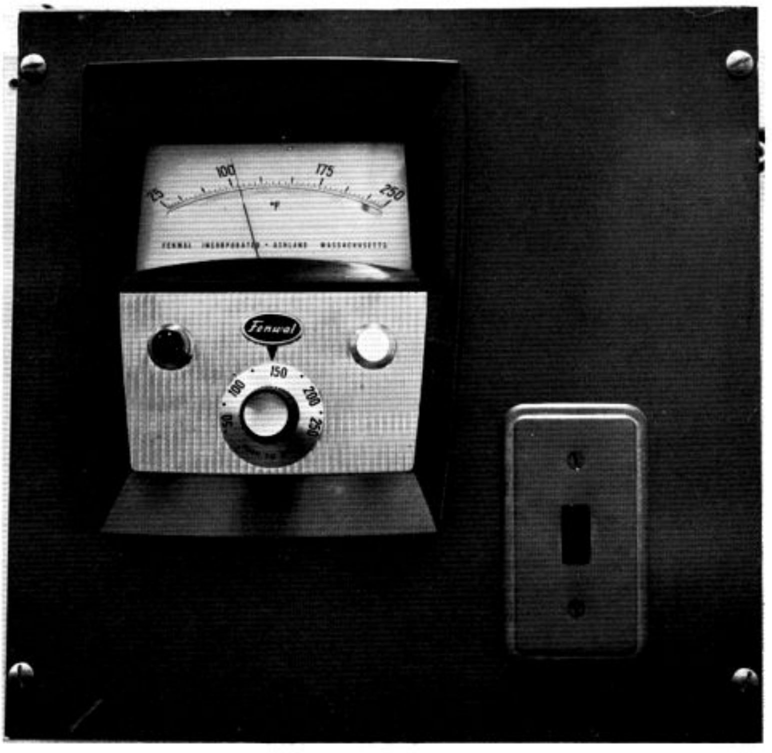

Figure 9. Temperature controller

Experimental Procedure

The block diagram in Fig. 4 illustrates the test equipment assembled for this procedure. All gas connections are of 3.2 mm Teflon tubing to minimize the permeation of moisture through the walls of these connections.

The gas supply system is shown in Fig. 5. Dry nitrogen from the cylinder flows through a sensitive regulator to reduce the pressure to approximately 1000–1500 mm. The wet and dry gas values may be balanced against each other to adjust the delivery of moisture to the main gas stream and to calibrate the operation of the system. The manometer need not be accurate. It is used only to insure that the pressure from test to test remains the same or as a cue to a leaking cup. The mixing chamber assures the thorough distribution of added moisture before the gas stream is diverted to the rest of the system.

Clear plastic is used in fabricating the absorption cups (Fig. 6). The importance of relocating them precisely in the identical area for a test

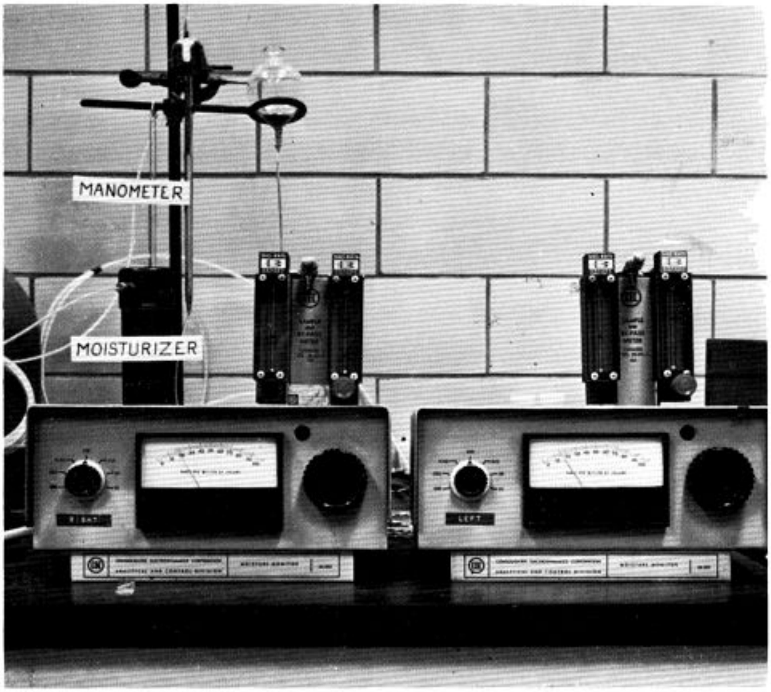

Figure 10. Moisture monitor assembly

series requires sufficient visibility for locating placement marks exactly. Note the concentric sections. Dry air in the center one sweeps away the moisture for measurement while a vacuum in the outer section holds the cup in place. A vacuum of more than 130 mm should never be used, as this may injure the subject. Preferably it should remain between 50–75 mm.

The cups are placed into the shaved axillae of the subject after he has been rolled into the heating chamber (Fig. 7) and is comfortable on his back. The gas stream is turned on at about 1200 cc per minute, and the whole system is allowed to dry down. The subject should not be perspiring at this point.

The heating chamber (Fig. 8) consists essentially of a large inverted box on legs into which a subject, lying on his back, may be rolled. His holding the trapeze-like accessory both positions and limits the motion of his arms which may disturb the cups. With the side doors closed the temperature is raised by a circulating hot air blower and controlled by an electronic temperature sensing device. A clear plastic plate (6 mm) has been used throughout its construction to forestall claustrophobic tendencies of the subjects by allowing them to see out on all sides.

The temperature controller (Fig. 9) senses the temperature in the air duct rather than in the chamber and is set for a temperature higher than that actually applied to the subject. However, it is calibrated to produce the desired exposure temperatures, which are read on an auxiliary thermometer. The rapid cycling of the heater that results from this arrangement maintains extremely stable exposure temperatures.

The level of temperature to which each subject is exposed depends

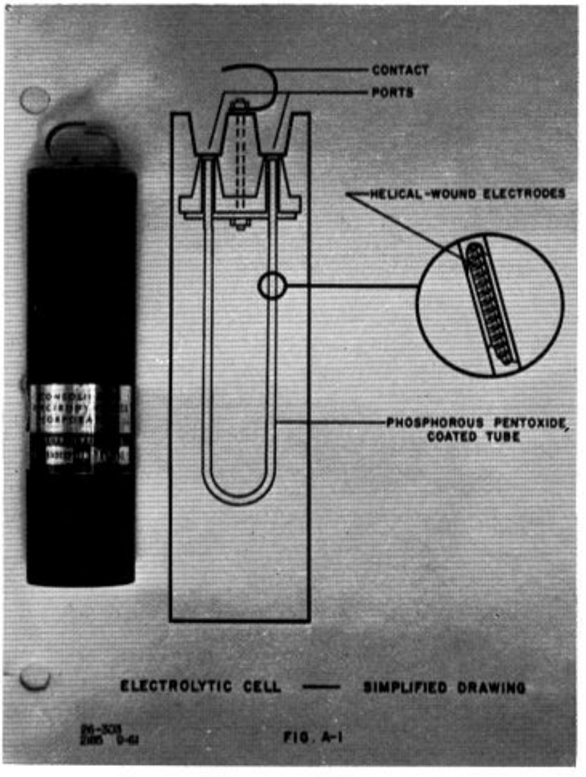

Figure 11. Phosphorous pentoxide cell

upon his particular nature and to outside relative humidity. Each individual has a different and critical temperature-humidity ratio above which active perspiration ensues. The relative humidity tends to remain fairly stable during tests; thus the critical temperature of the subject is of greater concern and is determined at the start of a test for each. During a test the subject is heated to his critical temperature or slightly below. His perspiration is then brought about by having him work his legs as if riding a bicycle. To decrease the perspiration he is allowed to

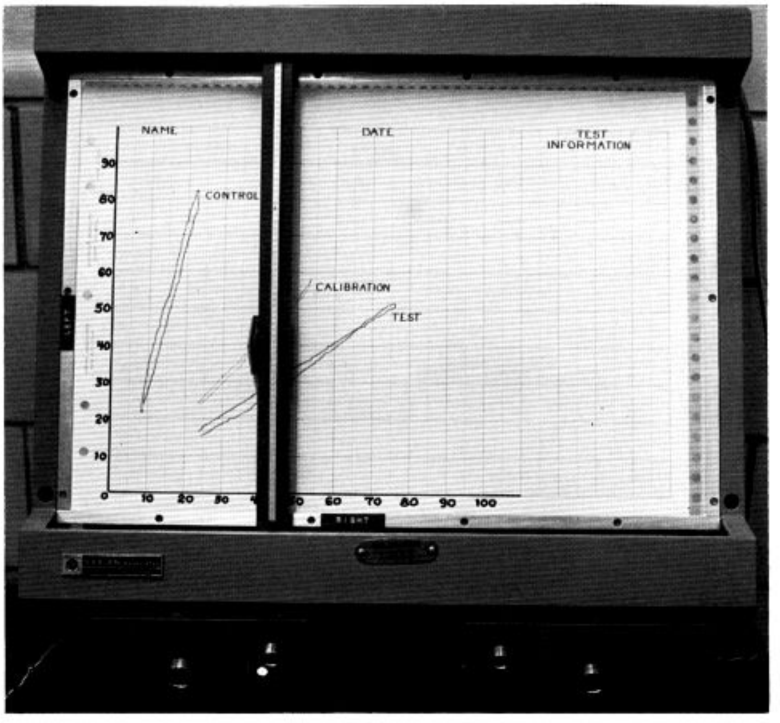

Figure 12. x-y recorder

rest. In this way, the variation in perspiration will cause the *x-y* recorder to trace a sloped pattern on the graph.

It has been found that when a subject lies still in the warm atmosphere he may be lulled to sleep by the hypnotic drone of the equipment. When asleep, his perspiration can become quite erratic. An actual alternating pulse of one axilla followed by the other has been observed.

The moisture monitors (Fig. 10) are placed side by side so that their meters may be viewed simultaneously. The two flow meters on the top right of each instrument measure the total flow of gas and the quantity that is sampled for moisture content. The system is calibrated to read in μl/l (parts per million) of moisture when the sample flow is set for 10 ml/min. Since the measurements required are all relative, the exactness of this calibration is unimportant. However, the gas flows should not change during a test.

Several scales may be selected by the attenuator switch on the left front of each instrument. Its position will depend on the relative output of perspiration of the subject under test.

The large black knob on the right front of each instrument encloses the moisture sensing cell (Fig. 11). It consists of a capillary U-tube containing two separate spiral electrodes. The whole assembly is en-

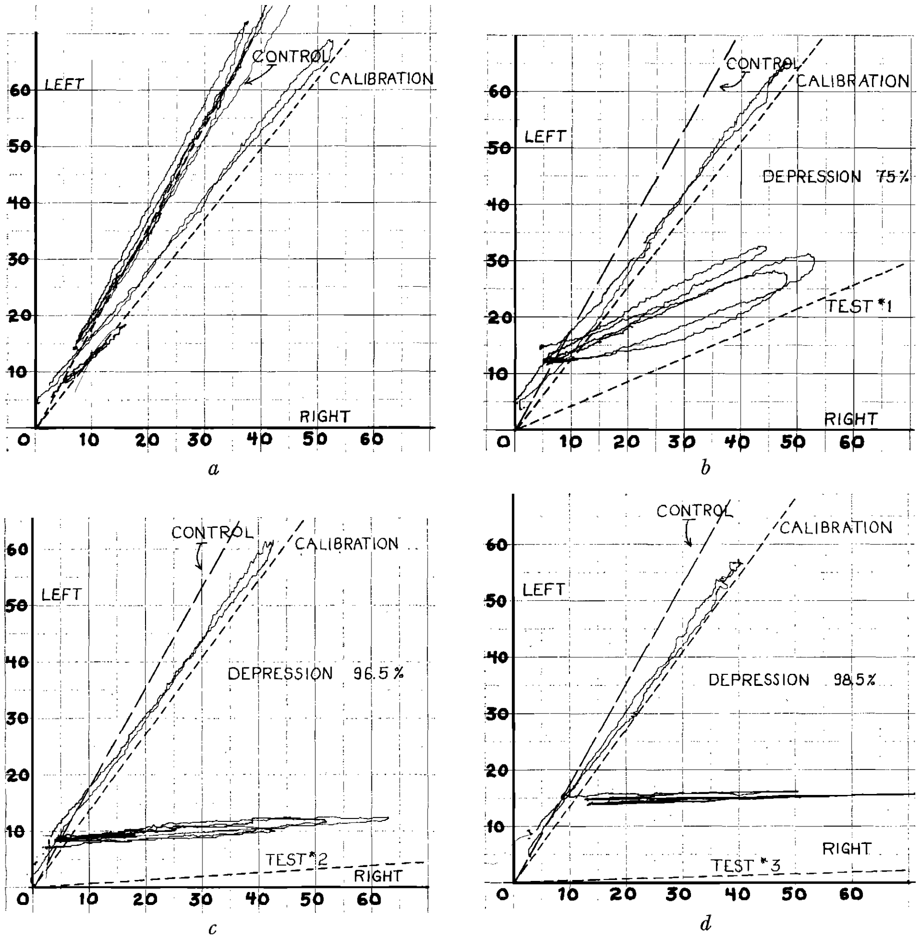

Figure 13. Results of a series of tests as outlined in Table 1: 13a is the control; 13b is Test 1; 13c is Test 2; and 13d is Test 3 (note changing slopes)

capsulated in epoxy resin. The electrodes are activated with phosphoric acid which, when subjected to an electric current, is converted to the non-conducting phosphorus pentoxide by the electrolytic destruction of the water present. As a result, the conductivity of the cell is reduced essentially to zero. When the cell senses moisture, its conductivity will rise accordingly. The meter reads this conductivity and will balance when the input of moisture equals its destruction.

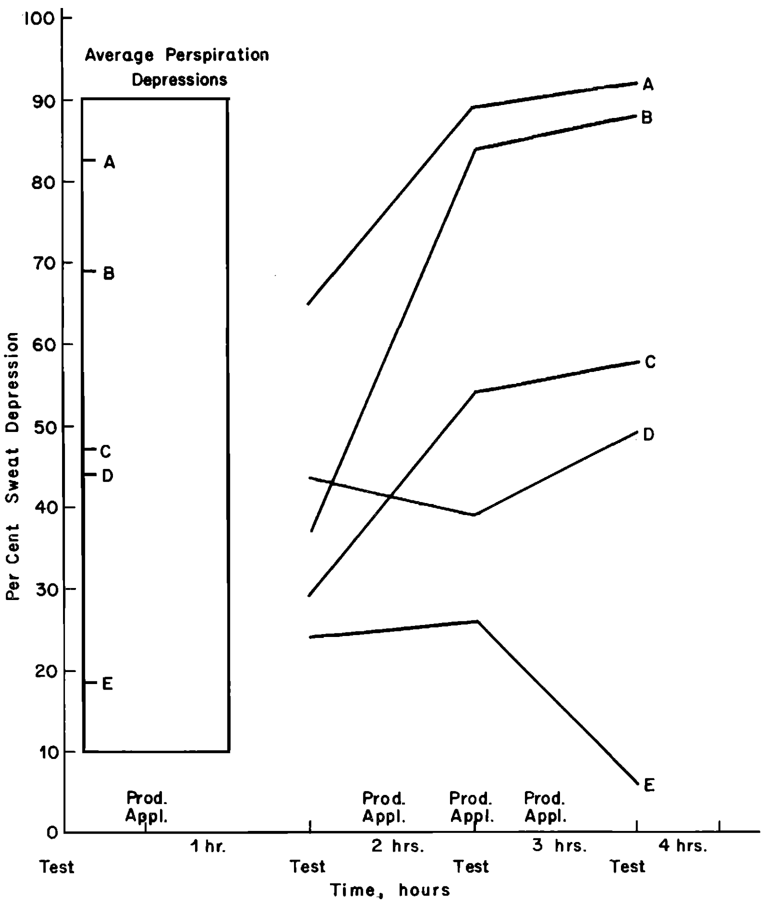

Figure 14. Graphic comparison of the test results obtained for five products, each tested on five subjects

This type of sensor was specifically chosen because it records all of the moisture present in the stream. It is insensitive to relative humidity variables in the gas stream caused by temperature changes. The slight changes which may occur in the gas velocity due to small temperature changes are negligible.

Finally, the electric signals representing changing moisture levels in the two gas streams are delivered to an *x-y* recorder (Fig. 12). This machine automatically plots the values received from each area being measured against one another. The simultaneous variations in perspiration rates represented by these values appear as a line pattern with a distinct slope representing the desired ratio. Retraces should be run for a period of time, generally 15 to 30 min, which is sufficient to produce a suitable pattern from which an accurate slope may be determined. After each test a blank run is made to determine the normal slope the machine will produce with both cups sensing equal moisture levels. This may be done by first sealing the sensing part of the cups with plastic caps. Then, manual manipulation of the wet gas valve will cause this calibration line to be drawn. Deviations in the slopes of these lines appearing in a set of tests may be utilized to correct the test associated with them. It has become standard practice to correct all charts to a calibration with a slope of 1. All charts may then be compared directly.

Results

A series of four charts (Fig. 13) illustrates the information developed from a test designed to obtain the maximum perspiration reduction in four hours. The testing procedure is as outlined in Table I.

In Fig. 13a the pattern labelled "control" is the recording obtained from an individual with no product applied to either side. The pattern labeled "calibration" represents what the system will record when both cups are sensing equal or nearly equal moisture levels. This graph represents the type of initial control information obtained from each test subject and demonstrates the normal ratio for the subject under test before a product is applied.

Figure 13b shows the new ratio (test 1) obtained, after the first application (See Table I) has depressed the perspiration of the left side. The dotted line lobeled "control" has been drawn in to show the relationship of the original ratio to the new ratio labeled test 1. A reduction of 75% of the original perspiration rate may be calculated from this chart.

Figures 13c and d show the further change in the ratios measured as more product is applied in accordance with the schedule in Table I. When compared to the original control line, the pattern, labeled test 2 in Fig. 13c, is lower than the one for test 1 and represents a depression in the perspiration rate of 96.5% in Fig. 13d. The pattern for Test 3 is even lower and represent a 98.5% reduction of the perspiration rate.

Data showing the effect of a product on five subjects which was obtained in the manner described above are compiled in Table II. One can see how the effect of a product can vary from individual to individual, particularly on the initial application. Similar data comparing one experimental and four commercial products in Fig. 14 show a wide

Table I
Outline of the Testing Procedure

Time	Test	Product Application[a]
0	√	
.5		√
1		
1.5	√	
2		√
2.5	√	√
3		√
3.5	√	
4		

[a] Product applied before test.

Table II
Typical Results Obtained for a Test of One Product on Five Subjects

Product: A	Test No. 1	Test No. 2	Test No. 3	Average	Dev.	Dev.^{2}
W. V.	89.0	80.0	94.5	87.8	+ 5.6	36
J. M.	80.0	98.5	98.5	92.7	+10.5	121
L. M.	95.0	96.5	95.0	95.5	+13.3	169
F. S.	22.5	73.5	82.5	59.5	−22.7	529
R. G.	41.0	98.0	96.0	78.3	−3.9	16
Average	65.4	89.3	92.0	82.7		S.D. ± 14.7

All values are per cent depression of perspiration.

variety of results. Considering the implication of the claims made for the commercial products *B*, *C*, *D*, and *E*, much investigation is still needed before these implications of high efficiency may be stated as fact.

Summary

In summarizing, a new electronic system of measuring anti-perspirancy has been described. Since it continuously records the ratio of perspiration rates between two areas it has illuminated several facts:

1. The ratio of perspiration rates between two areas on the same human body remains constant over a considerable range of perspiration. The original assumption that this was true has been proven to be correct.

2. Previous methods which developed the ratio from the averages of recorded data have had an unnoticed additive error built into their calculations.

3. The new method has demonstrated a means of eliminating this error in order to obtain more accurate information about the effect of antiperspirants on human subjects.

4. The method produces results about as rapidly as the subject in test can generate perspiration.

(Received May 10, 1966)

REFERENCES

(1) Daley, E. W., Antiperspirant testing: A comparison of two methods, *Proc. Sci. Sect. Toilet Goods Assoc.*, **30,** 1 (December, 1958).
(2) Brun, R., Studies on perspiration, *J. Soc. Cosmetic Chemists*, **10,** 70 (March, 1959).
(3) Takahashi, T., and Wada, M., The permanent recording of sweat by plastic impression, *J. Invest. Dermatol.*, **38,** 197 (1962).
(4) Kilmer, F. S., Reller, H. H., and Snyder, F. H., The antiperspirant action of topically applied anticholinergics, *J. Invest. Dermatol.*, **43,** 363 (November, 1964).
(5) Fredell, W. G., and Read, R. R., Antiperspirants and axillary method of determining effectiveness, *Proc. Sci. Sect. Toilet Goods Assoc.*, **15,** 23 (May, 1951).
(6) O'Malley, W. J., and Christian, J. E., An evaluation of the ability of compounds to reduce perspiration flow, *J. Am. Pharm. Assoc., Sci. Ed.*, **49,** 402 (June, 1960).
(7) Jenkins, J. W., Quellette, P. A., Healy, D. J., and Della Lana, C., A technique for perspiration measurement, *Proc. Sci. Sect. Toilet Goods Assoc.*, **42,** 12 (December, 1964).
(8) O'Malley, W. J., and Christian, J. E., The design of a continuous recording in vivo method of measuring sensible perspiration over a limited area, *J. Am. Pharm. Assoc., Sci. Ed.*, **49,** 398 (June, 1960).
(9) Custance, A. C., Cycling of sweat gland activity recorded by a new technique, *J. Appl. Physiol.*, **17,** 741 (1962).
(10) Jacobi, O. K., Does insensible perspiration exist independent of the activity of the sweat gland, *Am. Perfumer*, **78,** 23 (August, 1963).
(11) Thiele, F. A. J., and Schutter, K., Moisture meters for measuring the water balance of human skin, *Proc. Sci. Sect. Toilet Goods Assoc.*, **40,** 20 (December, 1963).
(12) Van Gasselt, H. R. M., and Vierhout, R. R., Registration of insensible perspiration of small quantities of sweat, *Nether. Soc. Dermatol.*, **127,** 255 (1963).
(13) Bullard, R. W., Continuous recording of sweating rate by resistance hygrometry, *J. Appl. Physiol.*, **17,** 735 (1962).
(14) Bernard, G. I., and Maibach, H. I., Effect of systemically administered epinephrine on palmar sweating, *Arch. Dermatol.*, **92,** 192 (1965).
(15) Randal, W. C., and Kimara, K. K., Pharmacology of sweating, *Pharm. Reviews*, **7,** 3 (September, 1955).