THE SPECIFIC DYNAMIC ACTION OF CARBOHYDRATE, FAT AND PROTEIN IN FIVE WOMEN

by

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Thesis submitted to the Graduate faculty of the
Virginia Polytechnic Institute
in candidacy for the degree of

MASTER OF SCIENCE

in

HUMAN NUTRITION AND FOODS

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June, 1966

Blacksburg, Virginia

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE NUMBER PAGE

ACKNOWLEDGEMENT

The author wishes to express her sincere appreciation to Dr. Marian E. Moore, her major professor, for guidance, assistance and encouragement, to Miss Mary K. Korslund for her suggestions and aid throughout the study and to Dr. R. E. Webb for his interest.

Appreciation is also expressed to all persons serving as subjects, to Dr. S. J. Ritchey for his help and suggestions, to Miss Gray Rivers for helping with the gas analysis and to Miss Page Godsey and Mrs. Sue Koons for their assistance in conducting the energy metabolic tests.

To Miss Lucy Towe and Mrs. Ruth Wright, for their technical assistance, and to the many others who helped make this study possible, the author is grateful.

CHAPTER 1

INTRODUCTION

The term "Specific Dynamic Action of Foodstuff" was introduced approximately sixty years ago by Rubner (1). He defined the "Specific Dynamic Action of Foodstuff" as a measure of a specific kind of energy which was evolved after the ingestion of food; this extra energy being the amount over and above the requirement of energy by the organism.

Most of the studies of the specific dynamic action of foodstuffs were conducted in the earlier part of the twentieth century. At this time controversial theories underlying the cause of specific dynamic action were proposed. Although modern investigators have contributed a few more details, no adequate theory has been established as yet.

The specific dynamic action of a food can best be determined by administering a basal metabolism determination to a subject in the morning and having him ingest a measured amount of one or a mixture of the nutrients: carbohydrate, fat and protein. In the following hours a rise in heat production, increase in oxygen consumption and an increase in carbon dioxide production will be observed with a later decline and return to normal. The extent of the increase above basal energy metabolism will depend on many factors, including the amount of foodstuff and the type of compound administered, the basal energy metabolism of the subject and physical and/or psychic factors affecting the subject.

Investigators, differing in opinions as to the best method to use in expressing the energy increase of specific dynamic action, have applied numerous methods to determine the extra energy observed following the ingestion of a foodstuff. Some studies have used the non-protein respiratory quotient as a guideline for determining the peak of specific dynamic action and the decline to the basal line; total heat production over an area for a period of time has been applied by others.

The purpose of this study was to determine the specific dynamic action of the individual nutrient: carbohydrate, fat and protein in five women of two age groups. The extra energy produced was observed as energy increment resulting in changes of respiratory quotient and as the energy expenditure increase above basal metabolism in relationship to time after the ingestion of the nutrient.

Studies that have previously been conducted using sucrose are quite limited in number and types of subjects. Numerous experiments measuring the specific dynamic action of high-fat meals, high-protein meals and mixtures of fat, carbohydrate and protein are found in the literature, but no study has been conducted to determine the specific dynamic action of the individual nutrient: carbohydrate, fat and protein in women.

Looking toward the future, the use of specific dynamic action of foodstuff in human subjects may become valuable for diagnosing borderline cases of hyperthyroidism and be suggestive of the most opportune time for treatment (2). The number one health problem in the United States today, obesity, has been and should continue to be studied in greater detail from the viewpoint of the specific dynamic action of foodstuffs (3-5). This area in human nutrition has an urgent and increasing need for more fundamental research.

CHAPTER II

REVIEW OF LITERATURE

The phrase, "the specific dynamic action of foodstuffs" which was first introduced by Rubner (1) has been termed "thermic energy" by Kellner (6) and Mollgaard (7) Zuntz (8) has referred to the same phenomenon as "energy of the intestinal work." In the following discussion, the terminology will be the specific dynamic action of nutrients.

Summary of Specific Dynamic Action Theories

Four theories on specific dynamic action have been summarized by Brody and Proctor (9) as follows: 1. Voit's theory is the one most widely known and accepted in the United States. He believed that the body cells are excited by the nutrient fragments (amino acids) to a higher level of energy metabolism. Along this same line of thinking was Grafe's ammonium stimulating theory which proposed that the ingestion of ammonium chloride and acetamide increased the heat production in the body. Grafe found that the ammonia or amino group stimulated the metabolic activity of the body cells. Lundsgaard agreed with Grafe's theory and believed that the cause of specific dynamic action must be some phase of urea synthesis or that it is due to the cell-stimulating action of the amino or ammonia groups liberated during deamination. On the contrary, Benedict states: "It seems clearly established that acid bodies are absorbed from the food which circulate in the blood and increase cell activity markedly, so that when food is supplied the cells are stimulated to a metabolic level considerably above that of the fasting animal." (Original not seen)

2. Rubner proposed that the specific dynamic action of protein represented "the free energy" liberated incident to the transformation of the excess amino acids to sugar and urea.

3. According to the Zuntz theory, the specific dynamic action represents the energy expense of digestion, absorption, excretion and secretion.

4. The mass action theory of the specific dynamic action is that increased concentration of given metabolites in the body accelerates the speed of their metabolism in accordance with the chemical law of mass action.

In 1933 Brody and Procter studied these four theories and concluded: "It is probable that the specific dynamic action is an unknown function of many, or all of the factors considered in the above theories; and that the true quantitative formulation of the ultimate explanation of the specific dynamic action will await the accumulation of adequate data on the contributions of each of the factors enumerated to the total heat of specific dynamic action."

Specific Dynamic Action of Carbohydrate

In the historical accounts of the effect of food upon metabolism, considerable increases in heat production were reported with protein. It is not surprising that researchers expected a considerable rise in the metabolism with both fat and carbohydrate ingestion. The specific dynamic action of carbohydrate, being less than that for fat or protein, has been given less attention by researchers (10).

In 1908 Johansson (11), having large numbers of subjects consume various sugars, measured the increment in carbon-dioxide production. The greatest increase was observed after the subjects had ingested either levulose or sucrose while the least energy increment was produced after the ingestion of dextrose. Following the ingestion of 150 gm. of each sugar, the maximum increase was found, and the total increase in heat production above basal never exceeded six hours, the time usually accepted for the passage of food through the small intestine. Levulose gave twice the increase in the carbon-dioxide excretion as was observed with the same amount of dextrose. Dextrose and milk sugars showed an increase approximately fifty per cent less than the other sugars.

By studing changes in the respiratory quotient and variations in the total heat production during the first hour after the ingestion of the sugars, Deuel (12) compared the specific dynamic action of the various carbohydrates. An adult man ingesting 75 gm. of the various carbohydrates had the following specific dynamic action: sucrose ten per cent of the caloric value of the ingested carbohydrate, maltose nine per cent, glucose and galactose eight per cent and fructose, lactose and cooked cornstarch seven per cent. The maximal heat production usually occurred two hours after ingestion of each of the sugars, with the exception of maltose and lactose, for which the maximum increase occurred two and one-half hours after ingestion. After the ingestion of sucrose, the maximum increases in heat production occurred at 30 minutes and two hours. Following the ingestion of either sucrose or maltose, the subject returned to the basal state of energy metabolism in four and one-half hours. The specific dynamic action of lactose continued for two and one-half and three hours.

Raw cornstarch caused a slight rise at the beginning of the second hour after ingestion while cooked cornstarch pudding caused an immediate increase in heat production that continued throughout the first hour, after which it dropped to the basal level. With cooked cornstarch, a slight rise was evident at the termination of the second hour when the heat production had increased from the basal expenditure of 61.6 calories to 65.4 calories. The return to the basal level was observed in the subjects in four and one-half hours after the ingestion of the cooked cornstarch. Except for the raw starch, the cooked cornstarch had the smallest specific dynamic action of any of the carbohydrates tested.

Hydrolysis did not delay the rapidity with which sucrose could become utilized. After the subject's ingestion of sucrose the maximum respiratory quotient was observed within thirty minutes and a return to the baseline was found in four and one-half hours after the ingestion. Little relationship existed between the time of maximum heat production and that of the highest quotient.

Benedict and Carpenter (10) have summarized the heat production and changes in respiratory quotient observed when three men consumed varying amounts of sucrose (Appendix, Table 1-2). The normal respiratory quotient for post-absorptive individuals has been observed at 0.81 to 0.83. A respiratory quotient of 0.90 and above is found frequently after the ingestion of carbohydrates.

An increase in production of carbon dioxide, as well as respiratory quotient, has been found after the ingestion of carbohydrate (10). Three possible explanations for this increase are (10): 1) fat-carbohydrate-protein combustion is replaced by an exclusively protein-carbohydrate combustion, without altering in any way the total amount of energy transformed, 2) transformation of carbohydrate into fat occurs, and 3) an increase in the total catabolism is caused by an increased tonus and an increased activity in the digestive tract due to the stimulating effect of the absorbed food materials upon the body cells.

It has been reported that the specific dynamic action increases with increased food intake (12). Law and Gay (13) investigated the production of heat after various carbohydrates were administered to a healthy eleven year old girl. The specific dynamic effects of ingesting 1.75 gm. of carbohydrate per kg. of body weight are given in Appendix, Tables 3-4 .

The increase in heat production in Law's subject was much greater than that observed by Lusk (14). Lusk concluded after dogs ingested 50 gm. of various carbohydrates that the greatest increase in heat production after ingestion of the sugars occurred as follows: fructose, sucrose, dextrose, galactose, and lactose (14). In contrast, Law observed that the greatest increase in heat production occurred after the ingestion of sucrose while after the consumption of dextrose the least increase in heat production was evident (Appendix, Table 4). However, Lusk's data is supported by the findings of Deuel (12).

For various carbohydrates there is a close relationship between the time of greatest increase in production of heat and that of the peak of the blood sugar curve (13).

Specific Dynamic Action of Fat

While carbohydrate can easily be consumed by subjects, finding subjects willing to ingest large quantities of fat is more difficult. In reviewing the literature only two accounts of the specific dynamic action of fat in human subjects were found. One of these studies was conducted in 1901 by Koraen who consumed 65.6 gm. of fat and found no increase in energy metabolism after ingestion of the fat. Some authors question the validity of Koraen's baseline (10).

In 1911 Gibon (16) conducted two experiments and observed, following the ingestion of 50 gm. of olive oil, a distinct decrease from basal metabolism. With 150 gm. of oil the energy metabolism increased slightly above basal.

The ingestion of cream caused increased heat production (10). The heat increment was found to be less than that produced with an equivalent amount of energy from either carbohydrate or protein.

Specific Dynamic Action of Protein

Protein produces a greater effect upon the energy metabolism than either carbohydrate or fat (10) It produces such an increased energy metabolism that earlier observers thought the specific dynamic action of this nutrient was the only one that could be measured (10). Very few experiments have been recorded in which relatively pure protein has been ingested by human subjects.

In 1910 Benedict and Carpenter (10) recorded the first attempts to determine by direct calorimetery the influence on energy metabolism of ingesting protein. Glidine, a vegetable product from gliadine of wheat containing 87 per cent protein, was ingested in amounts of 45 and 70 gm. by two subjects. Observations were made using a chair calorimeter. The results are given in Appendix, Tables 5-6 . After the ingestion of 45 gm. of glidine, marked effects upon metabolism were shown and an even more pronounced and longer effect was produced after the consumption of 70 gm. of glidine.

Benedict and Carpenter (10) also conducted four experiments with two subjects who consumed gluten, a pure vegetable protein, along with skim milk. This study indicated a distinct increment in energy metabolism following the ingestion of protein (Appendix, Table 7). Increments were found in gaseous metabolism, heat production, and nitrogen excretion, all considerably higher than basal energy metabolism even at the end of the period of observation. The greatest increase in heat output occurred in the first four hours of the experiment.

In two experiments plasmon, an animal protein derived from milk, was administered to two human subjects (Appendix, Table 8). One hundred gm. or more of plasmon with two-hundred ml. or more of skim milk, increased the heat output considerably over the basal metabolism for at least ten hours. None of the experiments cited indicated a clear-cut difference between the influence of animal or vegetable protein on energy metabolism.

Benedict and Carpenter (10) concluded that the effect of protein ingestion in almost any amount invariably produces an increase over basal metabolism which may be 25 per cent for several hours and for very short periods it may rise to 45 per cent. No definite mathematical relationship between the amount of protein ingested and the increment in the total energy metabolism has as yet been determined.

Goldzieher et al. (17) administering a meal of two egg whites, toast and tea, reported an average heat increase of 13 per cent based upon one measurement made two hours after the food was ingested. Abel (2), questioning the small amount of protein used by Goldzieher et al., fed a meal containing 123 gm. of protein and five gm. of fat. Maximum increases in energy metabolism of 20 and 19 per cent, occurred during the third and fifth hour, respectively.

To determine the effect of age on specific dynamic action values, a protein meal of 25 gm. was provided for six males age 72-84 years of age and eight males ages 20-30 years of age (18). The specific dynamic action, expressed as total excess oxygen utilization, was essentially the same in both age groups.

Normal, obese, and thin individuals were given a protein meal in an effort to determine any influence of specific dynamic action upon the development of abnormal nutritional states (5). The results indicated that nutritional states are not directly related to the differences in specific dynamic action of food in human subjects. Strang _et al_. (5) states: "The heat of the reaction to food may be reflected in sensations such as satiety and thus may influence the amount and type of food intake, which, in turn are principal factors productive of weight changes."

Approximately thirty per cent of the caloric value of protein after ingestion is given off as heat (19). Rapport and Beard (20) studied the specific dynamic action of protein and concluded that it is fully accounted for by the summated specific dynamic action of its constituent amino acids.

The studies of Lundsgaard (21) have shown that glycine, alanine, glutamic acid, aspartic acid and tyrosine all produced dynamic effects on the energy metabolism. An investigation showed positive specific dynamic effects after rats had ingested glutamic acid, glycine, alanine, tyrosine, aspartic acid and asparagine in considerable quantities.

Hawk and co-workers (22) concluded that the time for one hundred gm. of beef to be completely emptied from the stomach varied from two and one-half hours to three and one-half hours in human subjects. Thus, any of the studies reporting the termination of specific dynamic action before a two to four hour period should be questioned (5).

CHAPTER III.

METHODS AND PROCEDURES

Subjects

Subjects were five healthy adult women of normal body size. Preliminary instructions in the procedures to be followed during the study and trial use of the respirometer were given to each subject prior to the experimental period. Height and weight measurements were recorded at that time.

On the day of the experiment the subjects in the post-absorptive state (without food for at least twelve hours) were brought to the laboratory at approximately six a.m., having exerted only minimum energy for activity. After resting in bed for one-half hour, two basal metabolism measurements six minutes in duration were made and samples of the expired air were collected to be analyzed for oxygen and carbon dioxide.

Subjects consumed on different days one of the following nutrients: carbohydrate, fat or protein. With the exception of maintaining a sitting position during the time required for the ingestion of the food, the subjects remained in bed quietly and as motionless as possible throughout the day until the termination of the experimental observations.

Administration of Food and Measurements

Each subject consumed a sufficient amount of the carbohydrate, fat or protein to provide 5.7 calories per kg. of her body weight. The time required for ingestion of the food was recorded. During each measurement samples of expired air were collected for analysis throughout a six-minute period at the following time intervals after the ingestion of the food: four to ten minutes, fifteen minutes, thirty minutes, forty-five minutes, one hour and every half-hour, thereafter, until the volume of expired air approximated that of the basal state.

The carbohydrate food consisted of sucrose dissolved in 250 ml. of boiling water and cooled to room temperature before it was drunk from a beaker. Cottonseed oil served as the fat and was drunk from a beaker. One-half teaspoon or less of lemon juice was given to the subject following the ingestion of fat to cleanse the mouth. Raw egg whites cooked 15 minutes to a medium-hard stage and gelatin dissolved in 300 ml. of boiling water were used in proportions so each would provide one-half of the total protein required for each subject. Egg whites were eaten with the fingers, and the subjects were permitted to season them lightly with salt and pepper. Two tablets of saccharin and two to three drops of lemon extract were added to the gelatin to make it more palatable. The gelatin mixture was drunk while hot either accompanying or after the consumption of the egg whites depending upon the preference of the subject.

Collection and Analysis of Expired Air

The Kofrányi-Michaelis respirometer was used to measure the volume of expired air, with a rubber attachment which served as a device for the collection of samples of expired air. Portions of the expired air was transferred immediately to Bailey gas-sampling bottles. The samples of expired air in the Bailey bottles were analyzed within twenty-four hours after collection for carbon dioxide and oxygen content by the use of the Haldane-Henderson gas analyzer, according to the procedures developed by Peters and Van Slyke (23).

Calculations

The percentage of carbon dioxide and oxygen in the sample of expired air was recorded as valid data provided the duplicate samples checked within ± .05 per cent. Based upon the standard caloric factor of 4.825 Cal./liter oxygen and the liters of oxygen consumed per hour, the calories produced per hour were calculated (24). Applying Du Bois' formula, the surface area for each subject was estimated (26). The relationship of the liters of carbon dioxide produced to the liter of oxygen consumed (respiratory quotient) was calculated for each metabolic determination. The data were expressed in calories per square meter of body surface per hour.

CHAPTER IV

RESULTS AND DISCUSSIONS

Because numerous methods are used by investigators to express the specific dynamic action of food, the comparison of the results from this study with those from similar studies is difficult. Data from this study indicated no correlation between respiratory quotient and heat production following the ingestion of carbohydrate, fat or protein by women. Thus, the findings of this study will be discussed from the viewpoint of changes in respiratory quotient and variations in heat production.

Changes in Respiratory Quotient Following the Ingestion of Carbohydrate, Fat and Protein

There was a general trend for subjects with higher basal energy metabolism to have greater increases in the respiratory quotient after the ingestion of protein, or fat, or carbohydrate. The basal energy expenditures of all the subjects were: 26.5, 29.9, 30.2, 33.8, and 39.9 calories per square meter of body surface per hour in subjects IV, III, V, II and I, respectively. The effects of sucrose, cottonseed oil and egg white plus gelatin on each subject's total increase in respiratory quotient during the entire period of observation are shown in Figures 1, 2 and 3.

A prompt elevation in respiratory quotient was observed in all subjects following the ingestion of carbohydrate (Figure 1). With

Figure 1. Changes in respiratory quotient in five women after ingestion of sucrose

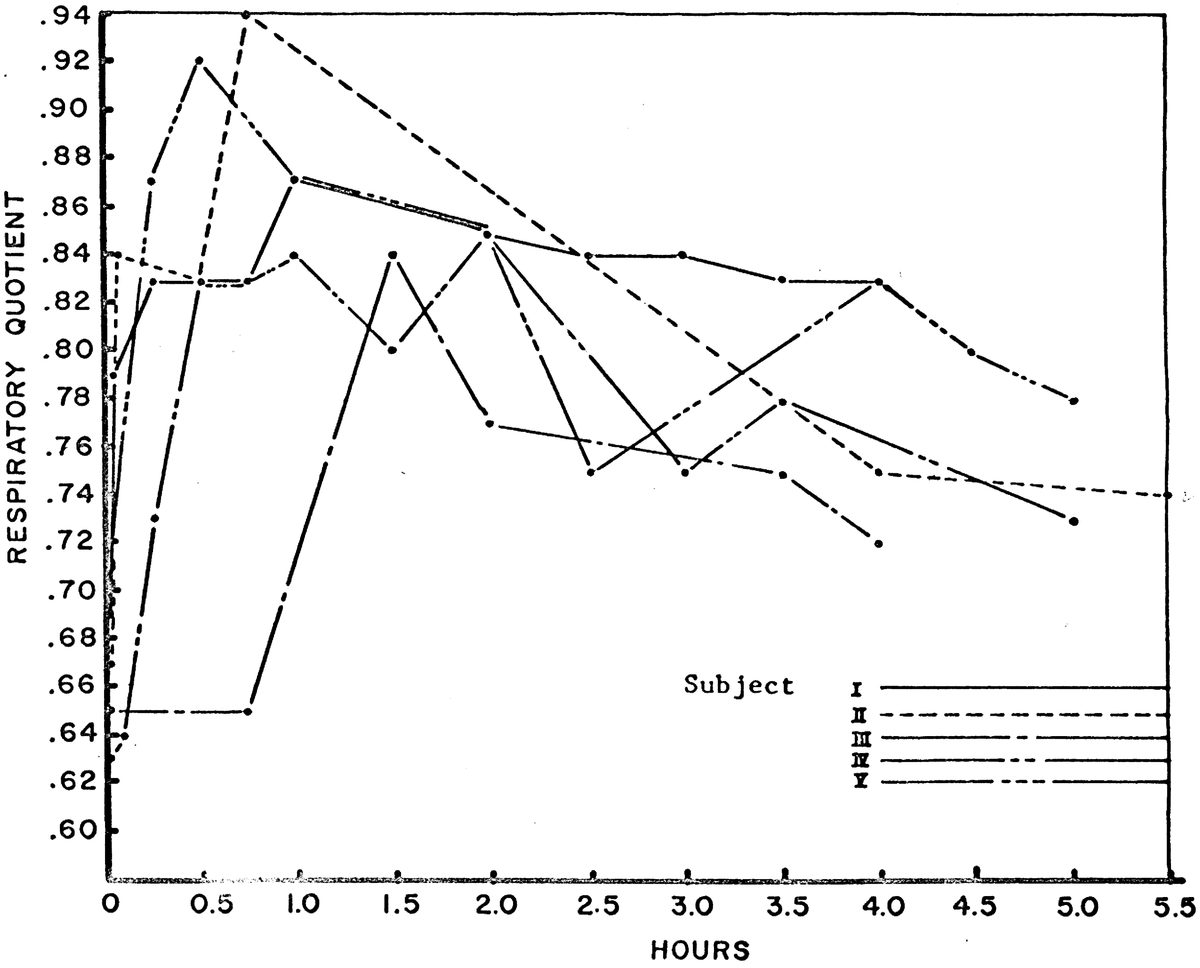


Figure 2. Changes in respiratory quotient in four women after ingestion of fat

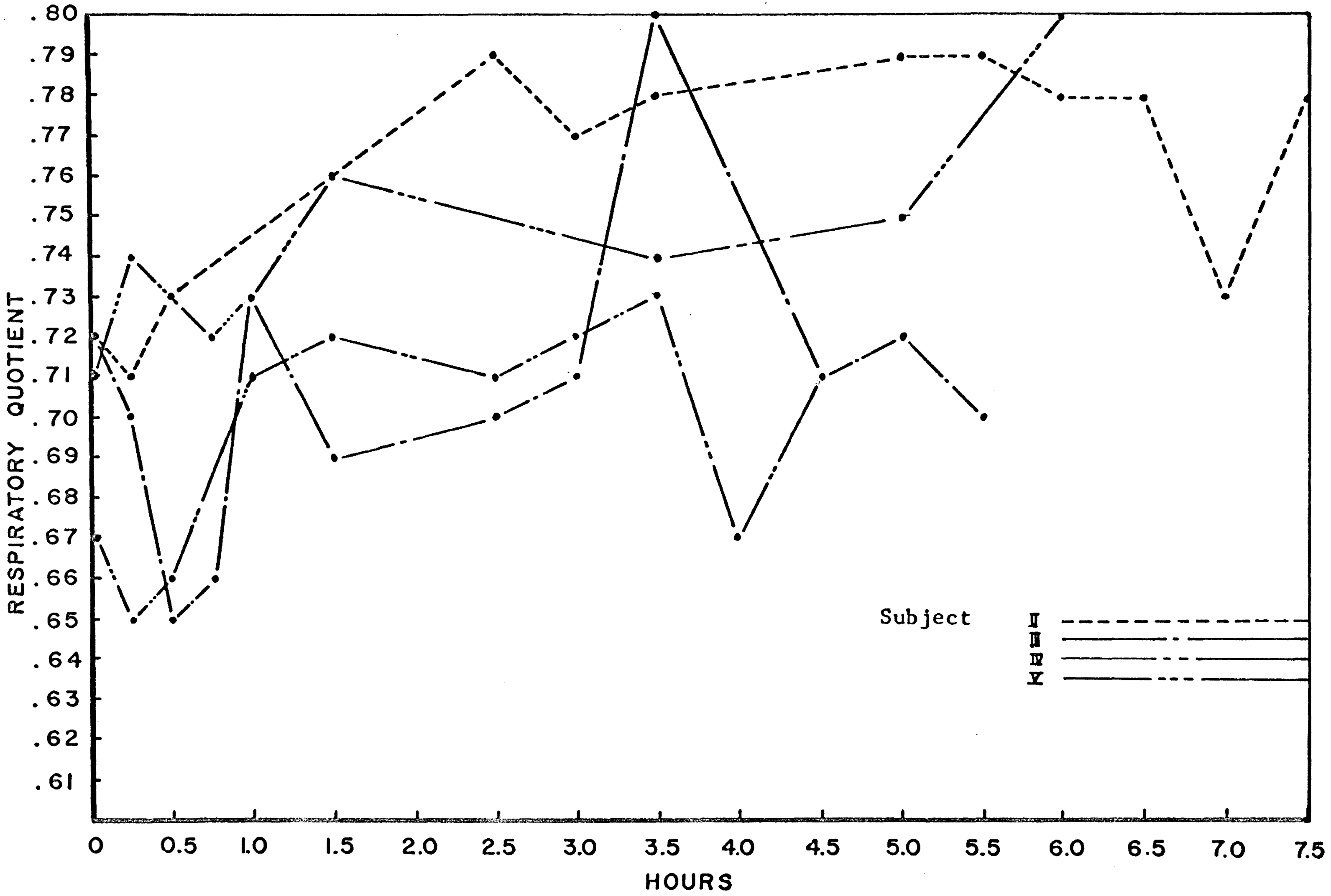
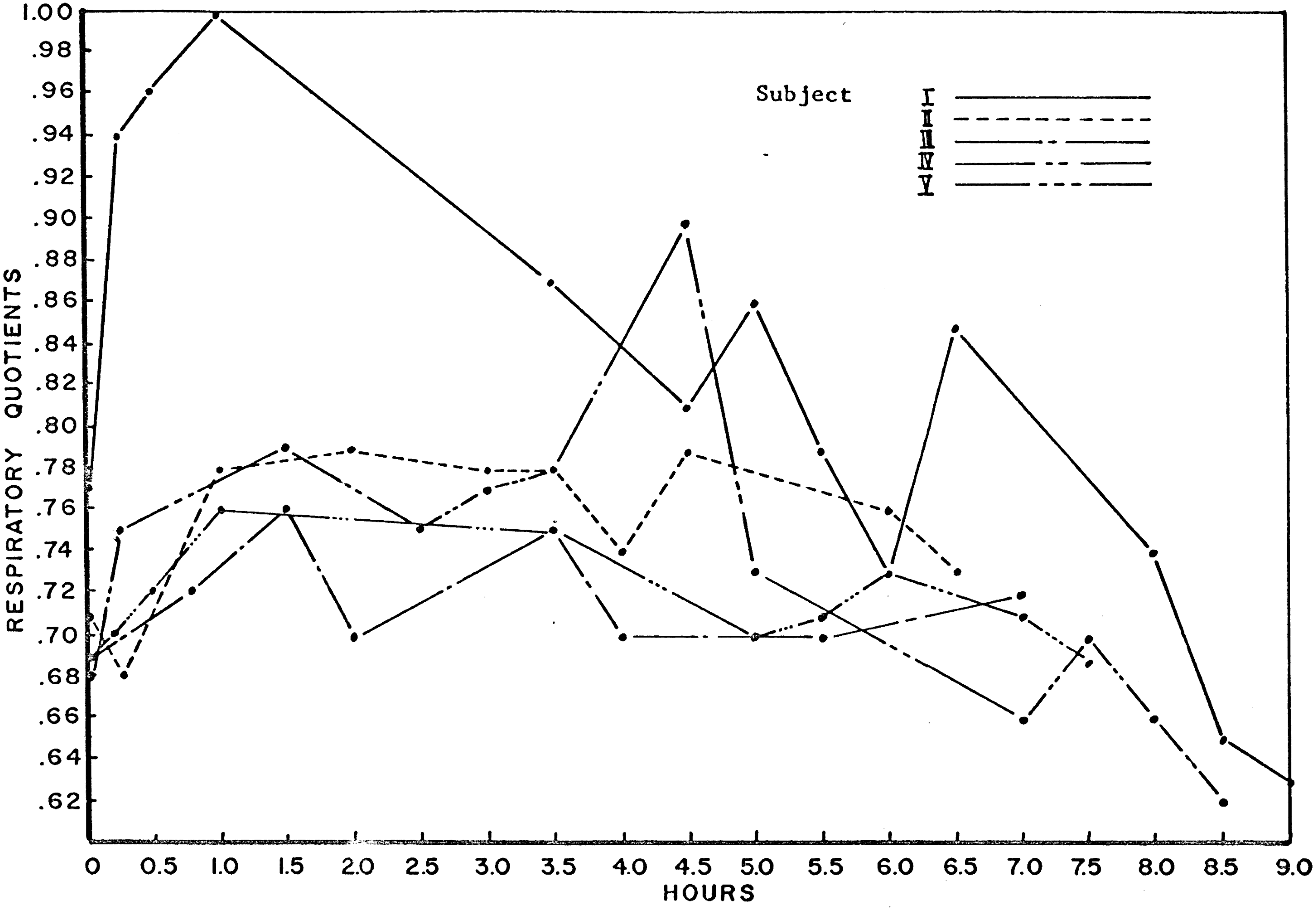


Figure 3. Changes in respiratory quotient in five women after ingestion of protein



the exception of subject III, all had similar total increases in respiratory quotient after the ingestion of sucrose.

In three of the five subjects the maximum respiratory quotient occurred one to two hours after sucrose ingestion. Benedict et al. (10) reported four studies with adult men who consumed one hundred gm. of sucrose each and in whom maximum respiratory values were found between one and two hours thereafter. The maximum respiratory quotient occurred at fifteen minutes in Subject II and at thirty minutes in Subject IV, after the ingestion of sucrose. This observation is similar to findings reported by Benedict and Carpenter (10), Deuel (12) and Law (13).

Before ingestion of carbohydrate, the fasting respiratory quotients of the subjects ranged from 0.63 to 0.72, averaging 0.67. None of the subjects showed a return to the fasting respiratory quotient at four hours or longer after the ingestion of sucrose (Figure I).

The total increase in respiratory quotients following the ingestion of fat was similar for all four subjects (Figure 2). Data from Subject I has been excluded because of her nervousness and apprehension about eating the fat. Subjects II and V who drank the greatest quantity of oil had the higher respiratory quotients. Fasting respiratory quotients were 0.72, 0.72, 0.67 and 0.71, which are lower values than those reported by Bowen and co-workers(3). They found a range in fasting respiratory quotient of 0.76 to 0.88 for individuals of normal body size. In the obese group, the variation was between 0.72 and 0.83, the average being 0.765. Bowen concluded that the respiratory quotients in the post-absorptive state were significantly lower for obese subjects than for normal subjects. All of the subjects in this study were of normal body size, yet all had a fasting respiratory quotient below those reported by Bowen _et al_. and Benedict _et al_. (3, 10). It is questionable whether obese individuals have a significantly lower fasting respiratory quotient than do normal subjects. The sex of the subjects in Bowen's study was not stated; this could account for the lack of agreement in the two reports.

The depression of respiratory quotient values that other investigators have observed after the ingestion of fat was observed in this study (3, 25).

The respiratory quotient at 15 minutes after ingestion of fat remained essentially unchanged for forty-five minutes in Subject IV, three and one-fourth hours in Subject III, and two and one-fourth hours in Subject II (Figure 2). The maximum respiratory quotient occurred at two and one-half hours in Subject III and at six hours in Subject V. Four and five hours after fat ingestion two subjects had fasting respiratory quotient values. After six or more hours, two subjects (I and V)had respiratory quotients considerably higher than their fasting respiratory quotients.

An increase in respiratory quotient was observed in four of the five subjects 15 minutes after the ingestion of protein (Figure 3). Two subjects reached a maximum respiratory quotient one hour after protein ingestion. Due to the bulk of the egg white and gelatin, all of the subjects indicated an uncomfortable feeling and some complained of nausea after ingesting them. The differences in time required by the subject to eat the protein foods varied from 13 to 54 minutes. With carbohydrate and fat there were no differences in eating time required by the subjects. These foods were consumed within five minutes or less by the subjects. Sitting for five minutes or lying in bed for five and one-half hours caused no significant changes in the volume of the expired air. (Appendix, p. 11). Considering the variations in eating time and the uncomfortable feeling of the subjects with protein, data collected prior to the first hour will not be included in this discussion. Changes in respiratory quotient during this time cannot be considered due entirely to the effect of the protein. Subjects I and V reached their maximum respiratory quotients at 1½ hours after the ingestion of protein, but it is questionable whether this increase was due entirely to the effect of protein (Figure 3). Subjects IV and II reached their highest respiratory quotients at four and one-half hours after the ingestion of the food. The total increase in respiratory quotients are similar for three of the five subjects throughout the period following the protein ingestion.

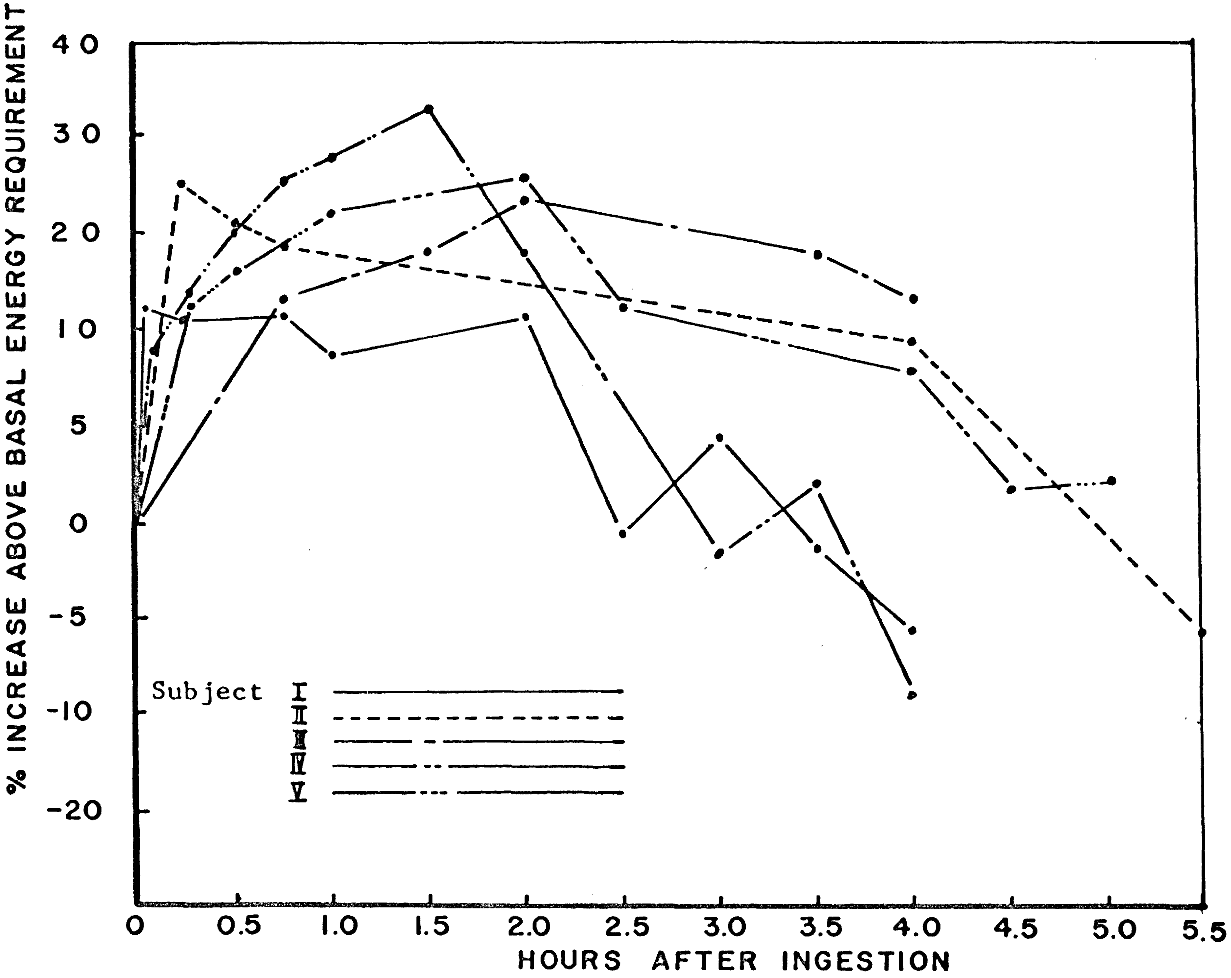
Return to the fasting respiratory quotient occurred in three of the five subjects at six, seven and seven and one-half hours after ingestion of the egg white and gelatin (Figure 3). The time required to return to the post-absorptive respiratory quotient appeared to be related to the quantity of food consumed by the subject. The three individuals (Subjects II, III and V) who consumed the larger amounts of protein approached their fasting respiratory quotients at a much slower rate than those individuals consuming lesser amounts of protein. One subject had a post-absorptive respiratory quotient at 7½ hours, while the other subjects showed no indication of approximating the baseline at 6½ to 7 hours after the ingestion of protein.

Variations in Heat Production After Ingestion of Carbohydrate, Fat and Protein

Law (13) observed the greatest increase in heat production one hour after the ingestion of sucrose. In this study Subject IV had the greatest heat production at one and one-half hours after sucrose ingestion. The time of maximum heat production for the other subjects was: Subject I, four minutes; Subject II, 15 minutes; Subject III, two hours; and Subject V, two hours (Figure 4).

In three of the five subjects there was a decline in heat production below the basal energy metabolism after ingestion of sucrose. Heat production decreased to -0.39 and -1.4 per cent of basal energy metabolism in Subjects I and IV, respectively, at two and one-half hours after the carbohydrate was ingested. Subject II was 5.5 per cent below the basal value for energy metabolism at five and one-half hours while the data for Subject III and V gave no evidence of a return to

Figure 4. The effect of ingestion of sucrose on heat production in five women



the baseline after four and one-half hours, respectively. These observations of variations in heat production do not parallel the changes in respiratory quotient following the ingestion of sucrose (Figures 1 and 4). In contrast, Deuel (12) reported a return to the fasting respiratory quotient at four and one-half hours after the consumption of sucrose, but he did not observe a return to basal heat production. The results from this study show no indication of the subjects' return to the fasting respiratory quotients, but three of the five subjects dropped to or below the basal heat production two and one-half to five and one-half hours after the ingestion of sucrose (Figure 4). These results (Table 1) are in agreement with Deuel's statement: "there seems to be no relationship between the amount of specific dynamic action occasioned and the degree of the total carbohydrate metabolism. There is little relationship between the time of maximal heat production and that of the highest quotient"(12).

The maximum increase in heat production in five women after ingestion of fat and the time required for the maximum increase to occur are given in Table 2. Age, basal energy metabolism, body size or amount of fat ingested do not seem to be the factors responsible for any similarities among the subjects in time required to reach maximum heat production or the magnitude of increase (Appendix, Table 14).

TABLE 1

Time required, after the ingestion of carbohydrate by five women, to reach highest respiratory quotient and highest heat production

Subject	Maximum Respiratory Quotient	Maximum Heat Production
I.	1 hr.	4 min.
II.	½ hr.	15 min.
III.	½ hr.	2 hr.
IV.	2 hr.	1½ hr.
V.	½ hr.	2 hr.

TABLE 2

Maximum increase in heat production in four women after ingestion of fat and time required for maximum increase to occur

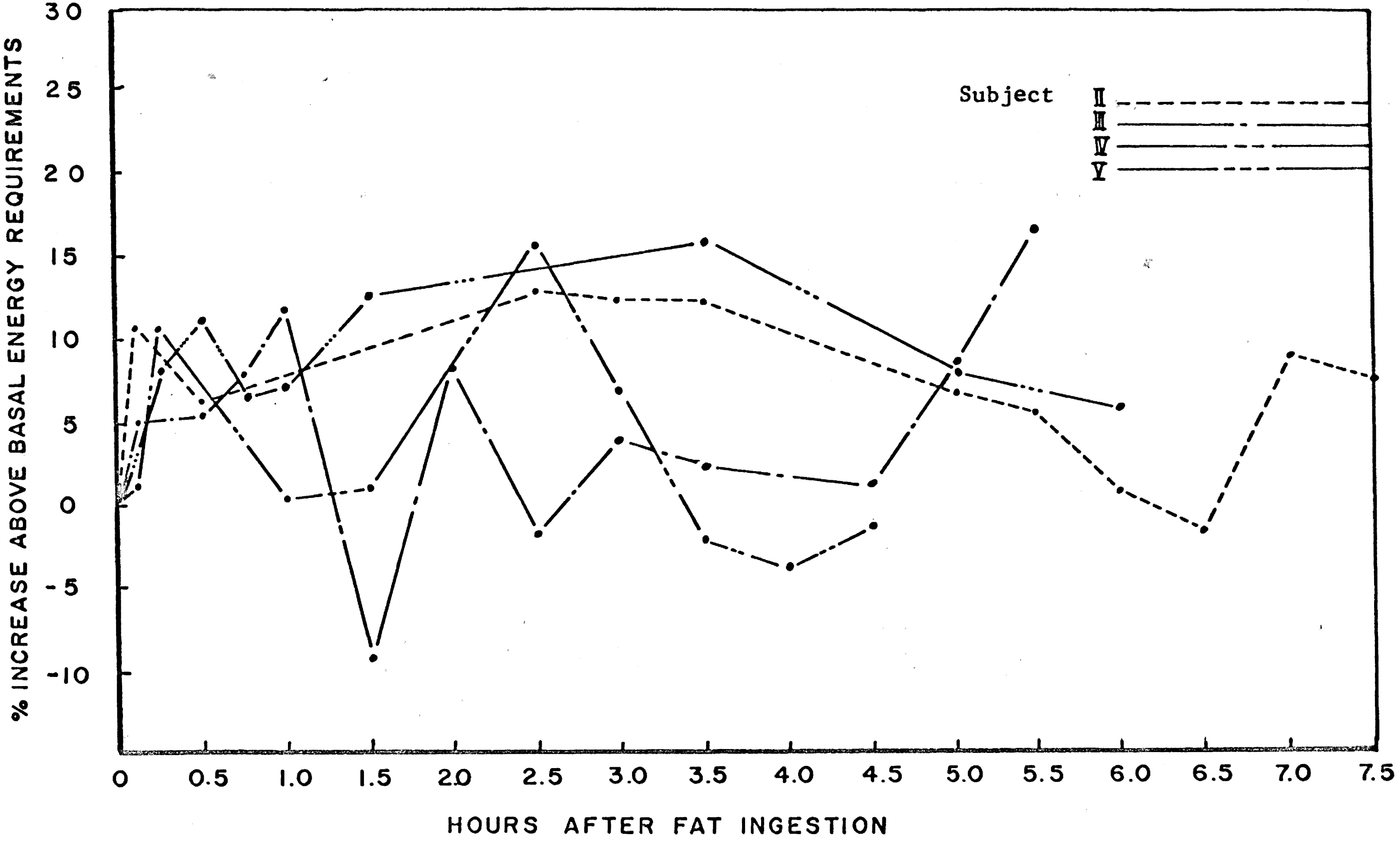
Subject	Hours	% Increase Above Basal
II.	2½	13.0
III.	2½	15.6
IV.	3½	15.6
V.	5½	16.4

A decline to basal heat production was observed in Subject II six and one-half hours after the ingestion of fat (Figure 5). In Subject III there was an increase in heat production at five and one-half hours after fat ingestion. Energy expenditure of 2.4 per cent below basal metabolism was observed in Subject IV, three and one-half hours after ingestion of fat, followed by an increase in heat production of 3.8 and 1.2 per cent above basal energy metabolism at four and four and one-half hours, respectively. After six hours, energy metabolism in Subject V was 1.6 per cent above the basal heat production.

There was no correlation between respiratory quotient and heat production with regard to the time required for return to the basal state. After five and one-half hours, subject III had a fasting respiratory quotient, but heat production had returned to the basal at three and one-half hours after the ingestion of fat. Subject IV had a post-absorptive respiratory quotient at four hours after the ingestion of fat, but the peak of the heat production was reached one and one-half hours later.

Bowen (3) has reported that the effect of the food on energy metabolism was evident in subjects at the end of five hours of observation, even though the respiratory quotients had returned to the fasting levels in the obese and obese diabetics. He concluded that the extra heat production is more or less independent of the magnitude of the variations of the respiratory quotients.

Figure 5. The effect of ingestion of fat on heat production in four women



The lowered heat production that occurred after the ingestion of fat in Subjects II, III and IV in this study is similar to changes that have been observed by others (3, 25, 26). Bernhardt found a "negative phase" after food only in subjects having high basal metabolism. No explanation as to the cause of this "negative phase" has been suggested.

The greatest increases in heat production above basal level were observed in four of the five subjects after protein ingestion. The maximum increase in heat production in five women after ingestion of protein and time required formmaximum increase to occur are given in Table 3.

None of the subjects had returned to basal heat production during observation over periods of six and one-half to nine hours after protein ingestion (Figure 6).

There was no correlation between the time at which maximum respiratory quotient occurred and the time at which maximum heat production was observed following the ingestion of protein. The respiratory quotients in three subjects indicated a return to the basal state at six, seven and seven and one-half hours after protein ingestion. However, variations in heat production did not parallel the respiratory quotient observations.

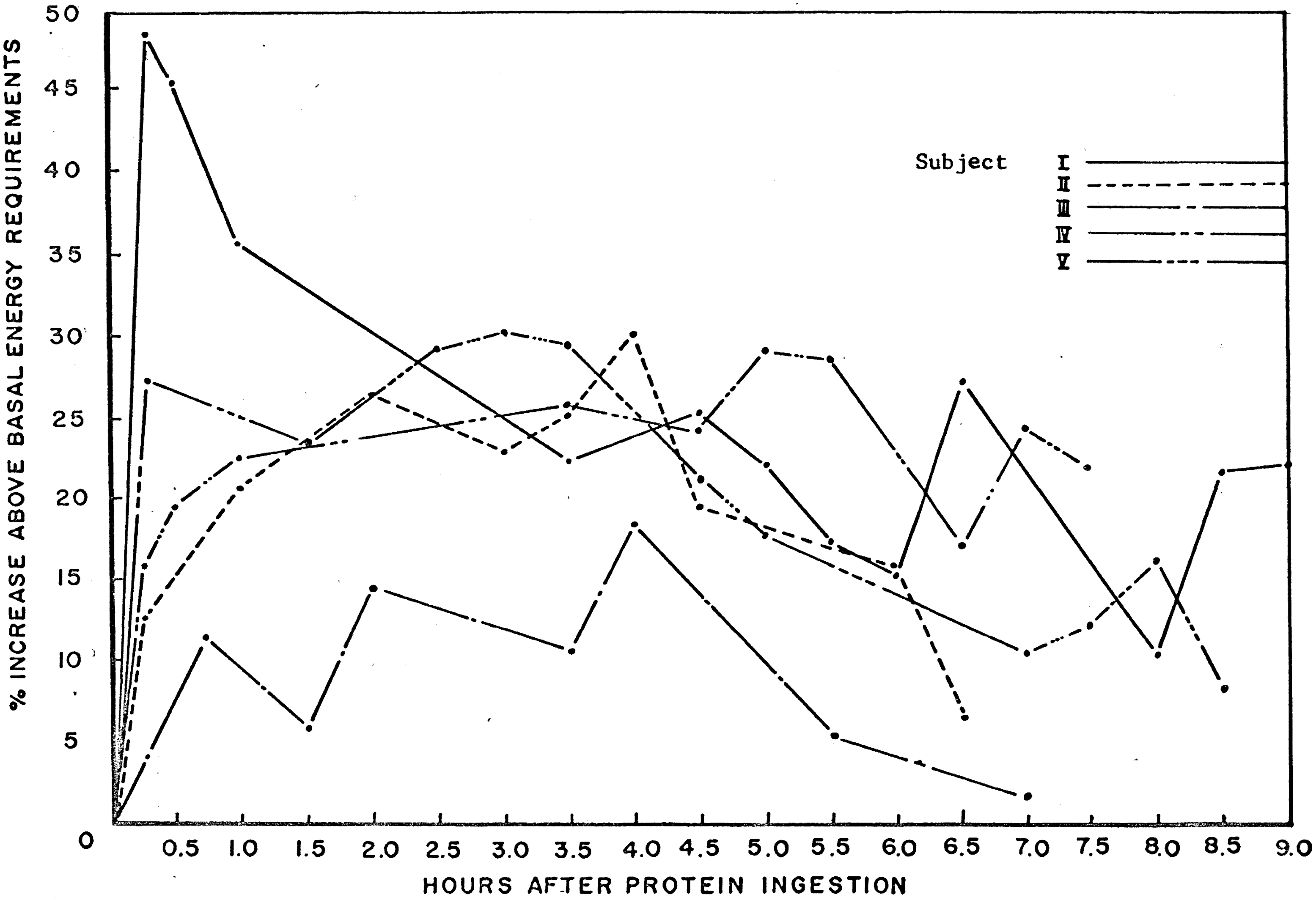
There were no significant differences in the responses of the subjects which could be related to the various age groups (Appendix, Table 15).

TABLE 3

Maximum increase in heat production in five women after ingestion of protein and time required for maximum increase to occur

Subjects	Hours	% Increase Above Basal
I.	4½	25.6
II.	4	30.4
III.	4	18.5
IV.	3	30.3
V.	5	29.3

Figure 6. The effect of ingestion of protein on heat production in five women



CHAPTER V

SUMMARY

The specific dynamic effects of carbohydrate, fat and protein were measured in five healthy women of normal body weight. Data from this study was studied from the viewpoint of changes in respiratory quotient and variations in heat production.

There was a general trend for subjects with higher basal energy metabolism to have greater increases in the respiratory quotient after the ingestion of protein, or fat, or carbohydrate. An increase in respiratory quotient and heat production was observed following the ingestion of each of three nutrients. The time required to reach the maximum respiratory quotient and the maximum heat production have been compared. There was no definite correlation between the changes in respiratory quotients and variations in heat production after the ingestion of carbohydrate, fat and protein by women.

The maximum increases in heat production were not observed in the subjects having the lower basal energy expenditures as was suggested by Abel (2).

Individuals varied in their responses to carbohydrate, fat and protein, but similarities among the individuals in their response to each of these foodstuffs was apparent.

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APPENDIX

TABLE 1

The effect on respiratory quotient and heat production in two men after the ingestion of sucrose[1]

Subject A.H.M., ingested 191 gm. sucrose with 119 gm. water; 25 minutes required for eating.

Time elapsed after eating	Heat Total Cal.	Heat Increase Above Basal Cal.	R.Q.
½ to 2½ hr.	192	28	0.95
2½ to 4½ hr.	185	21	.95
4½ to 6½ hr.	174	10	.86
6½ to 8½ hr.	173	9	.82
Total	724	68	

Subject A.W.W., ingested 80 gm. sucrose.

½ to 1½ hr.	84	66	1.19
1½ to 2½ hr.	83	5	1.02
2½ to 3½ hr.	74	-4	.80
3½ to 4½ hr.	77	-1	1.10
Total	318	6	

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[1] Bibliography reference number 10.

TABLE 2

The effect on the respiratory quotient and heat production in a man after ingestion of 100 gm. sucrose and juice of one lemon[1]

Subject F.M.M., urinary nitrogen 0.53 gm./hr. (Test 1), and 0.60 gm./hr. (Test 2); 12 minutes required for eating.

Time elapsed after eating	Heat Total Cal.		Increase Above Basal Cal.		R.Q.	
	Test 1	2	Test 1	2	Test 1	2
0 to 1 hr.	89	85	9	7	0.94	0.91
1 to 2 hr.	83	83	3	5	.99	.98
2 to 3 hr.	88	82	8	4	.87	.86
3 to 4 hr.	80	78	0	0	.89	.89
4 to 5 hr.	79		-1		.87	
Total	419	328	19	16		

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[1] Bibliography reference number 10

TABLE 3

The effect on the respiratory quotient in an eleven year old girl after ingestion of 48 gm. of various carbohydrates[1]

Nonprotein R.Q.

	Dextrose	Fructose	Galactose	Dextrimaltose	Lactose	Sucrose
Basal	0.75	0.74	0.92	0.75	0.76	0.83
Time after ingestion (minutes)						
30 min.	0.84	0.87	0.84	0.88	0.87	1.02
60 min.	0.87	0.91	0.88	.90	.87	.85
120 min.	0.87	0.88	0.93	.82	.92	.83
180 min.	0.92	0.86	0.69	.89	.85	.88
240 min	0.81	0.77		.74	.76	.89

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[1] Bibliography number 10

TABLE 4

The effect on the heat production in an eleven year old girl after ingestion of 48 gm. of various carbohydrates[1]

Heat Production

	Dextrose		Fructose		Galactose	
	Total Cal./Hr.	Percentage Increase Above Basal	Total Cal./Hr.	Percentage Increase Above Basal	Total Cal./Hr.	Percentage Increase Above Basal
Basal	46.86		49.00		45.0	
Time after ingestion (minutes)						
30 min.	49.23	5	55.1	12.5	46.2	4
60 min.	47.98	2	56.6	16.0	52.7	19
120 min.	48.20	3	53.0	8.2	49.1	10
180 min.	43.30	-8	46.0	-6.0	49.9	12
240 min.	47.00	0	50.8	4.0		

	Dextrimaltose		Lactose		Sucrose	
	Total Cal./Hr.	Percentage Increase Above Basal	Total Cal./Hr.	Percentage Increase Above Basal	Total Cal./Hr.	Percentage Increase Above Basal
Basal	44.7		46,1		40.9	
Time after ingestion (minutes)						
30 min.	52.0	16	52.5	14	51.4	26
60 min.	51.1	14	49.4	7	53.9	32
120 min.	51.4	15	49.1	7	49.2	20
180 min.	49.5	10	36.5	0	48.5	19
240 min.	46.5	4	46.1	0	43.7	7

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[1] Bibliography reference number 13

TABLE 5

The effect on the respiratory quotient and heat production in two men after the ingestion of 45 gm. of glidine[1]

Subject L.E.E., ingested glidine in 200 gm. of water; urinary 0.40 gm./hr.

	Heat		
Time elapsed after eating	Total Cal.	Increase Above Basal Cal.	R.Q.
½ to 1½ hr.	85	5	0.78
1½ to 2½ hr.	81	1	.83
2½ to 3½ hr.	79	-1	.82
Total	245	5	
Subject J.J.C., ingested glidine in 164 gm. water; urinary nitrogen 0.26 gm./hr.			
1 to 2 hr.	83	11	0.82
2 to 3 hr.	79	7	.79
3 to 4 hr.	83	11	.79
4 to 5 hr.	81	9	.78
Total	326	38	

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[1] Bibliography reference number 10

TABLE 6

The effect on the respiratory quotient and heat production in a man after the ingestion of 70 gm. of glidine[1]

Subject J.R., ingested glidine in 200 gm. of water; urinary nitrogen, 0.44 gm./hr. (Test 1 & 2)

	Heat		
Time elapsed after eating	Total Cal.	Increase Above Basal Cal.	R.Q.
½ to 1½ hr.	78	5	0.82
1½ to 2¼ hr.	96	23	
2½ to 3½ hr.	84	11	.88
3½ to 4½ hr.	85	12	.76
Total	343	51	

Subject J.R., ingested glidine in 20 gm. lemon juice and 400 gm. of water; urinary nitrogen, 0.44 gm./hr.

¼ to 1¼ hr.	76	4	0.86
1¼ to 2¼ hr.	83	11	.86
2¼ to 3¼ hr.	85	13	.85
3¼ to 4¼ hr.	84	12	.87
Total	328	40	

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[1] Bibliography reference number 10

TABLE 7

The effect on the respiratory quotient and heat production in two men after the ingestion of gluten bread and skim milk[1]

Subject H.R.D., ingested 100 gm. gluten bread and 221 gm. skim milk; 21 minutes required for eating.
Subject H.C.K., ingested 66 gm. gluten bread and 706 gm. skim milk; 37 minutes required for eating.

	Heat					
Time elapsed after eating	Total Cal.		Increase Above Basal		R.Q.	
	(Subject)		(Subject)		(Subject)	
	H.R.D.	H.C.K.	H.R.D.	H.C.K.	H.R.D.	H.C.K.
0 to 2 hr.	157	177	11	13	0.81	0.78
2 to 4 hr.	157	177	11	13	.96	.79
4 to 6 hr.	164	179	18	15	.78	.90
6 to 8 hr.	157	178	11	14	.78	.73
Total	635	711	51	55		

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[1] Bibliography reference number 10

TABLE 8

The effect on the respiratory quotient and heat production in two men after the ingestion of plasmon, plasmon milk biscuit and skim milk[1]

Subject H.R.D., ingested 100 gm. plasmon, 70 gm. plasmon milk biscuit, 206 gm. skim milk; time required for eating 36 minutes.

	Heat		
Time elapsed after eating	Total Cal.	Increase Above Basal Cal.	R.Q.
0 to 2 hr.	172	26	
2 to 4 hr.	177	31	0.83
4 to 6 hr.	153	7	.87
6 to 8 hr.	159	13	.76
Total	661	77	

Subject H.C.K., ingested 100 gm. plasmon, 47 gm. plasmon graham biscuits, 438 gm. skim milk; time required for eating 34 minutes.

¼ to 2¼ hr.	191	27	0.77
2¼ to 4¼ hr.	179	15	1.01
4¼ to 6¼ hr.	178	14	.79
6¼ to 8¼ hr.	160	-4	.76
8¼ to 10¼ hr.	180	16	1.01
10¼ to 12¼ hr.	158	-6	.79
Total	1,046	62	

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[1] Bibliography reference number 10

AGE, WEIGHT, HEIGHT AND SURFACE AREA OF SUBJECTS

Subject	Age	Weight kg.	Height cm.	Surface area
I.	30	51.36	167.48	1.49
II.	30	70.34 68.18*	175.77	1.82
III.	23	61.14	166.12	1.66
IV.	56	56.82	165.86	1.60
V.	51	64.09	165.10	1.68

* Subject II. lost weight before the protein experiment.

ESTIMATED GRAMS OF FOOD EQUIVALENT TO ONE CAL.[1]

Pure Nutrient	Grams
White granulated Domino sugar	0.26
Wesson cottonseed oil	0.11
USDA Grade A Large egg whites	1.96
General Biochemicals gelatin	3.54

[1] All of the above nutrients were calculated from Composition of Foods Agriculture Handbook Number Eight by B. W. Watt and A. L. Merrill, Agricultural Research Service, United States Department of Agriculture, published by Superintendent of Documents, U.S. Government Printing Office of Washington, D.C., 1963, except the gelatin value which was provided by General Biochemicals at Chagrin Falls, Ohio.

VOLUMES OF EXPIRED AIR OF ONE SUBJECT AFTER PANTOMIMING THE ACTIVITY OF EATING

Test Number	Total Liters of Expired Air	Time After Pantomine* (Minutes)
1	24.26	Basal
2	24.92	5
3	23.56	30
4	25.23	60
5	24.00	90
6	24.13	120
7	23.01	150
8	24.79	180
9	23.74	210
10	24.19	240
11	24.46	270
12	24.28	300
13	22.74	330

* Subject sat up in bed and pantomimed eating for five minutes.

Calculations of Total Calories and Grams of Nutrients Ingested

Subject	Caloric value of food ingested	Sucrose gm.	Fat gm.	Egg White gm.	Gelatin gm.
I.	292.75	76.03		286.90	41.35
II.	400.94*	104.14	45.39	380.85	54.89
III.	348.50	90.51	39.45	341.53	49.22
IV.	323.87	84.11	36.66	317.39	45.74
V.	365.31	94.87	41.35	358.01	51.60

* Subject II. lost weight before protein experiment so the total calculated caloric value for the egg white and gelatin was 388.63 Cal.

Respiratory Quotients After Ingestion of Carbohydrate

Subject	I	II	III	IV	V
Basal	0.69	0.67	0.65	0.63	0.72
Time after ingestion					
4 min.	.79	.84	.70	.64	
15 min.	.83		.88	.73	.87
30 min.		0.94	.90	.83	.92
45 min.	.83		.65	.83	
1 hr.	.87		.84	.80	
2 hr.	.85		.77	.85	.85
2½ hr.	.84				.75
3 hr.	.84			.75	
3½ hr.			.75	.78	
4 hr.	.83	.75	.72	.74	.83
4½ hr.				.77	.80
5 hr.				.73	.78
5½ hr.		.74			

Respiratory Quotients After Ingestion of Fat

Subject	I-II	III	IV	V
Basal	0.72	0.72	0.67	0.71
Time after ingestion of fat				
15 min.	.71	.70	.65	.74
30 min.	.73	.65	.66	.73
45 min.		.66		.72
1 hr.		.73	.71	.73
1½ hr.		.69	.72	.76
2 hr.				
2½ hr.	.79	.70	.71	
3 hr.	.77	.73	.72	
3.5 hr.	.78	.80	.73	.74
4 hr.			.67	
4.5 hr.		.71	.71	
5 hr.	.79	.72		.75
5.5 hr.	.79	.70		
6 hr.	.78			.80
6.5 hr.	.78			
7 hr.	.73			
7.5 hr.	.78			

Respiratory Quotients After Ingestion of Protein

Subject	I	II	III	IV	V
Basal	0.77	0.71	0.69	0.68	0.69
Time after ingestion of protein					
15 min.	.94	.68		.75	.70
30 min.	.96				.72
1 hr.	1.00	.78	.72*		.76
1½ hr.			.76	.79	
2 hr.		.79	.70		
2½ hr.				.75	
3 hr.		.78		.77	
3½ hr.	.87	.78	.75	.78	.75
4 hr.		.74	.70		
4½ hr.	.81	.79		.90	.74
5 hr.	.86			.73	.70
5½ hr.	.79		.70		.71
6 hr.	.73	.76			
6.5 hr.	.85	.73			.73
7 hr.			.72	.66	.71
7½ hr.				.70	.69
8 hr.	.74			.66	
8½ hr.	.65			.62	
9 hr.	.63				

* Respiratory quotient was observed 45 minutes after the ingestion of protein.

Subject I Per Cent Increase Above Basal and Total Cal/M^2/Hr. Expended After Ingestion of Carbohydrate, Fat and Protein

	Carbohydrate		Protein	
	Cal/M^2/Hr.	Per Cent Increase Above Basal	Cal/M^2/Hr.	Per Cent Increase Above Basal
Basal	40.57		39.91	
Time after ingestion of food				
4 min.	45.56	12.29	59.29	48.56
15 min.	45.08	11.11	57.98	45.28
30 min.				
45 min.	45.51	12.12	54.21	48.56
1 hr.	44.02	8.49		
1½ hr.				
2 hr.	44.90	10.65		
2½ hr.	40.41	- .39		
3 hr.	42.50	4.742		
3½ hr.	40.02	-1.36	48.55	21.65
4 hr.	38.34	-5.51		
4½ hr.			50.12	25.57
5 hr.			48.90	22.51
5½ hr.			46.98	17.71
6 hr.			46.06	15.39
6½ hr.			50.95	27.67
7 hr.				
7½ hr.				
8 hr.			44.67	10.65
8½ hr.			48.75	22.15
9 hr.			48.89	22.49

Subject II Per Cent Increase Above Basal and Total Cal./M^2/Hr. Expended After Ingestion of Carbohydrate, Fat and Protein

	Carbohydrate		Fat		Protein	
	Cal./M^2/Hr.	Per Cent Increase Above Basal	Cal./M^2/Hr.	Per Cent Increase Above Basal	Cal.	Per Cent Increase Above Basal
Basal	5.29		33.72		35.32	
Time after ingestion of food						
15 min.	44.01	24.69	37.22*	10.38	39.68	12.36
30 min.	42.74	21.12	35.84	6.27		
45 min.	42.03	19.02				
1 hr.					42.57	20.54
2 hr.					44.80	26.85
2½ hr.			38.09	13.00		
3 hr.			38.04	12.81	43.48	23.10
3½ hr.			38.05		44.19	25.12
4 hr.	38.79	9.92			46.04	30.36
4½ hr.					42.28	19.72
5 hr.			36.10	7.04		
5½ hr.	33.33	-5.53	35.49	5.23		
6 hr.			34.07	1.03	40.89	15.77
6½ hr.			33.16	-1.66	37.55	6.31
7 hr.			36.72	8.90		
7½ hr.			36.31	7.68		

* Total Cal./M^2/Hr. expended 10 minutes after ingestion of fat.

Subject III Per Cent Increase Above Basal and Total Cal./M^2/Hr. Expended After Ingestion of Carbohydrate, Fat and Protein

	Carbohydrate		Fat		Protein	
	Cal./M^2/Hr.	Per Cent Increase Above Basal	Cal./M^2/Hr.	Per Cent Increase Above Basal	Cal./M^2/Hr.	Per Cent Increase Above Basal
Basal	29.89		29.94		34.87	
Time after ingestion of food						
15 min.			31.47	5.08		
30 min.			31.51	5.22		
45 min.	33.54	12.22	32.30	7.86	38.83	11.35
1 hr.			33.45	11.71		
1½ hr.	35.55	18.94	29.68	-.87	36.93	5.90
2 hr.	36.67	22.67	32.24	7.65	39.84	14.24
2½ hr.			29.57	-1.26		
3 hr.			31.16	4.05		
3½ hr.	35.47	18.66	30.67	2.42	38.61	10.71
4 hr.	34.00	13.73			41.33	18.53
4½ hr.			30.46	1.723		
5 hr.			32.45	8.36		
5½ hr.			34.88	16.48	36.72	5.30
7 hr.					35.55	1.95

Subject IV Per Cent Increase Above Basal and Total Cal./M^2/Hr. Expended After Ingestion of Carbohydrate, Fat and Protein

	Carbohydrate		Fat		Protein	
	Cal./M^2/Hr.	Per Cent Increase Above Basal	Cal./M^2/Hr..	Per Cent Increase Above Basal	Cal./M^2/Hr.	Per Cent Increase Above Basal
Basal	27.71		26.50		30.83	
Time after ingestion of food						
5 min.	30.01	8.28				
15 min.	31.25	12.75	26.02	1.59	39.19	27.10
30 min.	33.37	20.403	29.21	10.22		
45 min.	34.88	25.86				
1 hr.	35.54	28.24	26.42	.03		
1½ hr.	36.43	31.47	26.86	1.36	37.99	23.22
2 hr.	32.79	18.33				
2½ hr.			30.65	15.66	39.82	29.15
3 hr.	27.33	-1.37	28.34	6.95	40.17	30.29
3½ hr.	28.38	2.41	25.87	-2.38	40.05	29.89
4 hr.			27.51	3.819		
4½ hr.			26.82	1.208	37.42	21.36
5 hr.	25.17	-9.17			36.46	18.25
7 hr.					33.88	9.90
7½ hr.					34.30	11.231
8 hr.					35.91	16.46
8½ hr.					33.36	8.18

Subject V Per Cent Increase Above Basal and Total Cal./M^2/Hr. Expended After Ingestion of Carbohydrate, Fat and Protein

	Carbohydrate		Fat		Protein	
	Cal./M^2/Hr.	Per Cent Increase Above Basal	Cal./M^2/Hr.	Per Cent	Cal./M^2/Hr.	Per Cent Increase Above Basal
Basal	32.93		30.238		32.44	
Time after ingestion of food						
15 min.	36.91	12.10	32.74	8.27	37.59	15.88
30 min.	38.08	16.65	33.57	11.02	38.68	19.25
45 min.			32.20	6.49		
1 hr.	39.88	21.11	32.50	7.48	39.79	22.67
1½ hr.			34.03	12.54		
2 hr.	41.26	25.32				
2½ hr.	36.97	12.28				
3½ hr.			34.95	15.58	40.83	25.87
4 hr.	35.60	8.13				
4½ hr.	33.47	11.64			40.36	24.40
5 hr.	33.55	1.90	32.61	7.85	41.95	29.32
5½ hr.					41.85	29.00
6 hr.			31.88	5.44		
6½ hr.					37.00	17.13
7 hr.					40.53	24.93
7½ hr.					39.75	22.52

ABSTRACT

The specific dynamic effects of carbohydrate, fat and protein were measured in five adult women. Basal metabolic rates were measured while subjects were in the post-absorptive state. Subjects ingested 5.7 Cal./kg of body weight of the nutrients on different days. Measurements were made at regular time intervals after the meal until the amount of expired air approximated that of the basal state. Samples of expired air were analyzed for oxygen and carbon dioxide. Changes in the respiratory quotient and Cal. per square meter of body surface, with relationship to time of ingestion of each pure compound were studied.

There was a general trend for subjects with higher basal energy metabolism to have greater increases in the respiratory quotient after the ingestion of carbohydrate, or fat or protein. An increase in respiratory quotient and heat production was observed following the ingestion of each of three nutrients. There was no definite correlation between the changes in respiratory quotient and variations in heat production after ingestion of carbohydrate, fat and protein by women. Individuals varied in their responses to carbohydrate, fat and protein, but similarities among the individuals in their response to each of these foodstuff was apparent.