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A PHOTOGRAPHIC RECORD METHOD FOR ESTIMATION OF INDIVIDUAL FOOD CONSUMPTION: DEVELOPMENT AND VALIDATION

by

Laurie A. Wadsworth

A thesis
presented to the University of Manitoba
in partial fulfillment of the
requirements for the degree of
Master of Science
in
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The undersigned certify that they have read a Master's thesis entitled: A PHOTOGRAPHIC RECORD METHOD FOR ESTIMATION OF INDIVIDUAL FOOD CONSUMPTION: DEVELOPMENT AND VALIDATION

submitted by LAURIE A. WADSWORTH

in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE

The Thesis Examining Committee certifies that the thesis (and the oral examination, if required) is:

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Advisor

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A PHOTOGRAPHIC RECORD METHOD FOR ESTIMATION OF INDIVIDUAL FOOD CONSUMPTION: DEVELOPMENT AND VALIDATION

BY

LAURIE A. WADSWORTH

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

ABSTRACT

A photographic record method was developed to decrease the error associated with subjective quantification of food intakes, as well as to decrease the respondent burden associated with present record methods. The method described the calculation of volumes from a two-dimensional representation of a food item using a cylindrical reference object and contour shadow lines in the photographic recording of such items. Standard objects of known volumes and different shapes, were first studied to develop the technique used and to validate the method. Photographic records of individual food items were then assessed to determine the usefulness of such a method when applied to foods.

Photographic volume estimates for a right rectangular block revealed no significant differences from actual volumes. Volume estimates of standard objects of four shapes (right rectangular block, right cylinder, right wedge, sphere) and three sizes (100 mL, 200 mL, 400 mL) were significantly affected by object shape but not by object size. The inter-operator reliability of the photographic record method appears to be acceptable for survey work, since comparable volume estimates were given by six investigators.

Significantly different effects were found between three integration formulae (Arithmetic Mean, Triangular Mean, Simpson's Formula), each using a different concept for the calculation of volume. It was concluded that Simpson's Formula would be best applied to volume estimation of food items.

Using 20 food items, a strong relationship was found between photographic volume, weight and nutrient content estimates and the corresponding gravimetric values. Similar results were obtained whether manually determined or published density figures were used to convert volumes to weights. The consistency of food items had a significant effect on the photographic volume estimates.

The overall performance of the developed photographic record method showed promise as an alternate method for estimating individual food consumption. Based on the results of this study, further investigation was suggested to clarify the usefulness of this tool in survey situations.

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Chapter I

INTRODUCTION

Estimation of food and nutrient consumption as related to the health of individuals and groups has been pursued by researchers since the late 1800's. The desire to determine dietary intakes of non-institutionalized persons has led to the development of several dietary methodologies which either measure current intake or assess past food habits (Marr, 1971; Block, 1982).

The prospective recording of present intakes is most often achieved by use of either the weighed food record or the estimated food record. The weighed record involves the weighing and recording of food items as they are consumed. The method referred to as an estimated food record involves recording of food intakes by the estimation of food portion sizes rather than by weighing. The maximum duration for these two recording methods is considered to be two weeks (Marr, 1971; Burk and Pao, 1976).

Methods to retrospectively measure dietary intake can cover recent or long-term past intakes. The present dietary recall method, similar to that introduced by Burke and Stuart (1938), aims to reconstruct recent food intakes. The time period involved is usually the twenty-four hours previous to the interview, but periods of up to seven days have been used (Burk and Pao, 1976;Block, 1982).

The three methods as outlined allow for the quantification of nutrient intakes. The diet history method, originally developed by Burke (1947), yields more qualitative than quantitative information (Burke, 1947; Burk and Pao, 1976). Habitual intakes have been determined with this tool for periods of up to one year, although shorter terms of four to six weeks are most common (Marr, 1971).

Inherent to the common dietary methodologies are sources of variation and actual error (Pekkarinen, 1970; Marr, 1971). The purpose of this research project was to develop and validate an alternate dietary method which addressed some of the major sources of error. This method was designed to provide quantifiable estimates of an individual's food consumption from photographic food records.

Chapter II

REVIEW OF LITERATURE

Common dietary methodologies can be either retrospective or prospective in nature. Some methods allow for quantification of nutrient intakes while others yield qualitative information. Error is inherent to each of the common methodologies (Marr,1971).

2.1 SOURCES OF ERROR

Beaton and co-workers (1979) have put forth the following definition of error:

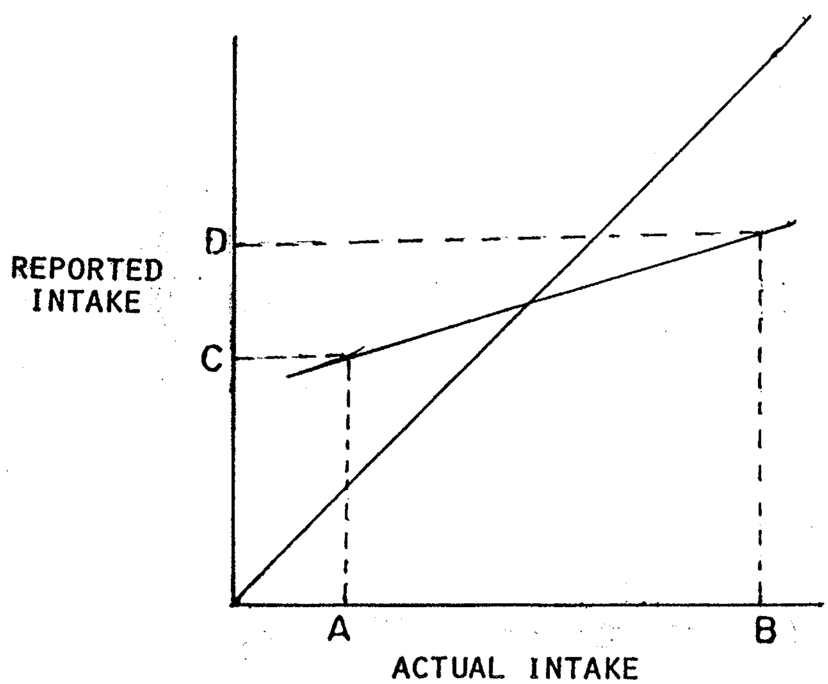
> "In the statistical sense, "error" in dietary methodology is any source of variance that serves to reduce the reliability of the individual data and the group mean. In a dietary study, standardization and other control procedures are intended to reduce this error to a minimum."

2.1.1 Quantification

The quantification of food items involves a number of error sources. The success of the estimated food record and the retrospective methods, the dietary history and the dietary recall, depends on the ability of the subject to accurately estimate food quantities and to convey these estimates to the investigator (Burk and Pao, 1976).

A study designed to test the validity of recalled intake data as compared to the actual intake obtained by trained observers was conducted by Madden and associates (1976). The study involved seventy-six elderly subjects who were participants in a congregate meal program. A review of the literature on validity of the 24-hour recall and analysis of data from their own study led Madden and co-workers to describe the Flat-Slope Syndrome. This is a tendency by the subjects to overestimate low intakes and underestimate high intakes.

The flat sloped line shown in Figure 1 is a result of regression analysis where the slope is less than 1 and the intercept is greater than zero. In this hypothetical illustration of two groups, the difference between the mean actual intakes (B-A) is greater than the difference between the mean recalled intakes (D-C) (Madden, et al., 1976; Gersovitz, et al., 1978).



(Gersovitz, et al., 1978)

Figure 1: Hypothetical Illustration of Flat-Slope Syndrome

If this phenomenon were present, there would be a downward bias in the number of subjects with extremely high or extremely low intakes. That is, a greater number of subjects would tend to report the mean. This occurence has been termed "talking a good diet", where subjects' reported intake is affected by what they think they should have eaten. That is, those consuming small amounts think they should eat more and subjects consuming large amounts think they should eat less (Gersovitz, et al., 1978).

The Flat-Slope Syndrome has been reported or suggested by data from other studies involving diverse population groups (Young, et al., 1952; Gersovitz, et al., 1978; Carter, et al., 1981).

Studies have demonstrated an overall underestimation of dietary intake when using the recall method (Burk and Pao, 1976). Acheson and co-workers (1980) conducted a dietary survey of twelve subjects stationed at an Antarctic base for one year. Subjects weighed and recorded all foods consumed throughout the study. Once a week they were asked to record everything they could remember eating during the previous twenty-four hours. A self-administered questionnaire was used to complete this task. Occasionally subjects were asked to complete this exercise on a blank sheet of paper.

Energy intake values for each subject were calculated from the recall and weighed record for the same day. Recalled values were compared to weighed record values. Of the eighty-six recalls, seventy-nine underestimated food intake. Subjects underestimated their energy intake by a mean of 21% using the structured questionnaire and by a mean of 33.6% using the blank sheet. This difference was significant at the .05 level.

The authors reported upon inspection of the recall and weighed records that subjects tended to underestimate portion sizes and that they usually omitted one complete food item in the recall (Acheson, *et al.*, 1981).

2.1.2 Memory Ability

The omission of food items in the dietary recall reported by Acheson and co-workers (1980) points to another major error source -- that of the subject's ability to remember. The retrospective dietary methodologies are susceptible to errors involving memory ability.

The use of a structured questionnaire produced significantly better food intake estimates than the use of a blank sheet of paper for the study conducted by Acheson and associates (1980), where subjects underestimated their energy intake by 21% with the former and by 33.6% with the latter. It is possible that the structured questionnaire prompted the subjects to recall more food items. It should be noted that since these subjects had both weighed and recorded their food intakes prior to the recall procedure, their level of recall was expected to be greater than that of subjects answering an impromptu recall.

Interviewing techniques which include persistance, probing and the use of memory aids have been shown to increase reported intake (Burk and Pao, 1976).

Dietary intake information from obese and non-obese women was analyzed by Beaudoin and Mayer (1956). One day dietary records were obtained from 162 subjects representing 58 women of normal weight, 59 overweight women and 45 underweight women. Completed dietary histories were obtained. These represented 20 normal weight women and 30 obese women. It can be seen from Table 1 that overweight women reported eating significantly more than their normal weight counterparts when a dietary history was used (p=.01), whereas the one-day estimated food record resulted in intakes for overweight women which were significantly lower than those of the normal weight women (p=.05).

TABLE 1

Mean Energy Intake of Two Groups from Two Dietary Methodologies

Method of Data Collection	Mean Energy Intake ($\bar{X}$±s.d.)		
	Overweight Women	Normal Weight Women	Statistical Probability
One Day Dietary Record	1964±594	2198±587	.05
Dietary History	2829±475	2201±475	.01

(adapted from Beaudoin and Mayer, 1953)

The differences found with the two methods could not be explained by differences in age and weight distributions between the two study groups. The authors concluded that the additional attention given to obese women by skilled interviewers resulted in greater total reported intake.

A methodological validation study conducted by Campbell and Dodds (1967) using the 24-hour recall, concluded that older subjects tended to omit more food items than younger subjects and that women recalled food intakes better than men. Subjects consisted of 100 persons over 65 years of age and 100 persons between the ages of 20 and 40 years. All subjects were institutionalized. Each subject participated in an impromptu 24-hour recall interview with minimal remarks from the interviewer. After the subjects had recalled what they could, the pattern was read back to them. Foods added at this point were not recorded as forgotten. The subject was then asked to review the menu made available by the institution. Foods added at this stage were recorded as items probed and used as an indicator of forgetfulness.

The proportion of additional information elicited by probing is shown in Table 2. The percent contribution of the probe to energy intake ranges from 12.5% for younger women to 35.2% for older men. The difference between younger and older subjects, in terms of energy, was significant ($p \leq .05$). This data also indicated a significant difference in recall ability between men and women ($p \leq .01$).

TABLE 2

Percentage Contribution of the Probe to Total Energy Intake of Four Groups

Group	Contribution to Energy Intake (%)
Younger Men	20.6
Younger Women	12.5
Older Men	35.2
Older Women	27.9

(adapted from Campbell and Dodds, 1967)

2.1.3 Recording Burden

The recording burden placed on subjects can affect the accuracy and reliability of collected data. The prospective recording of dietary intake information requires a high degree of co-operation and motivation on the part of the subjects. The weighing and recording of each food item eaten is time-consuming and can result in a low response rate (Trulson and McCann, 1959; Acheson, et al., 1980).

Gersovitz and associates (1978) attempted to obtain seven-day written records from 65 elderly subjects. Although 85% of the sample returned at least two useable records, only 60% returned a complete set of seven useable records. The portion of the sample returning a complete set of records formed a more highly educated group. Bias was, thus, introduced into the sample. The authors concluded that recording accuracy not only decreases with time but that the nature of the sample may be significantly altered by the subjects who fail to return a complete set of records.

Alterations to habitual food patterns may result due to the difficulty encountered by the subject when either weighing or describing complex food items (Burk and Pao, 1976). A weighed record requires that the sbject weigh each component part of a complex food item. This may be perceived to be socially unacceptable in some situations. Hence, subjects may obtain food items from other than their usual sources. An example of such an alteration was reported by Adelson (1960) where a couple chose a week free from social or business engagements that might interfere with record-keeping. The extent to which bias is introduced by such alterations is difficult to ascertain (Marr, 1971).

2.1.4 Interviewer Bias

Retrospective dietary methodologies conducted by interviews are subject to the introduction of interviewer bias (Marr, 1971). Beal (1967) outlined qualities required of a trained interviewer to minimize such bias. The ability to elicit true responses from subjects without suggesting answers or showing approval or disapproval is most important. Skill in judging the reliability of responses is a necessity. As well, the interviewer must be able to build a rapport with the subject and be adept at picking up clues for further questioning. Failure in any of these areas will jeopardize the accuracy of the estimated intake.

2.2 NON-TRADITIONAL DIETARY METHODOLOGY

Elwood and Bird (1983) have described a non-traditional method of photographically recording dietary intakes. This photographic method underwent a preliminary validation study in which seventeen office workers, thirteen women and four men, participated (Bird and Elwood, 1983). Subjects were issued a camera and food scales and were instructed to weigh and photograph all food items consumed over a four day period. Details of food items were recorded in a logbook. Quantification of the food items photographically recorded on 35mm slides was done subjectively by the investigator who viewed these slides alongside standard slides. Several different portion sizes of a single food item, together with a card which gave the weight of each portion, were shown on the standard slides. These enabled a weight estimate to be assigned to the subject's food records. Differences between mean daily intake estimates obtained by this method and the weighed record were small and none approached statistical significance. For the correlation between the daily intake estimates of major nutrients for both methods, all coefficients were high, ranging from r=0.84 for carbohydrate to r=0.97 for vitamin C. Bird and Elwood (1983) concluded that this method, though less demanding for the subject, required great care in assessing the weights of food items. They also suggested that this photographic method never be used alone but that an occasional meal be both weighed and photographed.

2.3 SUMMARY

Many research studies and clinical practices require dietary intake information from their subjects and clients. While a number of methods have been developed and adapted to meet this end, there is no one generally accepted method of measuring the food consumption of individuals. Existing methods have their own strengths and weaknesses (Marr, 1971;Block, 1982).

A method of collecting dietary intake data from individuals that minimizes errors due to subjective estimations of food quantities either by investigators or by subjects is needed to ensure a more precise estimate of food intakes. A prospective recording system would eliminate the need to recall foods, and with it, dependence on subject memory. Such a method should require less detailed written recording than is found with more traditional methods and thus decrease errors due to recording burden. An improved method of dietary record assessment would benefit by utilizing existing computer facilities to the fullest possible degree to limit human error.

The study reported here dealt with the development and validation of a photographic record method which involved an objective computerized procedure for estimation of food quantities from 35mm slide records. At a later stage, this procedure can be linked and tested with simple record-keeping to provide an alternate method for individuals to record their food consumption.

This photographic record method was expected to improve the accuracy of dietary intake information by addressing several areas of weakness encountered with common methodologies. The use of an objective computerized method for quantification of recorded food items would decrease the subjective judgements made by either the subject or the investigator during both production and evaluation of records. By its very nature, a record method will eliminate errors due to memory ability. As well, the simple record keeping that will be required by this method should result in minimal recording errors.

2.4 PURPOSE AND RESEARCH QUESTIONS

This study proposed to standardize procedures for making and interpreting a photographic record. The techniques for obtaining quantifiable estimates of individual food consumption from photographic food records were developed through the investigation of several variables.

The study was divided into two sections each with a major research question.

1. Do volume estimates of standard objects obtained by the photgraphic record method differ from the known volumes?

   To answer this question, volume estimates expressed as a ratio of the actual volumes were obtained from standard objects to determine the effects of the following image characteristics:

   a) the position of the standard object in relation to the camera lens

   b) the line width used to cast contour lines onto the object

   c) the size of the angle between the light source and the camera

d) the degree of magnification of the projected slide records

e) the shape of the standard objects

f) the size of the standard objects

g) the height of the reference object

h) the measurements of slide records done by different investigators

i) the integration formula used to calculate the volume estimate

2. Do estimates of volume, weight and nutrient content of actual food items obtained by the photographic record method differ from the physical values?

Volume estimates of actual food items were determined using the image characteristics previously defined as those associated with the least error for standard objects. A density factor was applied to these to determine a weight estimate. Nutrient content estimates were calculated from the weight estimates. The differences between the photographic and physical estimates for volume, weight and nutrient content were determined.

The shape of a food item is dependent on the consistency of that food item since the higher the fluid content of the food the less predictable the shape will be. In this study, actual food items were grouped according to their consistency. Differences between photographic and physical estimates of volume, weight and nutrient content were determined for each group.

2.5 HYPOTHESES

The null hypotheses and corresponding dependent and independent variables for the relationships to be statistically tested were:

1. The ratio of estimated volume to absolute volume obtained for a standard object will not be related to the position in which the object is observed.

   Dependent Variable -- estimated volume/absolute volume

   Independent Variable -- object position

2. The ratio of estimated volume to absolute volume obtained for a standard object will not be related to the angle between the camera and the light source.

   Dependent Variable -- estimated volume/absolute volume

   Independent Variable -- angle size

3. The ratio of estimated volume to absolute volume obtained for a standard object will not be related to the line width used to cast contour lines onto the object.

   Dependent Variable -- estimated volume/absolute volume

   Independent Variable -- contour line width

4. The ratio of estimated volume to absolute volume obtained for a standard object will not be related to the degree of magnification of the projected slide records.

   Dependent Variable -- estimated volume/absolute volume

Independent Variable -- degree of magnification

5. The ratio of estimated volume to absolute volume obtained for a standard object will not be related to the shape of the standard object.

Dependent Variable -- estimated volume/absolute volume

Independent Variable -- object shape

6. The ratio of estimated volume to absolute volume obtained for a standard object will not be related to the size of the standard object.

Dependent Variable -- estimated volume/absolute volume

Independent Variable -- object size

7. The ratio of estimated volume to absolute volume obtained for a standard object will not be related to the height of the reference object.

Dependent Variable -- estimated volume/absolute volume

Independent Variable -- height of the reference object

8. The ratio of estimated volume to absolute volume obtained for a standard object will not be related to the investigator obtaining the measurements.

Dependent Variable -- estimated volume/absolute volume

Independent Variable -- investigator

9. The ratio of estimated volume to absolute volume obtained for a standard object will not be related to the integration formula used to calculate the volume estimate.

Dependent Variable -- estimated volume/absolute volume

Independent Variable -- integration formula

10. Photographic volume estimates of individual food items will not differ from the physical volumes.

Dependent Variable -- estimated volume

Independent Variable -- physical volume

11. Photographic weight estimates of individual food items will not differ from the gravimetric weights.

Dependent Variable -- estimated weight

Independent Variable -- gravimetric weight

12. Photographic nutrient content estimates of individual food items will not differ from the gravimetric values.

Dependent Variable -- photographic nutrient content estimates

Independent Variable -- gravimetric nutrient content values

The dependent variable for this hypothesis was expressed in four ways, each tested separately. The four nutrient contents used were:

a) Energy

b) Protein

c) Carbohydrate

d) Fat

The null hypothesis was rejected if the probability was 5% or less.

Chapter III

METHODS

3.1 CONCEPTUAL FRAMEWORK

A physical object is defined in three dimensions. If measurements of the object are made from two-dimensional representations, or images, a minimum of three images of an object is required to define three dimensions for each and every point on the object. Without defining the relative position of all points individually, in three dimensions, it is not possible to calculate the volume that all points enclose. That is, volume can be achieved only if any point on the surface of an object can be defined in three dimensions. Theoretically the most accurate volume estimates are obtained by relating every discernable point with every other discernable point (Ballard and Brown, 1982).

To transform the information from three, or more, two-dimensional images into absolute measurements of the object in three dimensions, angle of view and relative distance are required for each image (Ballard and Brown, 1982).

Recording food consumption of non-institutionalized persons requires a method which is both fast and socially acceptable. Using familiar objects or techniques for the indirect recording of food items should satisfy these requirements. The recording burden placed on the subject must also be taken into account. Hence, in data collection, a photographic recording method must accept these restrictions:

1. use of one photograph only
2. food may be photographed from any angle in both the horizontal and vertical planes except perpendicular or parallel to the table top

The specific requirements of the subject would be to:

1. place lens cover/reference object next to the food items to be recorded
2. lean back in the chair and ensure that:
   a) both the reference object and the plate of food are in view
   b) some table can be seen in front and back of the plate
   c) plate is centered in photograph
3. release shutter
4. complete simple written log of descriptive notes on the food items recorded
5. repeat 1 - 4 for any other dishes of food

This recording would require that the camera be easy to operate. As well, the angle between the camera and the light source must be fixed. The difference between the vertical angles of the camera and light source should be zero.

The use of a single photograph for each dish of food would require, at most, four or five operations of the equipment for each instance of consumption. Neither angle of view, nor relative distance, should have to be recorded, as this would greatly increase the burden of recording.

If a single image is used, such characteristics must be apparent from the image itself.

With the use of only one image of a given object, information is limited. Firstly, information of points on the far side of the object is not available for any of the three dimensions. Secondly, the points on the side facing the viewer can be defined in two dimensions only. A method of volume estimation using one photographic image of the object will need to be modified in order to regain some of this lost information.

If the angle of elevation of the camera is anything other than 0^0 or 90^0, an estimate of the third dimension is obtained for points on the side facing the viewer. It is still possible to relate any one visible point to another visible point in the two dimensions of the image, but this relationship is now sensitive to changes in the third dimension.

To recognize the points that are related in some way, the use of contour lines is introduced. Contours enable the viewer to identify a series of points that share one spacial characteristic. When vertical contour lines are used this characteristic is the same vertical plane. The vertical plane is termed a slice in relation to the object as a whole. Contour lines can be produced by casting shadows onto the object at the time the image is recorded. Vertical contour lines have been introduced as part of the anthropometric tool of photogrammetric estimation of body surface area and volume (Pierson, 1963).

The points on any one contour line are all in one two-dimensional plane. Successive parallel contour lines on an object describe a series of parallel planes. If the line of sight is parallel to a plane, it is not possible to quantify the relationships of points in that plane to others within that plane, thereby effectively losing information on one dimension. Therefore, the angle between the camera and the source of the contour lines should be anything except 0^{0}.

If the angle of view is perpendicular to the plane of the contour lines, slices are cut from side to side through the object. None of the slices through the part of the object away from the viewer will be visible. Those slices will be entirely hidden. If on the other hand the angle of view of the contour plane is 60^{0} or less, at least two points will be visible for all but the smallest slices. These two points give the distance between successive slices and the direction of the slice in relation to the object. More data points will be available for more slices if the angle is, for example, 30^{0}.

Several assumptions must be made in order to gather information on the points at the back of the object. Since the contour lines fall on the horizontal surface both in front of and behind the object, a line along this surface can be identified which represents the bottom of the slice. This line assists the investigator in the identification of obscured or hidden points, which must all lie in the same vertical plane as the discernable points. Based on the measurements of these discernable points, the symmetry of the object and the experience of the investigator with similar objects, the relative positions of hidden points can be estimated. Provided the assumptions are correct, measurement of points at the back should be as accurate as those made at the front of the object.

The points describing one or more slices through the object are measured in two dimensions by recording X and Y co-ordinates. In order to determine the area of a slice, these points must first be transformed to make allowance for the image characteristics. These are:

1. the angle between the camera and the source of the contour lines
2. the angle of elevation of the camera (angle of view)
3. the deviation of contour lines (light source) from the vertical plane of the camera (vertical angle)
4. the distance of the camera from the object (magnification)

A cylindrical comparison object of known height and diameter must be present in all photographs. It is measurements of this comparison object taken from the photographic image that are used to correct for 2 through 4 above. In addition, a measurement of the angle formed by the contour lines and the horizontal defined by the comparison object, gives an indication of the true angle between the camera and the source of the contour lines. Once these three angles and the magnification are known, the observed slice can be transformed into the dimensions and shape of the same slice through the actual object. The transformation uses standard trigonometric formulae (Washington, 1972). The two dimensional area of the slice can then be determined using a formula to calculate the area of a polygon (Kemper, 1982).

The distance observed from the photograph, between one slice and the next, can also be transformed into the distance across the actual object, using simple trigonometric formulae (Washington, 1972). At this stage of calculation three dimensions of the object are known in actual values. A volume estimate is then calculated, using slice areas and slice widths. In theory, the sum of all three-dimensional slice volumes would give the total volume of the object. In practice, since the two-dimensional areas of successive slices differ in magnitude, a mathematical integration of slice areas is used. Three integration formulae were used in this study. These were:

1. Simpson's formula (Smith, 1966)
2. Arithmetic Mean
3. Triangular Mean

This integration incorporates the third dimension with the two dimensions already within each slice area. A total is reached which represents the object volume. This volume is an approximation of the true volume, since an infinite number of slices are not available.

The volume estimates of individual food items can be converted into weight estimates using standard density tables (Adams, 1975; Health and Welfare Canada, 1984). The weight estimates, in turn, can be converted into nutrient content for each food item (Health and Welfare Canada, 1984; Sevenhuysen, 1984).

Perspective is not taken into account for any of the measurements. It is assumed that perspective will not play a large role in the relatively small distance over which the object is measured and that the relative positions of contour lines will counteract error in measurement of co-ordinates due to perspective.

Straight lines between consecutive points on the surface of a two-dimensional slice through an object are assumed to approximate the curved surface of the object. The error associated with this assumption can be minimized by a skilled observer when identifying co-ordinates.

From this, it can be seen that the calculation of a three-dimensional volume from a two-dimensional representation of an object requires several assumptions. Each assumption is a source of error for the final volume estimate. Without these assumptions both data collection and analysis would be much too cumbersome and costly to be of practical use in a survey situation. The extent of the error involved with the assumptions must be quantified.

Sources of error:

1. variation in measurement of co-ordinates, horizontal angle and comparison object
2. estimate of slice shape for hidden parts of object
3. straight line approximation of all curves

3.2 PHOTOGRAPHIC RECORD METHOD TECHNIQUE

The photographic record method to be described here consisted of three stages:

1. Photographic recording
2. Measurement of image co-ordinates
3. Calculation of volume estimate

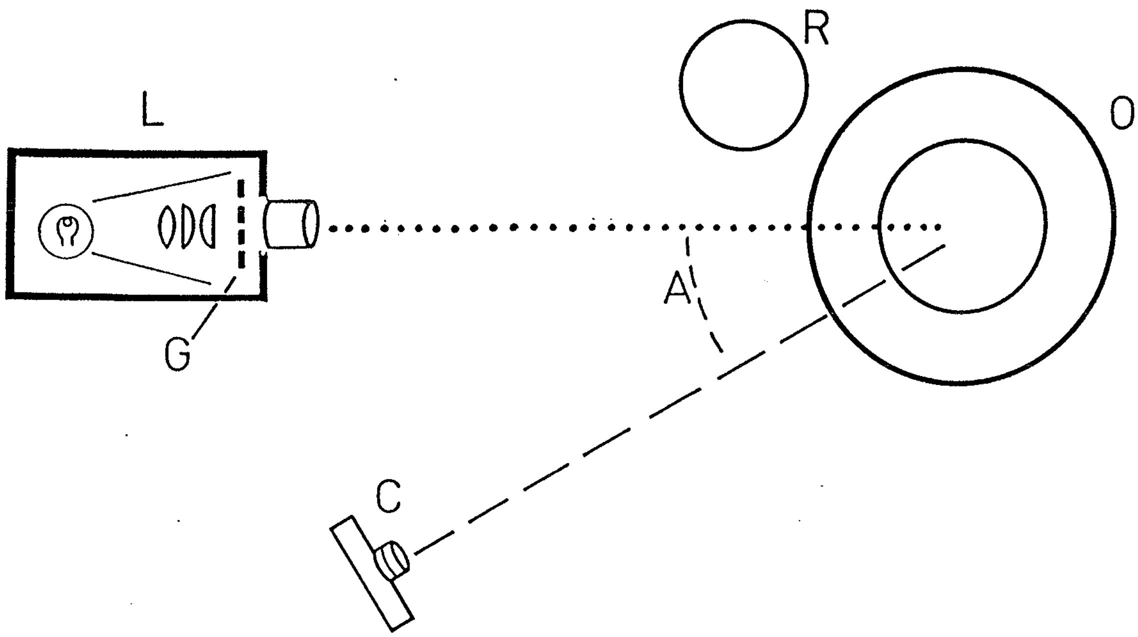
3.2.1 Photographic Recording

The equipment configuration used to make photographic records is shown in Figures 2 and 3.

The standard equipment configuration used when recording consisted of:

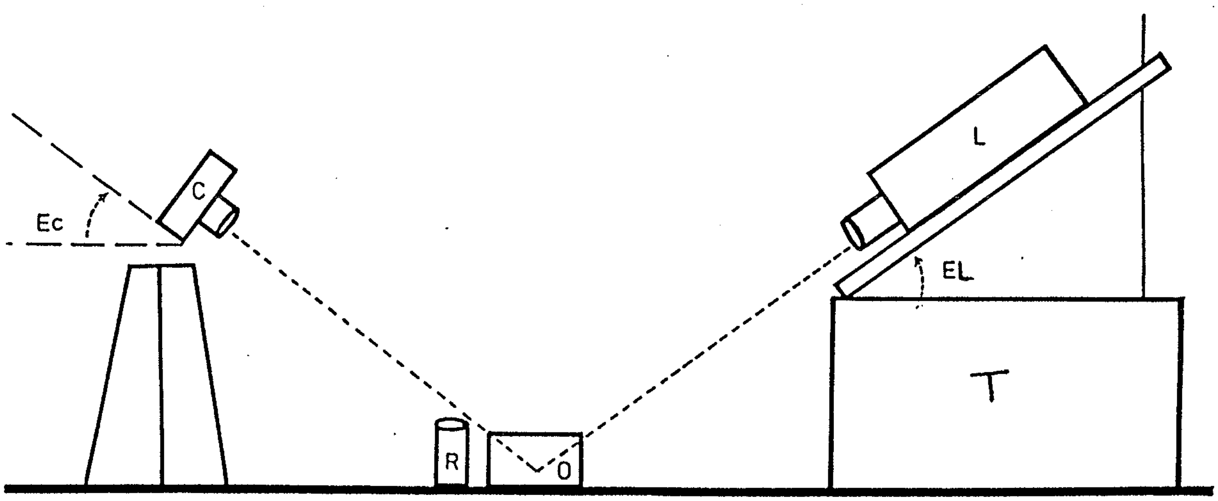
1. Elevation angle of camera (E) -- 30°
2. Elevation angle of light source (E) -- 30°
3. Angle between camera and light source (A) -- 30°
4. Contour line slide -- 1 mm
5. Object positioned over the central point with one straight side parallel to the 45° guide line
6. Reference object -- 6 cm high and 6 cm diameter

All photographic records for the study were taken with a 35 mm single lens reflex camera mounted with a 50 mm normal lens. The model used was a Pentax SP II. Film was 100 ASA Fujichrome color slide film produced by Fujifilm.



C - Camera
L - Light source
G - Contour Line Slide
O - Recorded object
R - Reference object
A - Angle between camera and
light source

Figure 2: Equipment Configuration for Photographic Recording
Top View



C - Camera
L - Light source
O - Recorded object
R - Reference object
E_L - Elevation angle of light source
E_C - Elevation angle of camera
T - Tilting device

Figure 3: Equipment Configuration for Photographic Recording
Side View

The camera was mounted on a Reditilt Mini tripod (Davis and Sanford Company, New Rochelle, New York) and a cable release was attached. The elevation angle of the camera was set by tilting the camera lens downward and reading the angle with a protractor. The camera and tripod were then set on the same horizontal surface used to position the objects to be recorded. The sheet of paper covering this surface was marked to indicate six angles used to position the camera (0°), the light source (15°, 30°, 60°) and the standard object (15°, 45°, 75°). The camera was positioned such that the line of sight of the lens followed the 0° line and was then focused on the central point. The lens was kept 38 cm above the horizontal surface and 72 cm from the central point.

A Kodak Ektagraphic Slide Projector -- Model AF was used to cast shadow contour lines (Kodak Canada Inc., Toronto, Ontario). The contour lines were produced by projecting a slide with dark and light vertical bands. For the standard contour line slide, these bands were 1 mm apart.

The projector was set on a tilting device designed specifically for this purpose, which was in turn placed on a horizontal surface higher than that on which the camera rested. The tilting device incorporated a hinged platform which allowed the projector to focus on the object to be recorded. The angle of elevation of the light source was measured using a protractor and ranged from 29° to 40°. To increase the depth of field, a disk with an aperture of 1.1 cm was attached to the front of the projector lens, thus decreasing the aperture from 5.0 cm.

Tne contour line slide was projected onto the lower horizontal surface. An edge of the centre contour line was lined up with the appropriate angle line indicated on the lower surface to define the angle between the camera and the light source (A) (Figure 2).

The f/stop and shutter speed of the camera were adjusted to achieve the greatest depth of field. If lighting conditions were poor, a longer shutter speed was required due to the use of a small aperture. The use of a single lens reflex camera made it possible to directly check the depth of field while noting the reading given by the internal light meter. For most records the f/stop was set near 8 while using a shutter speed of 1/125 s to 1/4 s.

The object to be recorded was placed over the central point on the lower surface. For objects with at least one straight side, the side was made parallel to an angle guide line to define the object position. A cylindrical reference object of known height and diameter was placed beside the object being recorded. The photographic record was made after checking to see that the object being recorded and the reference object were in focus and that contour lines could be seen on the surface in front of and behind the recorded object.

3.2.2 Measurement of Image Co-ordinates

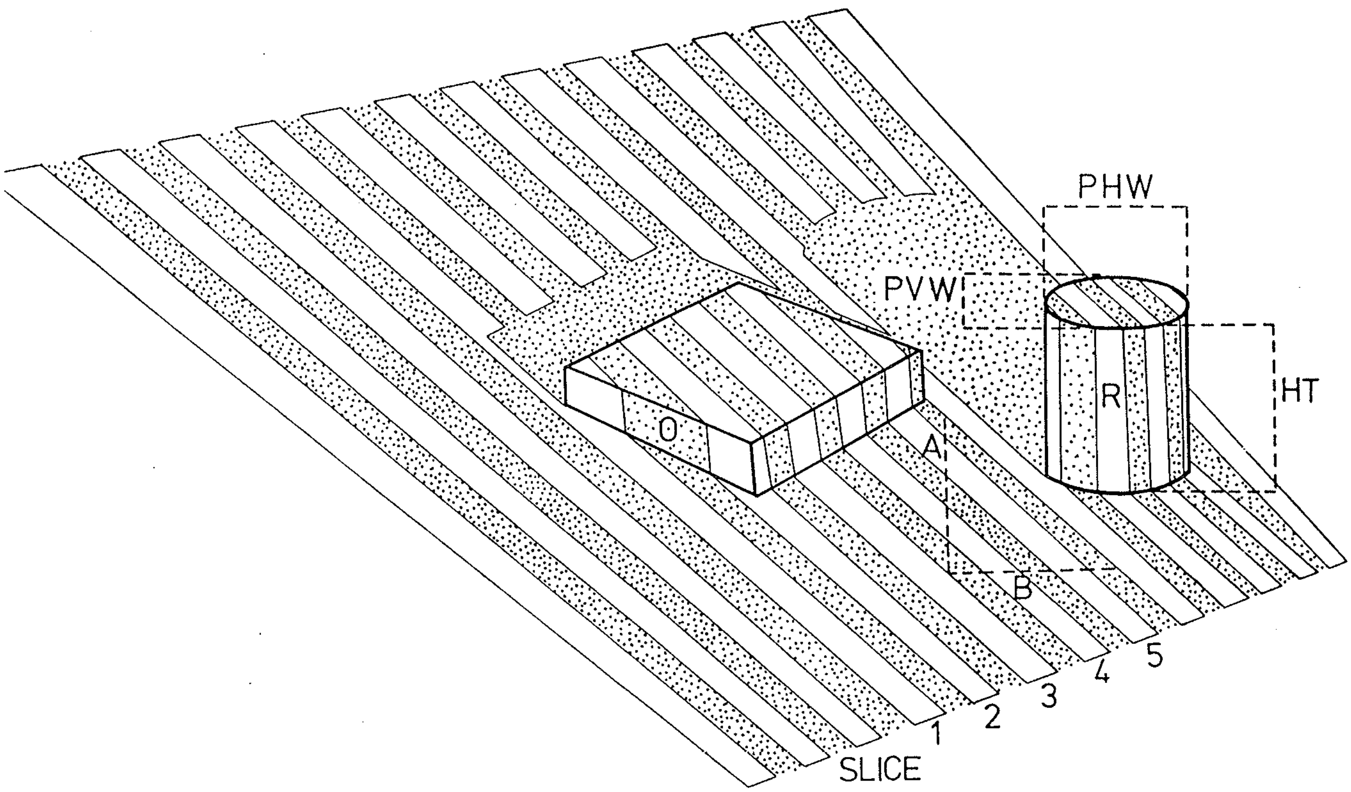
A computer program was written in BASIC which created files to store all the measurements taken from each photographic record (Microsoft,1982). The IBM Personal Computer was used for all data entry and calculation procedures required by the photographic record method. A Hipad digitizer from Houston Instruments with an 11 inch by 11 inch sensitive surface was used (Houston Instrument Division of Bausch and Lomb, Austin, Texas). Measurements were obtained using a cursor or stylus and were recorded in units. The surface of the digitizer was covered with a sheet of paper marked off in vertical and horizontal intervals which were used to position the projected photographic slide records prior to measuring. A housing was built to hold the digitizer upright in the manner of a projection screen and also to allow it to slide from left to right while the surface remained vertical. Due to the high degree of magnification, the entire slide record for large recorded objects could not always be projected onto the digitizer surface. The side-to-side movement of the digitizer allowed the investigator to position either the projected reference object or the recorded object onto the screen at one time.

The slide projector was positioned such that the lens was at the same height as the digitizer surface. It was assured that the projection struck the digitizer at a 90^0 angle to minimize distortion.

The photographic records were projected onto the digitizer surface using the Kodak Ektagraphic III slide projector. Magnification was adjusted so that the record appeared as large as was possible, usually between 2.5X and 2.8X.

The left or right side of the reference object was lined up with a vertical line on the digitizer surface. This alignment put the photographic record in the same horizontal and vertical planes as the digitizer surface.

Figure 4 depicts a projected photographic record of a block shape. The measurements made for each record are shown.



R - Reference Object
O - Recorded Object
PHW - Projected Horizontal Width
PVW - Projected Vertical Width
HT - Projected Height
A - adjacent side of horizontal angle
B - opposite side of horizontal angle

Figure 4: Projection of a Photographic Record

The BASIC program first allowed for the keyboard input of information required for the ultimate running of the Nutrient Analysis Program (NAP84) (Sevenhuysen,1984). These were the Person, Day, Location, Meal and Food Code identifiers. This preliminary information section also included the absolute height and diameter of the reference object.

3.2.2.1 Measurements of the Reference Object

The first measurements requested by the BASIC program were of the reference object. The number of contour bands across the top of the reference object was estimated. One full band consisted of one light and one dark band. The number of full bands was counted first and partial bands were then estimated to one decimal place and added to this number. This value was entered into the data file via the keyboard.

If the contour lines on the reference object were not parallel to its sides, the deviation was measured with a protractor and entered into the data file in degrees. If there was no deviation, the default value of 0° was allowed to stand.

The projected height, projected horizontal width and projected vertical width of the reference object were measured using the digitizer. The cursor or stylus was used to enter the two points at the extremes of these measures. The program calculated the absolute difference between the two points and stored the resulting value in the data file in units.

The projected height of the reference object was measured as the vertical distance from the bottom to the top of the object. The projected horizontal width was measured as the horizontal distance from one side to the other of the top of the reference object. It was important that this measurement ran through the marked centre of the top of the object to assure measurement of the diameter. The projected vertical width also ran through the marked centre of the reference object top. This measurement was the vertical distance from one side of the top to the other.

3.2.2.2 Horizontal Angle Measurement

The horizontal angle was the angle formed by the intersection of the contour lines with a horizontal line on the digitizer surface.

The distances of 'A' and 'B' were determined by the same technique as the previous three projected distances. The distances 'A' and 'B' were used to determine the size of the horizontal angle. This was done by application of the Pythagorean theorum (Washington, 1972).

The distance 'A' was measured as the vertical distance between the point that met a shadow line edge and a point on a horizontal line of the digitizer surface. The distance 'B' was measured as the horizontal distance between the lower point of the distance 'A' and a point that met the same shadow line used for 'a'. Thus, 'A', 'B' and the edge of a shadow line form a right angle triangle.

3.2.2.3 Measurement of Slice Co-ordinates

The size of the partial contour bands on both the left and the right side of the recorded object was estimated by the investigator and entered into the data file via the keyboard. The front of the recorded object was used for these estimations. The partial slice estimated on the left side of the object was considered to be the proportion of a full slice existing from the first slice to the left edge of the object. Similarly, the partial slice estimated on the right side was measured from the last slice to the right edge of the recorded object. If the recorded object had slices which tapered off in height towards the edges, as with a mound, the left edge (L) and right edge (R) estimates were entered as estimated. If, however, the edges of the object were of similar height to the nearest slice, as with a block, the L and R values were first doubled and then entered into the data file.

Each slice could be measured from either the left side or the right side of a dark shadow band. All photographic slide records were measured from both sides which increased the number of volume estimates determined. All objects were measured from the left-most slice to the right-most slice of the object.

An unlimited number of X and Y co-ordinate pairs could be chosen along the edge of each contour band, which would define the slice. For a block shape, four pairs of co-ordinates sufficed. Objects with curves, such as spheres or mounds, required more points to adequately approximate the shape of each slice.

Each co-ordinate pair was determined individually by marking an 'X' on the digitizer surface and using the cursor or stylus to enter each point. All points within one slice were determined before going onto the next slice.

Two points lying on the bottom horizontal plane or in a parallel plane were flagged for use in the calculations.

The first point fell along the bottom horizontal plane of the object (Xi_1) The last point fell in the same plane but was hidden from view (Xi_4). The determination of the position of this hidden point was done by placing a ruler along the edge of the shadow line as it appeared in front of and behind the object. For the block shape, a triangle was aligned with both a horizontal and a vertical line on the digitizer surface such that the vertical side was running through the third point (Xi_3). The estimated position of the fourth point (Xi_4) was at the intersection of the ruler and the triangle. Right wedges, cylinders and blocks had at least four points per slice. For more complex shapes, such as spheres or mounds, the obscurred portion of each slice was subjectively estimated by the investigator by using the bottom of the slice as a guide, their knowledge of the object and their experience determining similar shapes.

The same procedure was followed for each slice of the recorded object. When all slices had been entered for a given object, input was ended. The integration formula desired was then chosen and entered.

3.2.3 Volume Estimation Calculation

A BASIC program was writtem to perform the necessary calculations with the IBM - Personal Computer (Microsoft, 1982).

Each slice defined by the measured X- and Y- co-ordinates had two dimensions. The dietary image processing involved was based on principles of descriptive geometry similar to those used in engineering drafting problems. The two-dimensional image was rotated in space about points and lines to place the face of the slice perpendicular to the line of sight (Ballard and Brown, 1982; Warner, 1954). This was accomplished by the manipulation of the X and Y co-ordinates. An area was calculated for each slice. An integration formula and the slice width value was applied to areas to determine the volume estimate for the recorded object.

The manipulations of the X- and Y- co-ordinates for a block shape are graphically summarized in Figure 5. The slice shape, as measured (X_1,Y_1), is rotated about points and lines to yield a slice outline that is 90^0 on the line of sight (X_2,Y_3). Explanations of each transformation are given with the formulae in the following section.

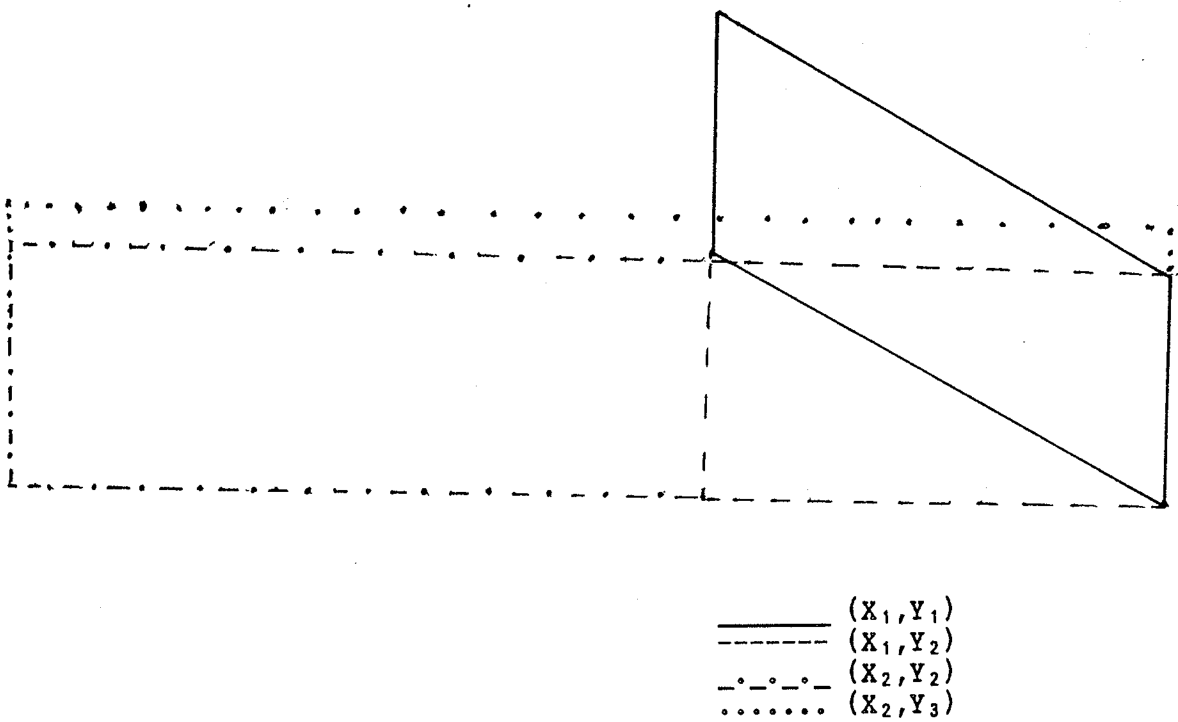


Figure 5: Graphic Representation of X and Y Co-ordinate Manipulations

3.2.3.1 Co-ordinate Manipulation

The first alteration consisted of decreasing all Y values, except those that were flagged, to bring the slice into the same horizontal as the line of sight. This was done by applying the following formula:

$$Y_{2i} = Y_{1i} + (X_{1i} - X_{f1})d/f$$

where Y_{2i} is the decreased Y co-ordinate value
Y_{1i} is the Y co-ordinate value, as measured
X_{f1} is the first flagged value
X_{1i} is the X co-ordinate value corresponding to Y_1
d is the absolute difference between the two flagged Y_{1i} values
f is the absolute difference between the two flagged X_{1i} values

The value of the hypotenuse of the horizontal angle was calculated as follows:

$$a_2 = a_1 \, (W_H / W_V)$$

$$c^2 = a_2^{\,2} + b^2$$

where W_H is the projected horizontal width of the reference object
W_V is the projected vertical width of the reference object
a_1 is the length of the side opposite the horizontal angle
a_2 is the converted a_1 value
b is the length of the side adjacent to the horizontal angle
c is the length of the hypotenuse

All X co-ordinates, except the first flagged X_1 value and those equal to it, were decreased which turned the slice to 90° on the line of sight in the horizontal plane. This was accomplished using one of the following formulae:

-- for co-ordinates with X_1 values greater than the first flagged X_1 value:

$$X_{2i} = X_{f1} + [(X_{f1} - X_{1i})(c/b)]$$

-- for co-ordinates with X_1 values less than the first flagged X_1 value:

$$X_{2i} = X_{f1} + [(X_{1i} - X_{f1})(c/b)]$$

where X_{2i} is the converted X_{1i} value

All Y_2 values, except the flagged Y values, were increased to bring the slice perpendicular to the line of sight. This was done using the following two formulae:

$$K = \cos Z\ [(W_H/W_A)(H_A)]/H_p$$

$$Y_{3i} = Y_{f2} + K(Y_{2i} - Y_{f2})$$

where K is a constant for any one slide
Z is the angle between projected contour lines and the side of the reference object
W_A is the absolute width of reference object
H_A is the absolute height of reference object, in cm
H_p is the projected height of reference object, in cm

and

where Y_{3i} is the converted Y_2 value
Y_{f2} is the second flagged Y value

3.2.3.2 Area Estimate Calculation

The area of a slice was calculated using the formula (Kemper, 1982):

$$A_1 = X_{2a}Y_{3b} + X_{2b}Y_{3c} + X_{2c}Y_{3d} + X_{2d}Y_{3a} - X_{2b}Y_{3a} - X_{2c}Y_{3b} - X_{2d}Y_{3c} - X_{2a}Y_{3d}$$

where X_{2i} and Y_{3i} are converted X and Y co-ordinates
i denotes the co-ordinate pair, i=a,b,...etc.
A_1 is the slice area in square units

The area of the slice in square units was transformed into square centimetres using the formula:

$$A_2 = A_1(W_A/W_H)^2$$

where A_2 is the absolute slice area

The slice width in centimetres was determined using the formula:

$$W_S = (W_H/S)(W_A/W_H) = W_A/S$$

where W_S is the width of the slice
S is the number of bands across the top of the reference object

3.2.3.3 Volume Estimate Calculation

The integration formulae and slice width were applied to the area estimates to determine a volume estimate in millilitres (Assumption: $cm^3 = mL$). For the purpose of calculation, one cubic centimeter was assumed to be equal to on milliliter. The three formulae used were:

1. Simpson's subroutine (Smith, 1966)

   For odd number of slices --

$$V_1 = W_S /3 (A_1 + 4A_2 + 2A_3 + \ldots + 2A_{n-2} + 4A_{n-1} + A_n)$$

   For even number of slices --

$$V_1 = 3/8(W_S)(A_1 + 3A_2 + 3A_3 + A_4) + (W_S/3)(A_4 + 4A_5 + 2A_6 + \ldots + 2A_{n-2} + 4A_{n-1} + A_n)$$

   where V_1 is the volume estimate

   A_n is the slice area

   n is the slice number, n=1,2,...n

2. Arithmetic Mean Subroutine

$$V_1 = (A_1 + A_2 + A_3 + \ldots + A_n)W$$

3. Triangular Mean Subroutine

$$V_1 = W_s[A_1 + A_2)/2] + [(A_2 + A_3)/2] + \ldots + [(A_{n-1} + A_n)/2]$$

The final portion of the volume estimate calculation accounted for the proportions of slice widths between the first and the last slice measured and the left and right edges, respectively, of the recorded object. Volumes of these portions were calculated and added to the volume determined by the integration formula resulting in the final volume estimate. This volume calculation was done by:

$$V_2 = [L(A_1)]/2 + [R(A_n)]/2$$

where L is the proportion of a slice width between the left-most slice and the left edge of the recorded object (recorded as decimal fraction of a slice)
R is the proportion of a slice width between the right-most slice and the right edge of the recorded object (recorded as decimal fraction of a slice)
A_1 is the left-most slice, in cm^2
A_n is the right-most slice, in cm^2

Final volume (V) was the sum of the two portions of volume estimated.

$$V = V_1 + V_2$$

This final volume estimate was written to an output file in a format acceptable to the Nutrient Analysis Program (NAP84) (Sevenhuysen, 1984).

Before NAP84 could be run with food item volumes estimated by the photographic record method, the data in the output file was uploaded to the Amdahl mainframe computer from the IBM Personal Computer.

3.3 RESEARCH DESIGN

This study was a series of completely randomized design experiments. The dependent variable for the experiments with standard objects was the photographic record method volume estimate. For experiments where actual food items were used, the dependent variables were the volume, weight and associated nutrient content estimates obtained by the photographic record method and NAP84.

The independent variables for the standard object studies were:

1. object position
2. contour line width
3. size of angle between camera and light source
4. magnification of projected slide records
5. object shape
6. object size
7. height of reference object
8. investigator
9. integration formulae

For null hypotheses 10-12, involving actual food items, the independent variables were the physical volume, weight and nutrient content values.

3.4 DATA COLLECTION

3.4.1 Standard Objects

To formulate a standard technique for the photographic record method, volume estimates of standard objects were determined for different image characteristics.

The shape, size and material of the standard objects used to collect data for the first section of the study are given in Table 3. The objects were measured using a ruler with a minimum increment of 1 mm. Therefore, the variation of the reported volumes was less than this smallest division of the measurement tool. All records using the wooden block were made with a reference object 3.3 cm in diameter and 3.4 cm high. The records made with the metal and styrofoam objects used a reference object 6 cm in diameter and 6 cm high.

1. Position of the standard object determined the shape and number of slices. Perception of the slices may be influenced by changes in position and lead to error. Therefore, the position of the standard object in relation to the camera was altered. The object was turned in the same horizontal plane through 60^0 to define three positions -- start, start + 30^0 and start + 60^0. The starting position was defined as one where a line at the base of the object formed a 15^0 angle with the line of sight of the camera lens. These determinations were done in duplicate using a wooden block of volume 129.8 millilitres.

TABLE 3

Shape, Size and Material of Standard Objects

Shape	Nominal Size 100 mL [material]	200 mL [material]	400 mL [material]	50 mL [material]	125 mL [material]
Right Square Prism	96.0 [stainless steel]	190.1 [stainless steel]	358.2 [stainless steel]	48.0 [stainless steel]	129.8 [wood]
Right Circular Cylinder	100.5 [aluminum]	200.1 [aluminum]	398.2 [aluminum]	----	----
Sphere	68.6 [styrofoam]	134.1 [styrofoam]	231.7 [styrofoam]	----	----
Right Wedge	100.6 [stainless steel]	201.1 [stainless steel]	403.4 [stainless steel]	----	----

2. Changes made to the angle between the camera and the light source affected the slice shape and the way in which the investigator perceived the slice. Therefore, this angle was given the three values of 15°, 30° and 60°. A wooden block of volume 129.8 millilitres was used for the duplicate determinations.

3. The error associated with volume estimates might have changed when a greater number of contour lines fell across the object. For this reason, two contour line slides with 1.0 millimetre and

0.5 millimetre contour widths were used to cast the contour lines onto the 129.8 millilitre wooden block.

These determinations were carried out in duplicate. Records for these three independent variables were collected in a factorial design yielding a total of 36 slide records and 72 volume estimates.

4. Changes in projected magnification altered the size of the projected image which may have resulted in measurement errors on the part of the investigator. Photographic records of a wooden block of volume 129.8 millilitres were projected at three magnifications -- x1-1/2, x2 and x3. Determinations were done in duplicate and yielded 18 photographic slide records and 18 volume estimates.

5. Recorded objects of different shapes may have affected the perceptions of the investigator as slices to be measured were also of differing shapes. Metal and styrofoam standard objects of four basic shapes were recorded. These shapes included sphere, right rectangular block, right circular cylinder and right wedge. These shapes were chosen as those basic to food shapes. Records were duplicated.

6. Size of the standard objects may have affected investigator perception and thus, may have contributed to the error associated with the volume estimates. Three sizes of standard objects for each of the four shapes were photographically recorded. The

volumes of the 100, 200 and 400 mL nominal sizes of the styrofoam and metal standard objects were as listed in Table 3. An attempt was made to keep these near 100, 200 and 400 milliltres, as these volumes were thought to be similar to average portion sizes (Sabry and Chery, 1985; Krebs-Smith and Smiciklas-Wright, 1985).

The total number of slide records gathered with the independent variables of shape and size was 24, yielding 48 volume estimates.

7. A change of the actual height of the reference object caused a change in the projected height of the reference object. The latter was dependent upon the investigator's perception for accurate measurement. Therefore, changes in the actual height of the reference object may have been a source of error in the photographic record method due to changes in investigator perception. Reference objects of three heights were used when recording a standard metal block of volume 190.1 millilitres. The heights used were 3 cm, 6 cm and 12 cm. These records were done in duplicate to yield six slide records and to give 12 volume estimates.

8. A possible source of error in the photographic record method existed for measurements made by different investigators. In an attempt to quantify this error, six investigators measured image co-ordinates for each of four photographic records of a wooden block of volume 129.8 millilitres. Training of investigators involved two hours of group instruction concerning the mechanics

of measurements and approximately one hour of practice measurement completed individually. Duplicate determinations were done to give 48 volume estimates.

9. Integration formulae might have performed differently on various shapes and might also have given differing weights to the individual slice areas. To determine which estimated volume most accurately, three integration formulae were tested. These formulae were applied to all slide records collected for the independent variables object position, angle A, contour line width, object shape and object size. The formulae were:

   a) Simpson's Formula

   b) Arithmetic Mean

   c) Triangular Mean

3.4.2 Individual Food Items

Twenty food items, chosen from foods frequently consumed in North America, were recorded and processed since this method would be more commonly used in survey settings (Health and Welfare Canada, 1975; Agriculture Canada, 1983). Prior to photographically recording these food items, their gravimetric weights and physical volumes were recorded. Weights of each food item were determined using a Sartorius top-loading balance. Volumes of liquid and semi-solid foods were measured using liquid and dry household measures previously checked by graduated cylinder. Volumes of most solid foods were obtained by water displacement. Those not amenable to this process were measured with a ruler and volume formulae applied for their particular geometric shapes (Washington, 1970). Density factors were calculated using these food weights and volumes. The average of the two density factors obtained for each food item was used to convert volume estimates to weight estimates prior to analyzing for nutrient content. Since the photographic record method involved no physical manipulation of food items, weight estimates of actual food items were determined using the photographic volume estimate and standard density tables for 10 of the food items (Adams, 1975; Health and Welfare Cañada, 1984). This method more closely resembled that expected to be used in a survey setting. All determinations were done in duplicate.

Since consistency of a food item affects both its shape and density, these food items were categorized into one of four density/consistency groups:

1. Solid foods -- no visible air spaces with density less than 1 (eg. mashed vegetable, meat, fruit)
2. Solid foods -- visible air spaces with density less than 1 (eg. french fries, salad, bread products)
3. Liquid foods -- with density greater than or equal to 1 (eg. beverages, broth soups, sauces)
4. Semi-solid foods -- with density greater than or equal to 1 (eg. pudding, yogurt, oatmeal)

The foods, listed according to density/consistency group, are contained in Appendix A. The 10 foods with published density figures are noted, as well.

When photographically recording, the position of the dish holding the food was randomly assigned. A piece of tape was attached running through the centre of the bottom of the dish, out of sight of the investigator placing the food onto the dish. The right side of this tape was positioned along the line of sight of the camera thereby avoiding any investigator bias of food positioning. A total of 76 photographic volume estimates of 20 individual food items were produced.

3.5 DATA ANALYSIS

Statistical analyses were performed using the Statistical Analysis System (SAS) (SAS Institute, Inc., 1983).

3.5.1 Standard Objects

Descriptive statistics, including the arithmetic mean, standard deviation, standard error and range, were determined for the volume estimates obtained for each of the null hypotheses 1 through 9 (Ho_1 through Ho_9). Frequency plots of the dependent variables were made and the median, mode and normality of the data were noted.

One-way analysis of variance was performed for each hypothesis to determine the effect of the independent variable on the dependent variable. Pairwise comparisons of the treatment means within each hypothesis were completed using Scheffe's procedure (Steel and Torrie, 1980).

A three-way analysis of variance was performed to test for the interaction between line width, angle A and object position.

Paired t-tests were performed to test the significance of differences between the absolute volumes and the volume estimates.

Pearson's correlation coefficients were determined for the correlation of the independent variable, dependent variable and absolute volume for each of hypotheses 1 through 9.

3.5.2 Individual Food Items

Mean, standard deviation, standard error and range were determined for the photographic volume estimates. Frequency distributions were plotted and the normality of the distributions tested.

Scattergrams were plotted of the photographic estimates of the six dependent variables against the physical estimates of the same variables.

One-way analysis of variance was performed to determine the effect of the consistency/density group on the photographic volume estimates and the subsequent weight estimates. A pairwise comparison of the treatment means was done using Scheffe's procedure.

A paired t-test was conducted on the differences between the dependent variables and the physical estimates of the same variables.

Pearson's correlation coefficients were determined for the dependent variables and their physical estimate counterparts.

Chapter IV

RESULTS

4.1 STANDARD OBJECTS

4.1.1 Wooden Right Rectangular Block Object

A total of 72 photographic volume estimates were obtained for the 129.8 mL right rectangular block object. These data were used to test the three hypotheses related to the independent variables object position, angle A and contour line width.

4.1.1.1 Pooled Wooden Right Rectangular Block Data

The mean photographic volume estimate for these data was 99.39% of the absolute volume with a standard deviation of 5.17% (N=72). The standard error of the mean was 0.16%.

A paired t-test was applied to the differences between the ratios of volume estimate to absolute volume and 1.0 (absolute volume:absolute volume). The differences were not found to be significant (t=1.01;p=0.3174). Based on this statistical analysis, the photographic volume estimates do not differ significantly from the absolute volume for a right rectangular block object.

A three-way analysis of variance procedure testing the possible interactions between contour line width, object position and angle A, found significant interactions between angle A and contour line width and between object position and contour line width for both of the statistical models tested. The full statistical model tested all possible interactions. Only those interactions that were significant were included in the modified model. Results for the full and the modified model are shown in Appendix B. The mean volume estimates for line width were determined and plotted for each of the three object positions and for each of the three angles A. Since interaction may be a difference in direction of response or magnitude of response, the plotted means, seen in Figures 6 and 7, indicated the interactions may be occuring at the 15^0 level of both angle A and object position due to the difference in magnitude of the responses at this level. These data indicated that the effect of contour line width is not consistent across the range of values used for either the object position or angle A.

4.1.1.2 Object Position

Results of a paired t-test performed on the differences between the ratio of photographic volume estimate to absolute volume and 1.0 (absolute volume:absolute volume) for three object positions are shown in Table 5. No significant differences were evident. Analysis indicates that the photographic record method is closely related to the absolute volume of a right rectangular block object. Mean photographic volume estimates expressed as percentages of the absolute volume for each of the object positions are shown in Table 5.

The three-way analysis of variance procedure indicated that the effect of object position alone was not significant ($F=1.66; p=0.1979$) (Appendix B). Therefore, the null hypothesis (Ho_1) was accepted, since

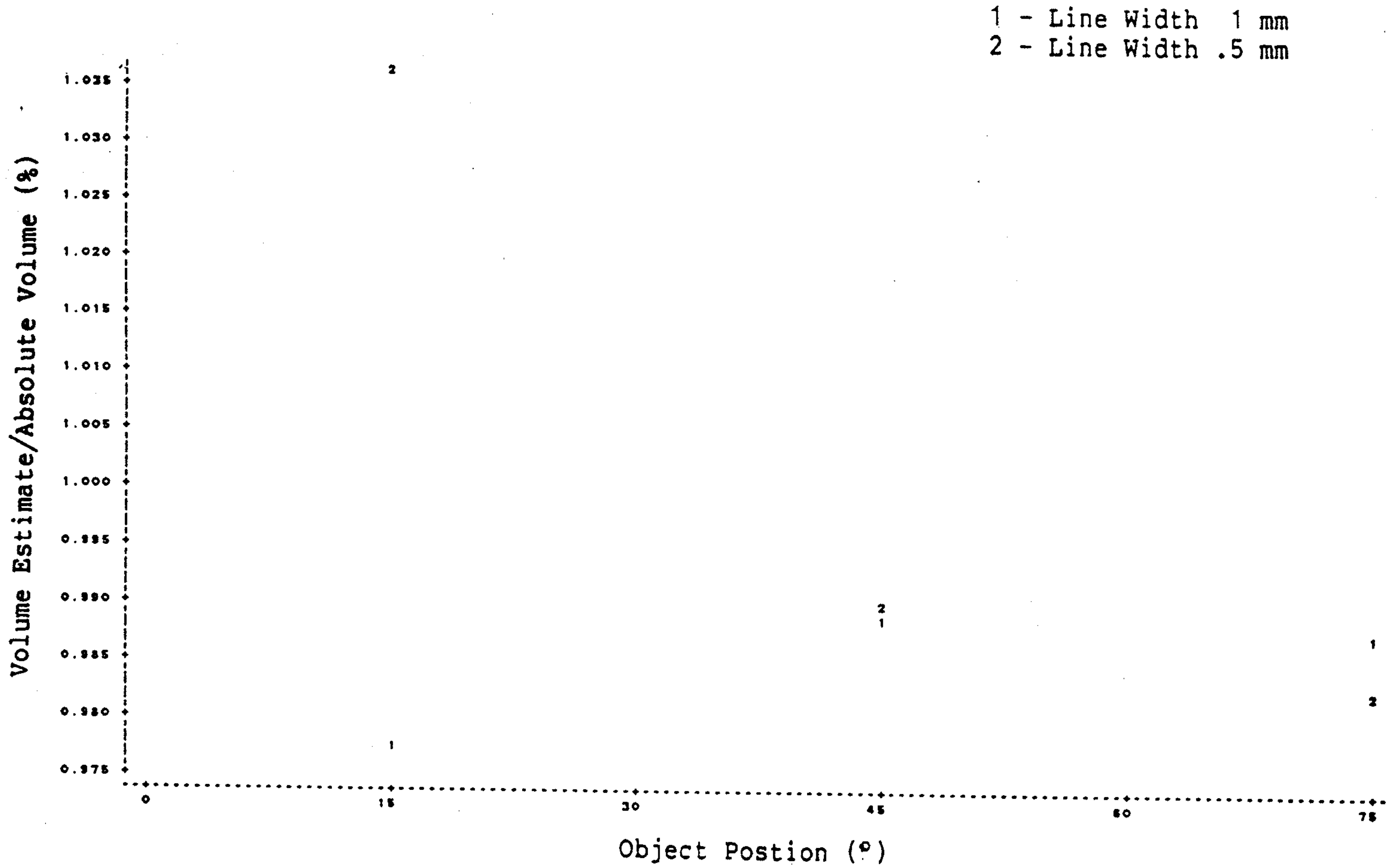


Figure 6: Plot of mean photographic volume estimates by line width for each of three object positions

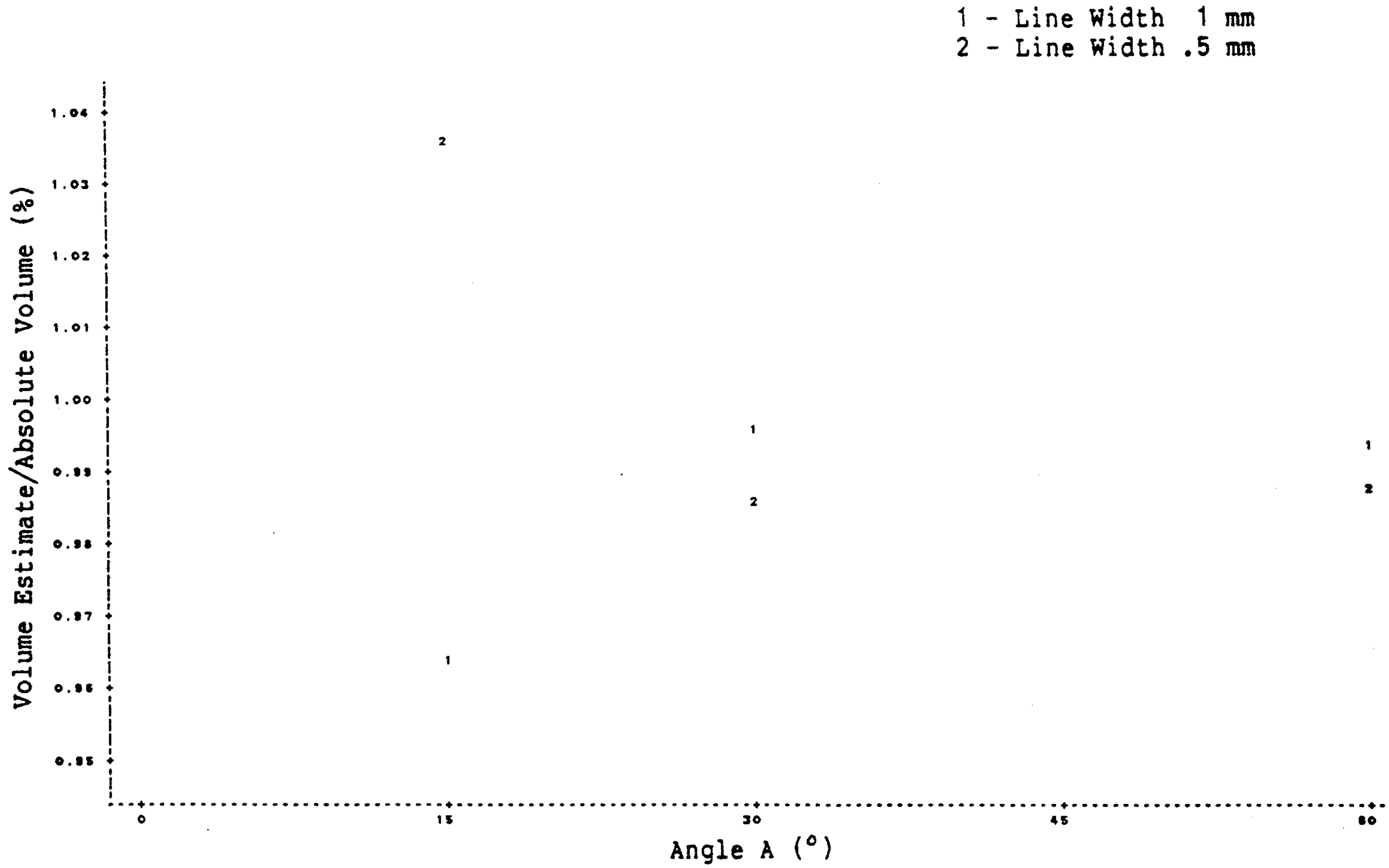


Figure 7: Plot of mean photographic volume estimates by line width for each of three angles A

TABLE 5

Mean photographic volume estimates expressed as percentages of absolute volume and paired t-test for difference between volume estimates and absolute volume for three object positions

Object Position	N	Mean	Standard Deviation	Standard Error	t value	Probability
15^0	24	100.73	6.67	1.36	-0.54	0.5966
45^0	24	98.95	3.87	0.79	1.33	0.1971
75^0	24	98.48	4.49	0.92	1.66	0.1101

it appears that object position alone does not affect the estimates of volume made by the photographic record method.

4.1.1.3 Angle A -- the angle between the camera and the light source

Mean photographic volume estimates obtained for each of the three angles are shown in Table 6. This table also contains the results of a paired t-test, performed on the difference between the ratio of photographic volume estimate to absolute volume and 1.0 (absolute volume:absolute volume) for three angles A. No significant differences were apparent.

The three-way analysis of variance procedure performed on these data indicated no significant effect of angle A alone ($F=0.33; p=0.7214$) (Appendix B). Therefore, the null hypothesis (Ho_2) was accepted.

TABLE 6

Mean photographic volume estimates expressed as percentages of absolute volume and paired t-test for difference between volume estimates and absolute volume for three angles A

Angle A	N	Mean	Standard Deviation	Standard Error	t value	Probability
15^0	24	99.99	6.53	1.33	0.00	0.9968
30^0	24	99.12	5.06	1.03	0.86	0.4001
60^0	24	99.05	3.70	0.75	1.26	0.2203

From these statistical analyses, it appears that the photographic record method is able to estimate volume for a right rectangular block without an effect from the angle A.

4.1.1.4 Contour Line Width

Mean photographic volume estimates obtained for the two contour line widths investigated and the results of a paired t-test performed on the difference between the ratio of photographic volume estimates to absolute volume and 1.0 (absolute volume:absolute volume) for the two contour line widths are shown in Table 7. These data seem to indicate that the 1.0 mm contour line width underestimates the absolute volume when compared with the 0.5 mm contour line width.

The three-way analysis of variance procedure indicated that the effect of contour line width alone was not significant (F=3.04;p=0.0861) (Appendix B). The null hypothesis (Ho_3) was accepted, since contour line width did not significantly affect photographic volume estimates. There were significant interaction effects for contour line width and position (F=3.58;p=0.0338) and for contour line width and angle A (F=6.43;p=0.0029). From Figures 6 and 7, it is indicated that the 0.5 mm line width overestimates the object volume at the 15^0 level of both angle A and object position. However, the range between the two line width means is small for both Figures 6 and 7.

While the results of the paired t-test seemed to indicate that the 1.0 mm contour line width underestimates the absolute volume when compared with the 0.5 mm line width, further analyses did not indicate any significant differences between the two contour line widths. Hence, it would appear that the photographic record method estimates absolute volume without any significant effect of contour line width.

TABLE 7

Mean photographic volume estimates expressed as percentages of absolute volume and paired t-test for difference between volume estimates and absolute volume for two contour line widths

Line Width	N	Mean	Standard Deviation	Standard Error	t value	Probability
0.5 mm	36	100.31	6.10	1.02	-0.31	0.7595
1.0 mm	36	98.46	3.90	0.65	2.37	0.0233

4.1.2 Magnification Level

Mean photographic volume estimates obtained for the three magnification levels are shown in Table 8. A paired t-test was performed on the differences between the ratio of estimated volume to absolute volume and 1.0 (absolute volume:absolute volume) for each of the three magnification levels. The results are also shown in Table 8. There were no significant differences evident between magnification levels. These data would indicate that the photographic record method is able to estimate absolute volume consistently for the levels of magnification investigated.

A one-way analysis of variance procedure was performed to determine the effect of magnification level on the photographic volume estimate(N=18). The effect was not found to be significant ($F=1.18; p=0.3349$). Thus, the null hypothesis (Ho_4) was accepted. This statistical analysis further indicates that the photographic record method volume estimates are not affected by the level of magnification.

TABLE 8

Mean photographic volume estimates expressed as percentages of absolute volume and paired t-test for difference between volume estimates and absolute volume for three magnification levels

Magnification Level	N	Mean	Standard Deviation	Standard Error	t value	Probability
1.5X	6	95.13	4.81	1.96	2.48	0.0557
2.0X	6	99.44	6.02	2.46	0.23	0.8299
2.5X	6	97.42	3.43	1.40	1.84	0.1246

4.1.3 <u>Pooled standard object shape and size data</u>

A total of 48 photographic volume estimates were obtained of standard objects for three sizes (100 mL, 200 mL, 400 mL) of each of four object shapes (right rectangular block, right circular cylinder, right wedge, sphere).

A two-way analysis of variance was performed to test for the possible interaction between object size and object shape. Results, seen in Table 9, show that object shape alone has a significant effect and that there is a significant interaction between object shape and object size.

The plot of the means of each object shape is shown in Figure 8. The significant differences between the right rectangular block objects and

TABLE 9

Two-way analysis of variance procedure for object shape and object size, N=48

Source	df	F value	Probability
Object shape	3	15.93	0.0001
Object size	2	2.38	0.1075
Shape*size	6	5.02	0.0008
Error	36	----	------
Total	47	----	------

both the right cylinder and the right wedge objects appear to be mainly due to the underestimation found for the 100 mL right rectangular block object. It can be noted that volumes determined for the 400 mL size of both the right cylinder and the right wedge objects were generally greater underestimates than with other object sizes.

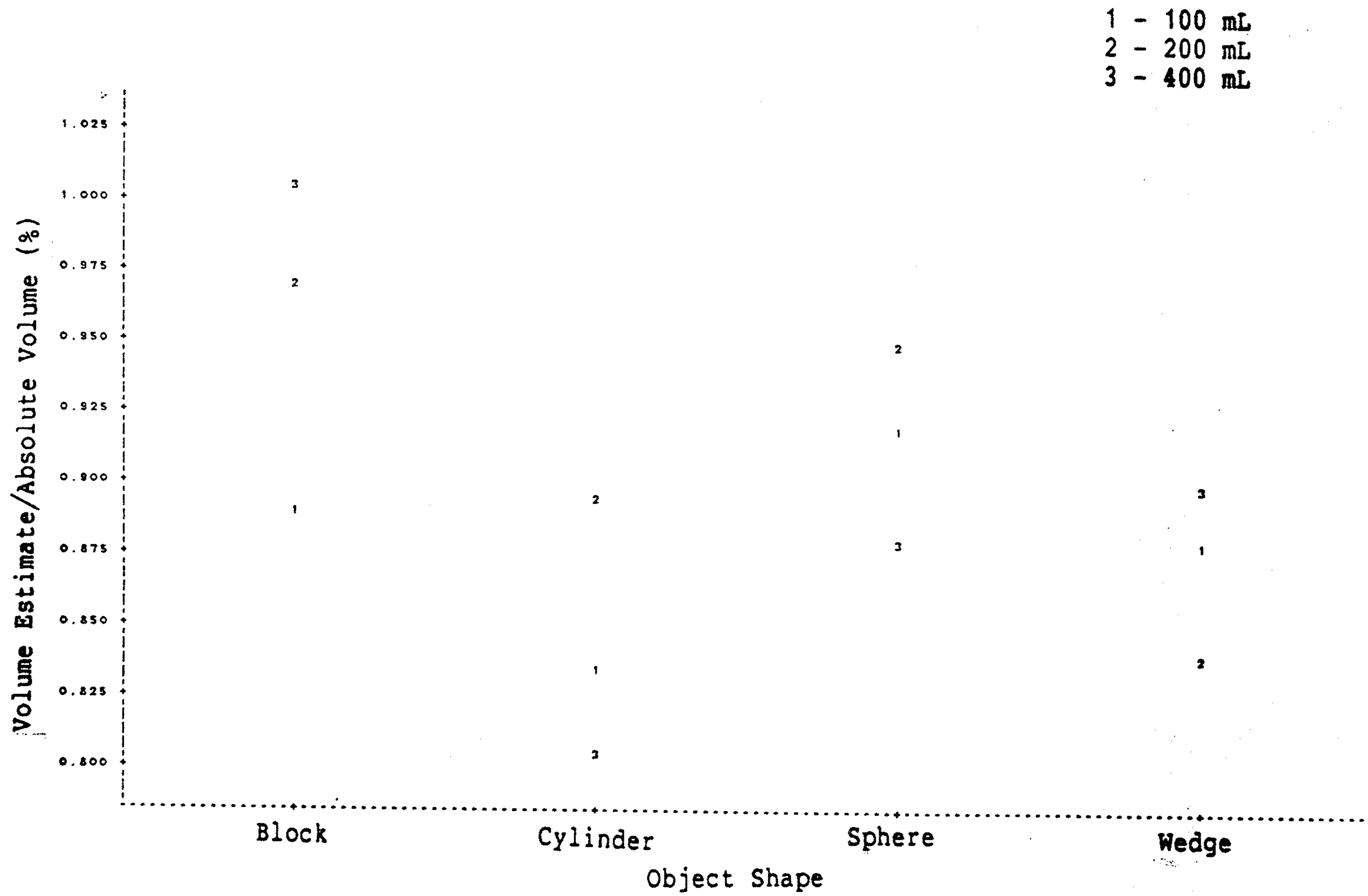


Figure 8: Plot of mean photographic volume estimate by object size against object shape

4.1.4 Object Shape

Using data of the four object shapes, a paired t-test was performed on the differences between the ratio of photographic volume estimate to absolute volume and 1.0 (absolute volume:absolute volume). The results are contained in Table 10. Differences were significant for all four object shapes. This could be an effect of the small sample size or of the fixed object position.

TABLE 10

Mean photographic volume estimates expressed as percentages of absolute volumes and paired t-test for differences between volume estimates and absolute volume for four object shapes

Object Shape	N	Mean	Standard Deviation	Standard Error	t value	Probability
Right Rectangular Block	12	95.37	5.76	1.66	2.79	0.0177
Right Circular Cylinder	12	84.54	7.75	2.24	6.91	0.0001
Right Wedge	12	87.28	3.84	1.11	11.45	0.0001
Sphere	12	91.68	5.46	1.58	5.28	0.0003

A two-way analysis of variance procedure indicated there was a significant effect of object shape on photographic volume estimates(F=15.93;p=0.0001)(Table 9). Therefore, the null hypothesis (Ho_5) was rejected. A paired comparison of the means for object shape using Scheffe's procedure revealed significant differences between the block and cylinder, the block and wedge and the sphere and cylinder shapes. The photographic record method does not appear to act consistently with the four shapes tested. Further investigation would be required to reveal the causes of such inconsistencies.

4.1.5 Object Size

4.1.5.1 Three sizes of four object shapes

Mean photographic volume estimates for each size are contained in Table 11. This table also shows the results of a paired t-test carried out on the differences between the ratio of photographic volume estimates to absolute volumes and 1.0 (absolute volume:absolute volume) for the three object sizes investigated. For all three sizes, volume estimates were significantly different from the absolute volumes.

A two-way analysis of variance procedure on the data indicated that there was not a significant effect of object size alone (F=2.38;p=0.1075). There was a significant interaction effect of object size and object shape (F=5.02;p=0.0008)(Table 9). The null hypothesis (Ho_6) was accepted since the photographic record method is not affected by object size alone when estimating volume.

TABLE 11

Mean photographic volume estimates expressed as percentages of absolute volumes and paired t-test for differences between volume estimates and absolute volume for three object sizes

Object Size	N	Mean	Standard Deviation	Standard Error	t value	Probability
100 mL	16	88.11	6.55	1.64	7.26	0.0001
200 mL	16	91.31	5.95	1.49	5.84	0.0001
400 mL	16	89.74	8.49	2.12	4.83	0.0002

4.1.5.2 Four sizes of right rectangular block shape

Sixteen photographic volume estimates were obtained of four sizes of right rectangular block objects. The mean volume estimates expressed as percentages of absolute volume for each size are shown in Table 12. A paired t-test was carried out on the differences between the ratio of photographic volume estimates to absolute volumes and 1.0 (absolute volume:absolute volume) for the four object sizes investigated. The results are shown in Table 12. Differences were significant for the 50 mL and the 100 mL sizes. Both the 50 mL and the 100 mL objects had only three or four contour lines falling across them. While this is enough for Simpson's formula to function, it may affect the precision of the volume estimates.

TABLE 12

Mean photographic volume estimates expressed as percentages of absolute volume and paired t-test for differences between volume estimates and absolute volume for four sizes of right rectangular block objects

Object Size	N	Mean	Standard Deviation	Standard Error	t value	Probability
50 mL	4	87.21	6.24	3.21	3.98	0.0283
100 mL	4	88.76	2.16	1.07	10.52	0.0018
200 mL	4	97.00	2.71	1.36	2.21	0.1142
400 mL	4	100.33	3.90	1.95	-0.17	0.8755

The effect of object size for the right rectangular block objects was significant when tested with a one-way analysis of variance ($F=12.6; p=0.0007$). A paired comparison of the object size means using Scheffe's procedure, showed the 400 mL size was significantly different from both the 50 mL and the 100 mL sizes and that the 200 mL size was significantly different from the 50 mL size.

4.1.6 Reference Object Height

Mean volume estimates for each of the three reference object heights investigated are contained in Table 13. The differences between the ratio of estimated volume to absolute volume and 1.0 (absolute volume:absolute volume) were subjected to a paired t-test. The results are also shown in Table 13. All differences were significant. The small sample sizes may have caused these differences.

TABLE 13

Mean photographic volume estimates expressed as percentages of absolute volume and paired t-test for differences between volume estimates and absolute volume for three reference object heights

Reference Object Height	N	Mean	Standard Deviation	Standard Error	t value	Probability
3 cm	4	82.68	2.38	1.19	14.58	0.0007
6 cm	4	91.15	2.75	1.38	6.43	0.0076
12 cm	4	84.16	1.87	0.93	16.95	0.0004

A one-way analysis of variance was performed to determine the significance of the effect of reference object height on photographic volume estimation. The effect was found to be significant ($F=15.57; p=0.0017$). Therefore, the null hypothesis (Ho_7) was rejected. A paired comparison of the mean volume estimates for each reference object height using Scheffe's procedure indicated that the 6 cm reference object was significantly different from both the 12 cm and the 3 cm reference objects ($p=0.05$). Figure 9 shows the plot of photographic volume estimates for each of the three reference object heights investigated.

The height of the reference object appears to affect the photographic volume estimate. However, insufficient data is available with which to make valid conclusions as to the influence of reference object height.

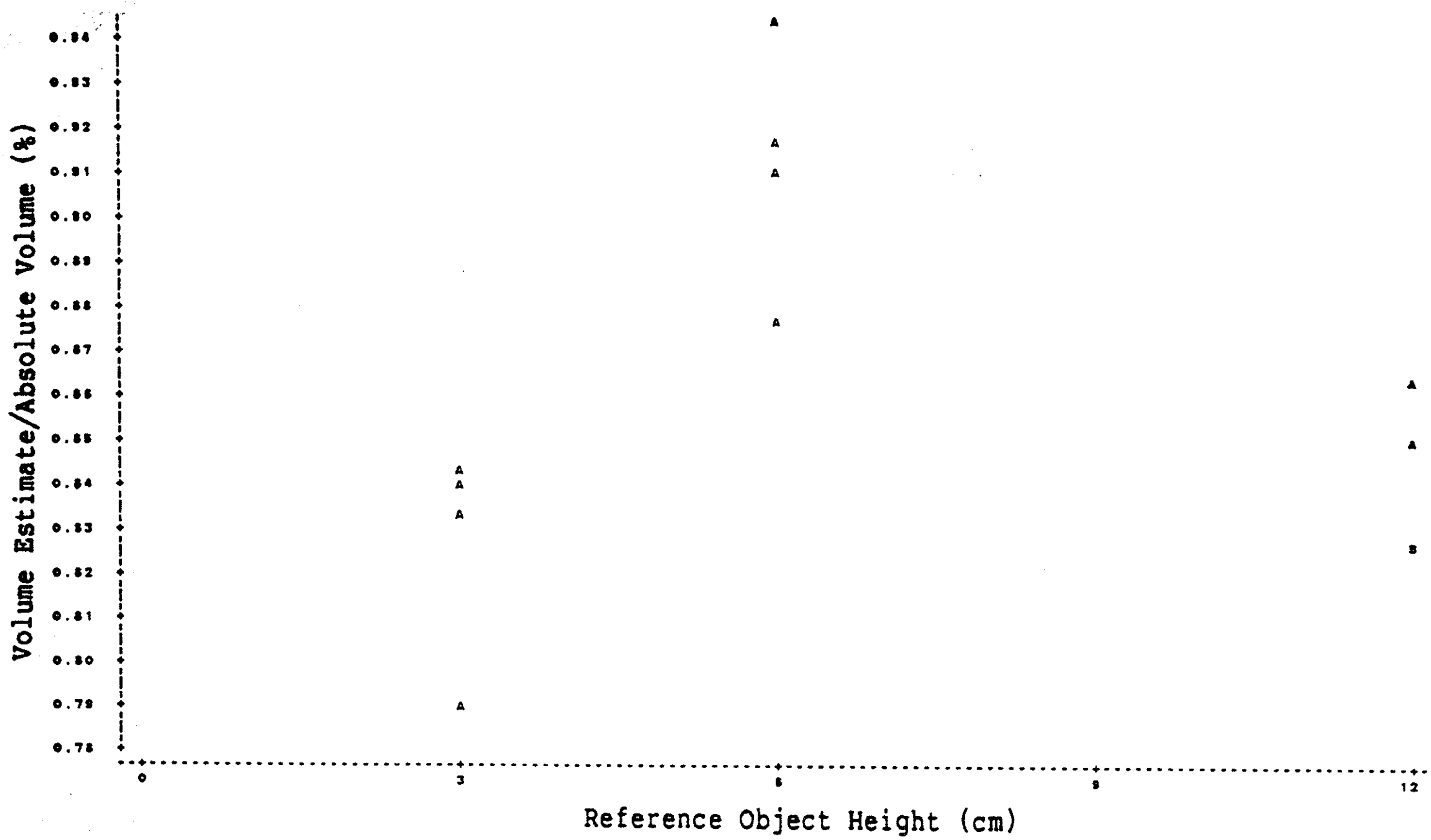


Figure 9: Plot of photographic volume estimates against reference object heights, N=12 (A=1 observation, B=2 observations)

4.1.7 Investigator

Mean volume estimates for each investigator are given in Table 14. This table also contains results of a paired t-test performed on the differences between the ratio of photographic volume estimate to absolute volume and 1.0 (absolute volume:absolute volume). Only estimates made by investigator 6 were significantly different from the absolute volume.

TABLE 14

Mean photographic volume estimates expressed as percentages of absolute volumes and paired t-test for differences between volume estimates and absolute volumes for six investigators

Investigator	N	Mean	Standard Deviation	Standard Error	t value	Probability
1	8	101.09	2.80	0.99	-1.10	0.3084
2	8	100.35	5.58	1.97	-0.18	0.8627
3	8	100.57	6.41	2.27	-0.25	0.8082
4	8	99.15	2.64	0.93	0.91	0.3907
5	8	97.81	5.57	1.97	1.11	0.3022
6	8	92.33	8.17	2.89	2.66	0.0327

A one-way analysis of variance procedure was performed on the data to determine the effect of investigator on photographic volume estimates (N=48). The effect was found to be significant (F=2.75;p=0.0311). Therefore, the null hypothesis (Ho_8) was rejected. A pairwise comparison of the mean volume estimates for each investigator using Scheffe's procedure revealed no significant differences.

The statistical analyses indicate that measurements of photographic records by different persons yield results that may not be significantly different in practice. It is reasonable to expect some differences to occur with the minimal training given the investigators. From this, the photographic record method appears to be a reliable tool for estimating object volume.

The mean photographic volume estimate as determined for the pooled investigator data was 98.55% of the absolute volume with a standard deviation of 6.05%. The standard error of the mean was 0.87%. A paired t-test was performed on the differences between the ratio of photographic volume estimates to absolute volume and 1.0 (absolute volume:absolute volume) for the pooled investigator data (N=48). There were no significant differences (t=1.66;p=0.1033). The photographic record method can be used by several investigators with consistent results.

4.1.8 Integration Formulae

Mean photographic volume estimates for each of three integration formula are shown in Table 15. A paired t-test was performed on the differences between the ratio of photographic volume estimates to absolute volume and 1.0 (absolute volume:absolute volume) for each integration formula. Results are shown in Table 16. Only differences of the Arithmetic mean formula for the metal block and cylinder objects and of the Simpson's formula for the wooden block object were not significantly different. Differences were noted between the wooden and the other standard objects. These differences were mentioned for Simpson's formulae while presenting the results for object shape. A similar explanation can be applied to the Arithmetic mean and Triangular mean formulae.

A one-way analysis of variance procedure was performed with the data to determine the effect integration formula had on photographic volume estimates. Results are shown in Table 17. Due to the significant F-value, the null hypothesis (Ho_9) was rejected.

A pairwise comparison of the mean volume estimates for each integration formula using Scheffe's procedure revealed, for the wooden block, metal block, cylinder and sphere, that the Arithmetic Mean formula was significantly different from both Simpson's and the Triangular Mean formulae (p=0.05). For the wedge shaped objects, a pairwise comparison of the mean photographic volume estimates using Scheffe's procedure revealed a significant difference between the Arithmetic Mean formula and the Triangular Mean formula. The Arithmetic Mean appears to give higher volume estimates than either of the other two formulae. Simpson's formula and the Triangular Mean seem to estimate volume similarly.

TABLE 15

Mean photographic volume estimates expressed as percents of absolute volumes of different shaped objects for three integration formulae

Integration Formula	Standard Object	N	Mean	Standard Deviation	Standard Error
Arithmetic Mean	Wooden Block	72	103.07	7.65	0.90
	Metal Block	12	105.32	10.59	3.06
	Cylinder	12	97.54	12.60	3.64
	Wedge	12	90.11	4.52	1.30
	Sphere	12	110.20	10.83	3.13
Simpson's Formula	Wooden Block	72	99.39	5.17	0.61
	Metal Block	12	95.37	5.76	1.66
	Cylinder	12	84.54	7.75	2.24
	Wedge	12	87.28	3.48	1.11
	Sphere	12	91.68	5.46	1.58
Triangular Mean	Wooden Block	72	98.39	5.22	0.62
	Metal Block	12	93.34	5.40	1.56
	Cylinder	12	81.69	8.09	2.34
	Wedge	12	85.39	3.78	1.09
	Sphere	12	87.89	5.12	1.48

TABLE 16

Paired t-test on differences between photographic volume estimates and absolute volume for three integration formulae

Integration Formula	Standard Object	N	t value	Probability
Arithmetic Mean	Wooden Block	72	-3.46	0.0011
	Metal Block	12	-1.74	0.1096
	Cylinder	12	0.68	0.5124
	Wedge	12	7.58	0.0001
	Sphere	12	-3.26	0.0076
Simpson's Formula	Wooden Block	72	2.37	0.3174
	Metal Block	12	2.79	0.0177
	Cylinder	12	6.91	0.0001
	Wedge	12	11.45	0.0001
	Sphere	12	5.28	0.0003
Triangular Mean	Wooden Block	72	5.29	0.0111
	Metal Block	12	4.27	0.0013
	Cylinder	12	7.84	0.0001
	Wedge	12	13.39	0.0001
	Sphere	12	8.20	0.0001

TABLE 17

Analysis of variance for effect of integration formulae

Standard Object	N	df	F value	Probability
Wooden[1] Block	216	2	11.65	0.0001
Metal[2] Block	36	2	8.23	0.0013
Cylinder[2]	36	2	9.56	0.0002
Wedge[2]	36	2	4.97	0.0132
Sphere[2]	36	2	40.02	0.0001

[1]Error df - 213
[2]Error df - 33

4.2 INDIVIDUAL FOOD ITEMS

4.2.1 Volume

For 20 individual food items, 76 photographic volume estimates were obtained. The plot of these photographic volume estimates against physical volumes is presented in Figure 10. Pearson's correlation coefficient (r) for the association between photographic volume estimates and absolute volumes was high and significant (r=0.90412; p=0.0001). From this, and the simple linear regression analysis, it appears that the photographic record method is highly related to the absolute volume of the food items recorded. Results of the linear regression analysis are contained in Appendix C. Results of two-tailed t-tests indicated that the regression line was not significantly different from a line through the origin with a slope of one (y=x) (Appendix C).

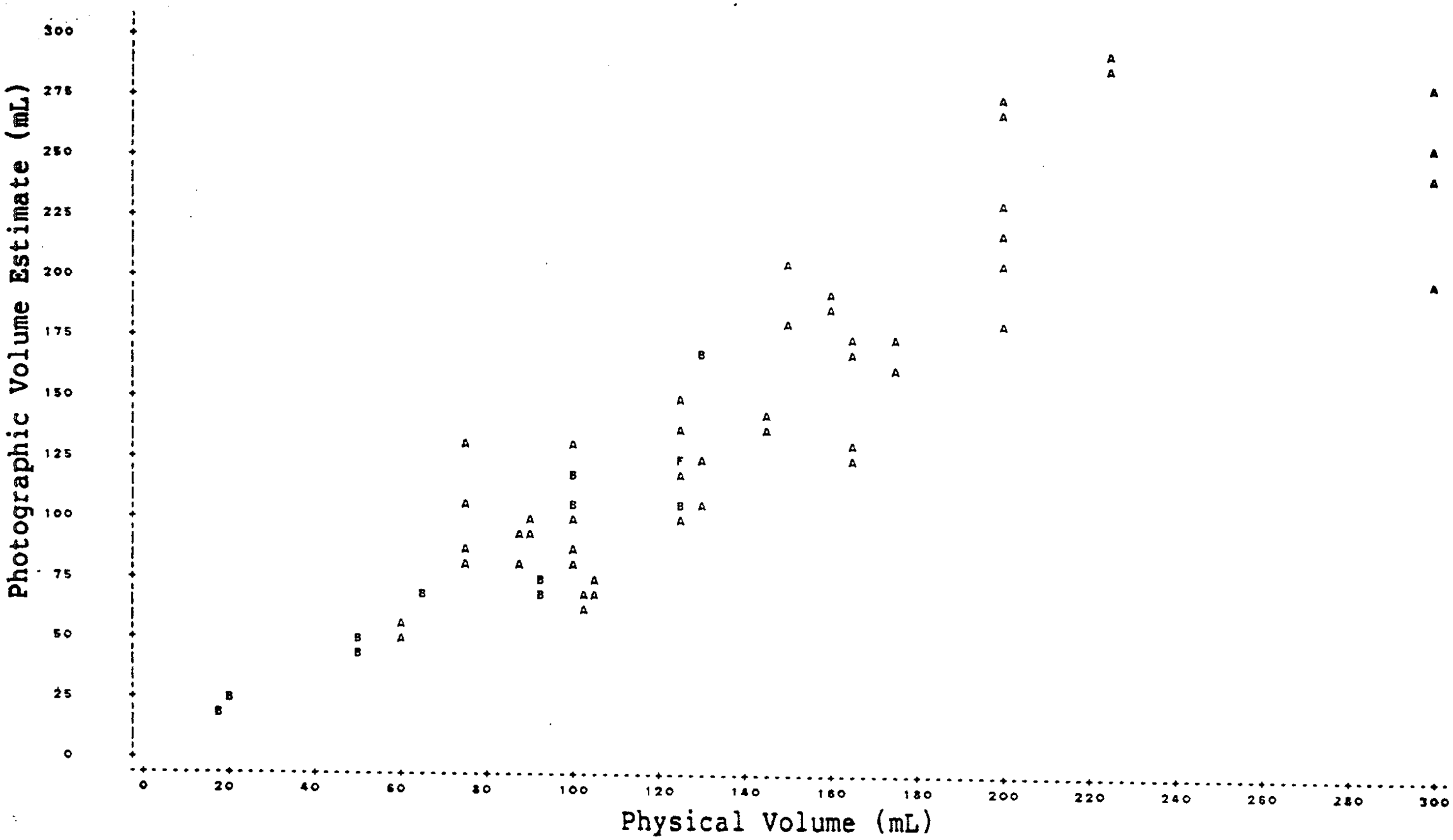


Figure 10: Plot of photographic volume estimates against absolute volumes for 20 individual food items, N=76 (A=1 observation, B=2 observations, F=6 observations)

A paired t-test was performed on the differences between photographic volume estimate and physical volume. The differences were not found to be significant ($t=-0.51$; $p=0.6125$). Therefore, the null hypothesis (Ho_{10}) was accepted.

The mean photographic volume estimate for 20 food items was 102.48% of absolute volume with a standard deviation of 20.52%. The standard error of the mean was 2.35%. As would be expected, the variability of photographic estimates seems to be greater with actual food items than with the more regular shaped standard objects. Pearson's correlation coefficient and the paired t-test, however, indicate that the photographic record method is closely related to the absolute volume of the food items.

4.2.2 Weight

For 20 individual food items, 76 weight estimates were calculated from the photographic volume estimates and experimentally determined density factors. These photographic weight estimates were plotted against gravimetric weights (Figure 11). Pearson's correlation coefficient (r) for the association between photographic weight estimates and gravimetric weights was both high and significant ($r=0.92792$; $p=0.0001$), indicating that the photographic weight estimations are good estimates of gravimetric weight. Simple linear regression analysis showed further the strength of these associations. These results, and those of the two-tailed t-tests, indicated that the sample regression line was not significantly different from a line through the origin with a slope of one ($y=x$) (Appendix C).

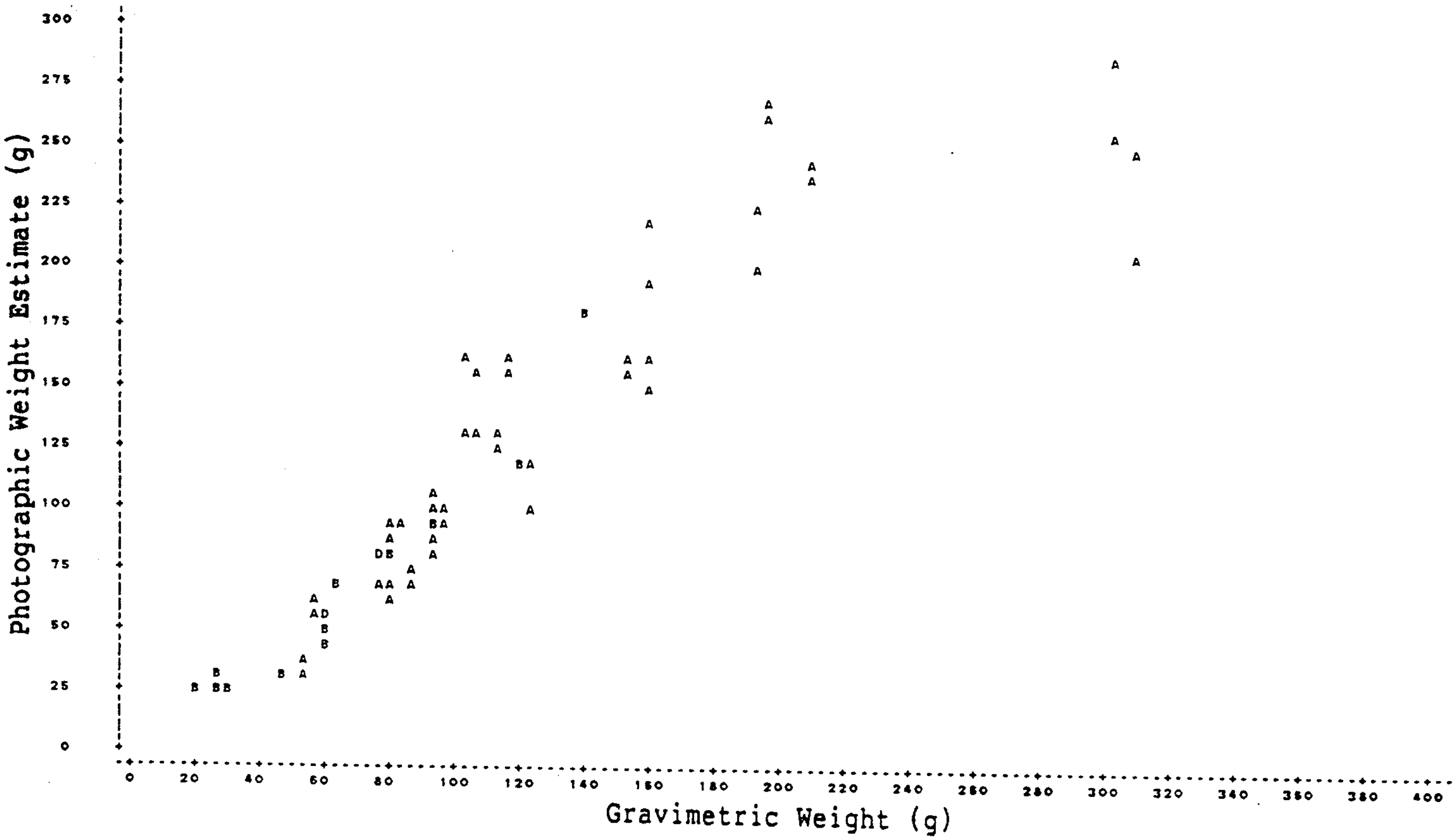


Figure 11: Plot of photographic weight estimate against gravimetric weight for 20 food items, N=76
(A=1 observation, B=2 observations, D=4 observations)

A paired t-test was performed on the differences between photographic weight estimates and gravimetric weights. The differences were not found to be significant ($t=-1.37$; $p=0.1738$). Therefore, the null hypothesis (Ho_{11}) was accepted. As expected, results are similar to those of the photographic volume estimates since the weight estimates are a function of these volume estimates.

The mean photographic weight estimate for the 20 food items was 102.59% of absolute volume with a standard deviation of 20.03%. The standard error of the mean was 2.30%.

4.2.3 Nutrient Content

Energy and nutrient contents in terms of protein, fat and carbohydrate were obtained for 20 individual food items with experimentally determined density figures (N=76). The plots of these photographic nutrient content estimates against the gravimetric nutrient contents can be seen in Figures 12, 13, 14 and 15, respectively.

Pearson's correlation coefficients (r) were calculated for the associations between the photographic nutrient content estimates and the gravimetric nutrient contents. These are shown in Table 18. Coefficients (r) for each of the four nutrient contents were found to be high and significant. This table also contains results of a paired t-test between photographic nutrient content estimates and gravimetric nutrient contents. Since no significant differences were found, the null hypothesis (Ho_{12}) was accepted. The results of the correlations were further substantiated by simple linear regression analysis (Appendix C). Two-tailed t-tests for the two null hypotheses that the intercept of the sample regression line was zero and that the slope was equal to one were conducted (Appendix C). The null hypotheses were accepted in all cases indicating that the sample regression line was not significantly different from the line y=x. Appendix C contains the t-values and associated probability values for these t-tests, as well as the slope and intercept values of the sample regression lines.

From the statistical tests completed on these data, the photographic record method appears to provide a good estimate of nutrient content, in terms of energy, protein, fat and carbohydrate. This would be expected since the photographic volume estimates are closely related to the absolute volumes.

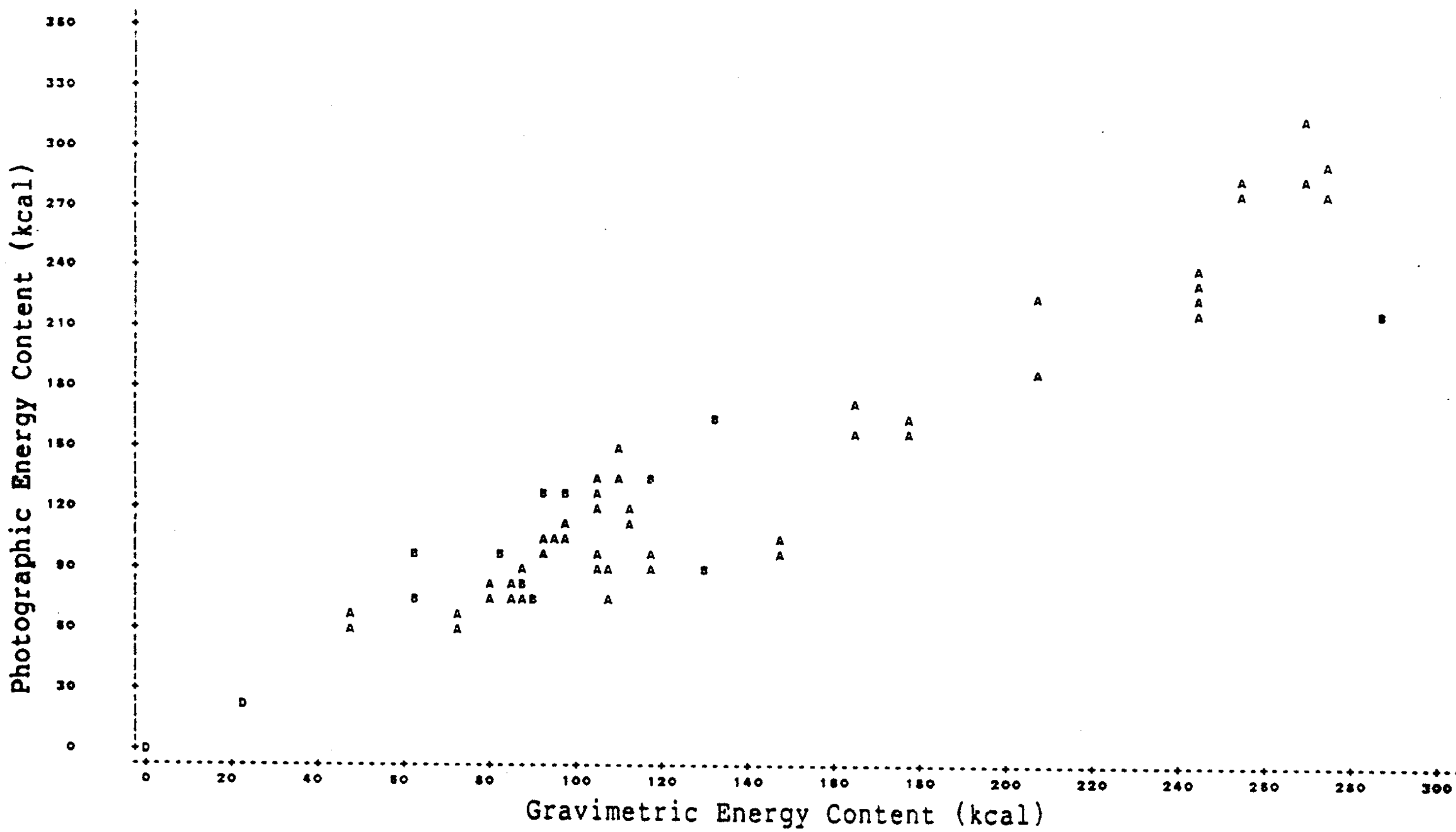


Figure 12: Plot of photographic energy content estimate against gravimetric energy content for 20 food items with experimentally determined density figures, N=76
(A=1 observation, B=2 observations, D=4 observations)

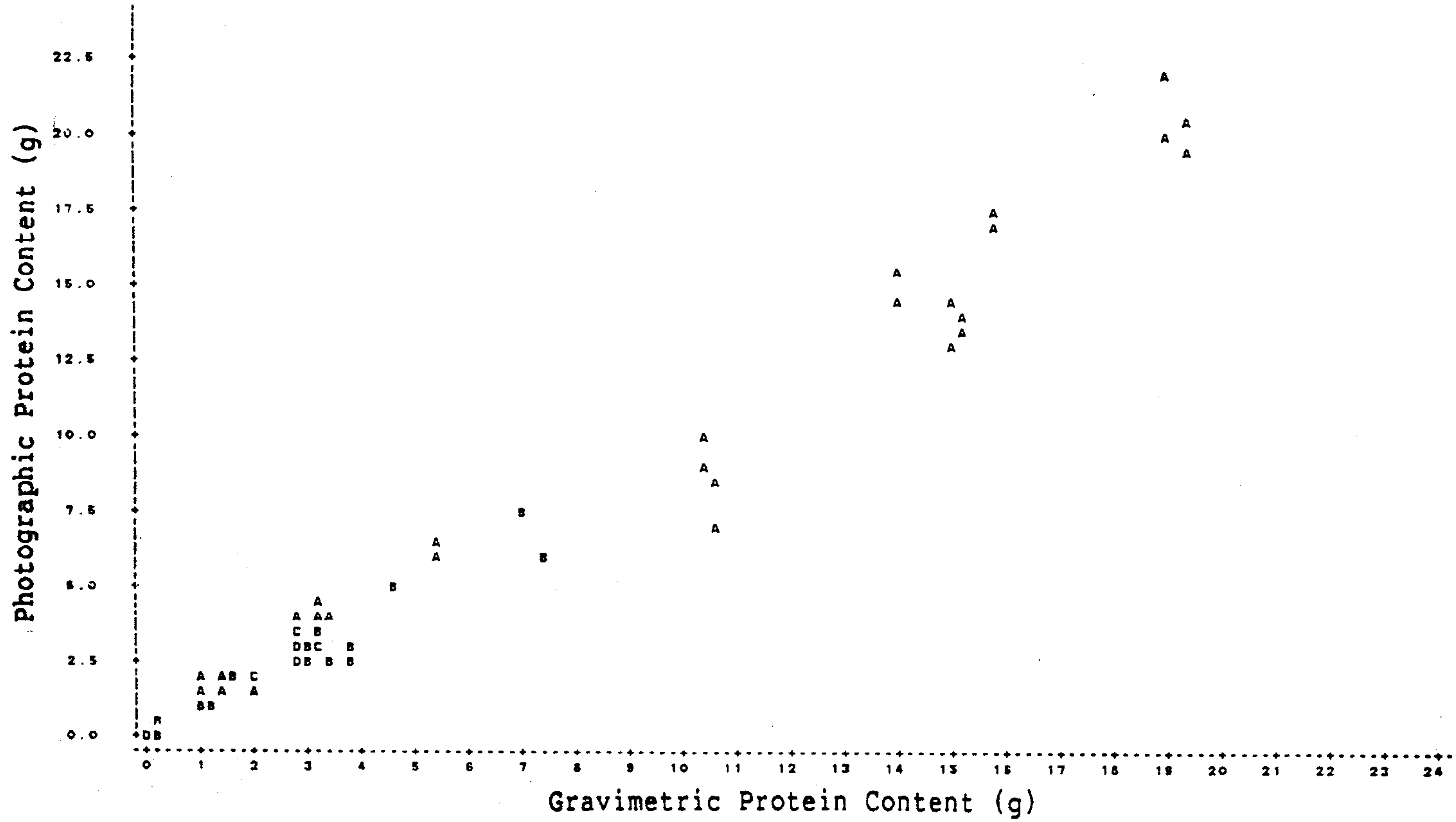


Figure 13: Plot of photgraphic protein content estimate against gravimetric protein content for 20 food items with experimentally determined density figures, N=76
(A=1 observation, B=2 observations, C=3 observations, D=4 observations)

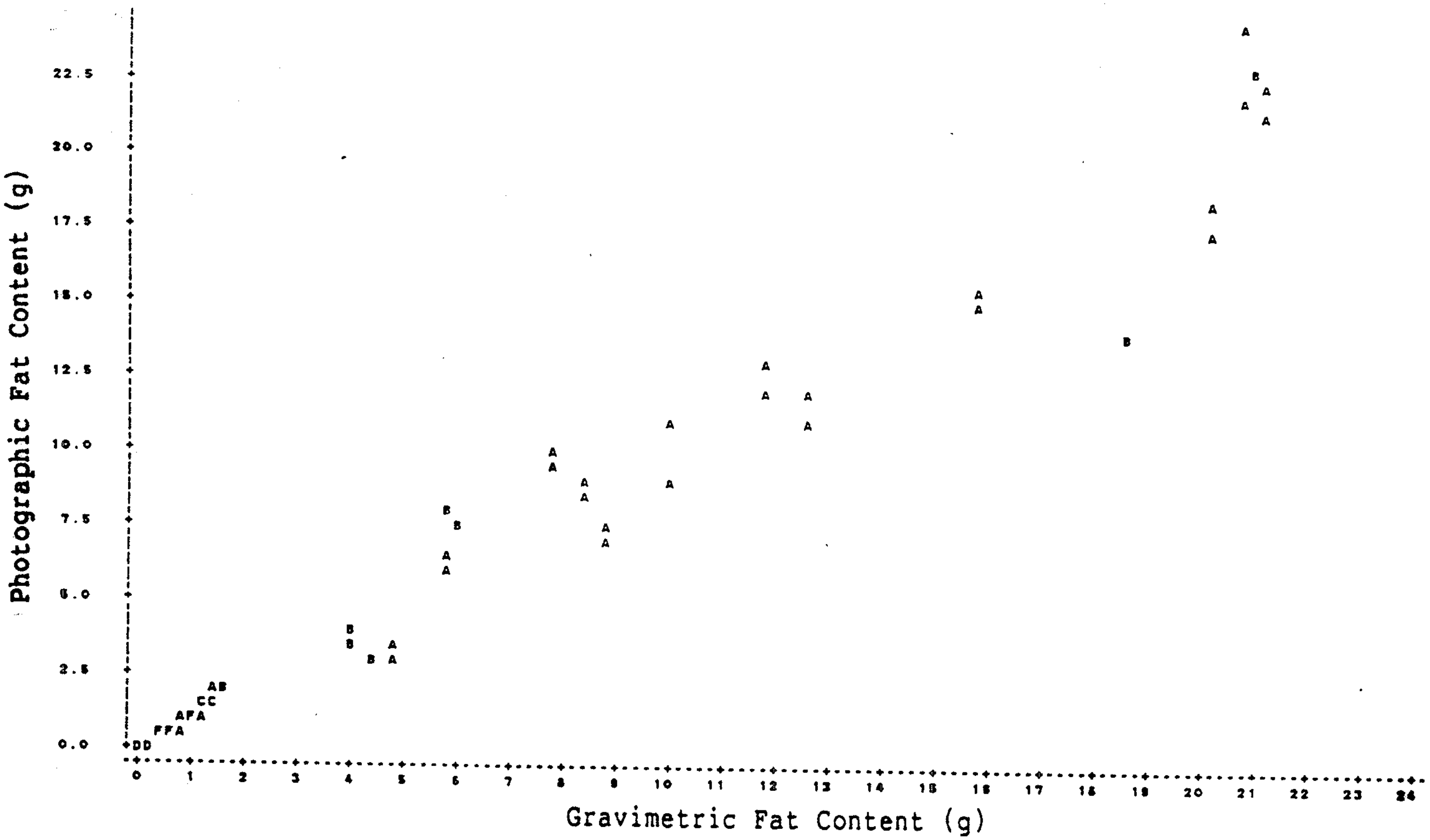


Figure 14: Plot of photographic fat content estimate against gravimetric fat content for 20 food items with experimantally determined density figures, N=76
(A=1 observation, B=2 observations, C=3 observations, D=4 observations, F=6 observations)

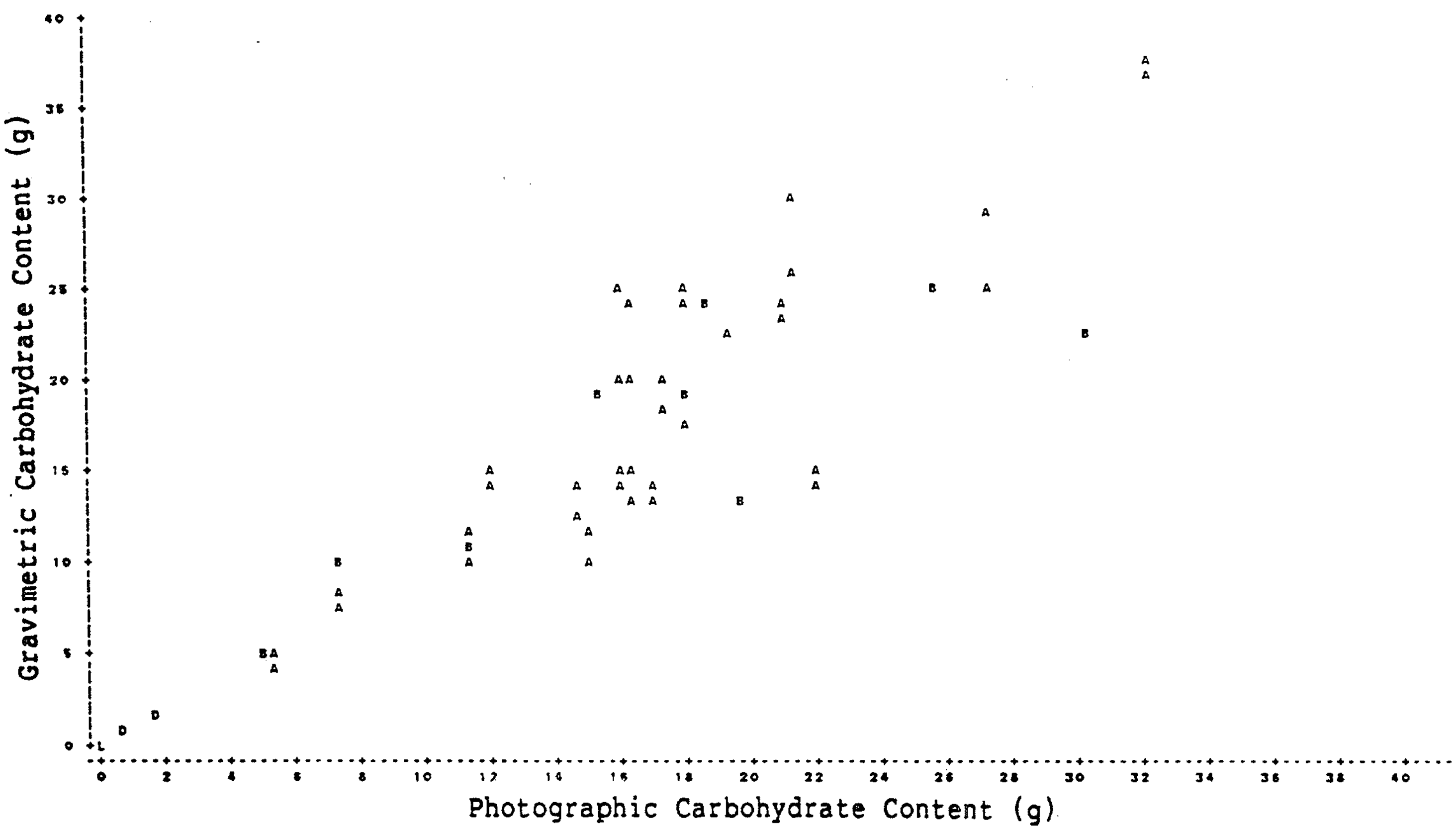


Figure 15: Plot of photographic carbohydrate content estimate against gravimetric carbohydrate content for 20 food items with experimentally determined density figures, N=76
(A=1 observation, B=2 observations, D=4 observations)

TABLE 18

Statistical analyses to test for difference between photographic nutrient content estimates and gravimetric nutrient contents for 20 food items (N=76)

Nutrient Content	Pearson's correlation		Paired t-test	
	r value	probability	t value	probability
Energy	0.9477	0.0001	-0.17	0.8669
Protein	0.9848	0.0001	0.27	0.7854
Fat	0.9834	0.0001	-1.22	0.2256
Carbohydrate	0.9362	0.0001	0.09	0.9263

4.2.4 Published Density Figures

For ten individual food items, published density figures were used to convert photographic volume estimates to weight estimates (N=38). Plots of the photographic nutrient content estimates against the gravimetric nutrient contents are shown in Figures 16, 17, 18 and 19, respectively.

Pearson's correlation coefficients were determined for the photographic nutrient content estimates from published density figures and gravimetric nutrient contents. These are shown in Table 19. A paired t-test was performed on the differences between photographic nutrient content estimates for foods with published density figures and gravimetric nutrient contents. Table 19 shows the results of this test. None of the differences were significant. As with the data for experimentally determined density figures, simple linear regression analysis was completed (Appendix D). Both the null hypotheses that the slope of the regression line was one and that the intercept was equal to zero were accepted in all cases indicating no significant differences between the sample regression line and the line y=x. Results of these tests are contained in Appendix D. The results of these statistical analyses show that published density figures rather than manually determined figures can be used to determine the weight estimates without adversely affecting the nutrient content estimates.

TABLE 19

Statistical analyses to test for difference between photographic nutrient content estimates and gravimetric nutrient contents for 10 food items with published density figures (N=38)

Nutrient Content	Pearson's correlation		Paired t-test	
	r value	probability	t value	probability
Energy	0.9509	0.0001	0.55	0.5851
Protein	0.9681	0.0001	-0.73	0.4709
Fat	0.9820	0.0001	0.57	0.5695
Carbohydrate	0.9746	0.0001	1.2	0.2380

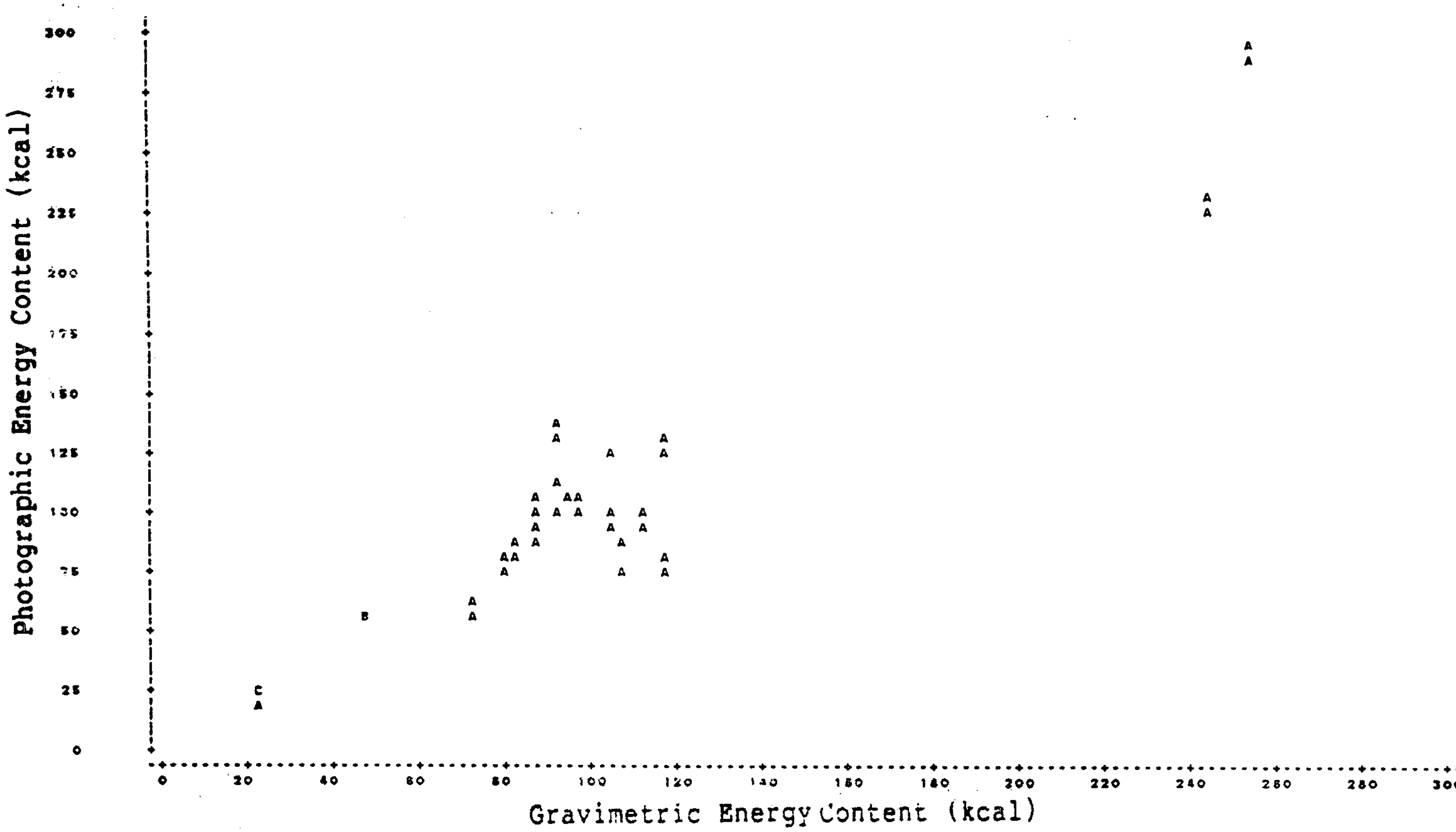


Figure 16: Plot of photographic energy content estimates against gravimetric energy contents for 10 food items with published density figures, N=38
(A=1 observation, B=2 observations, C=3 observations)

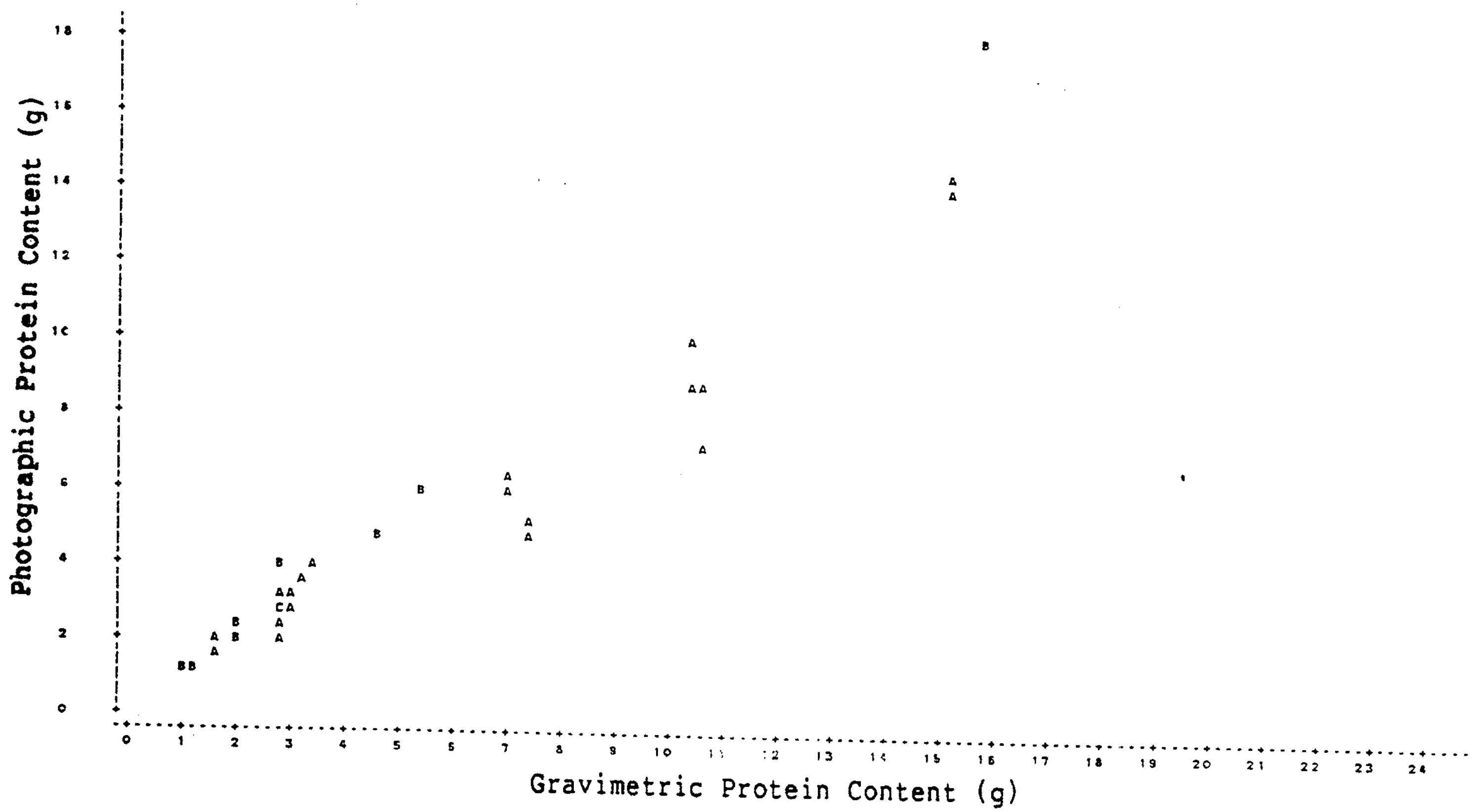


Figure 17: Plot of photographic protein content estimates against gravimetric protein contents for 10 food items with published density figures, N=38
(A=1 observation, B=2 observations, C=3 observations)

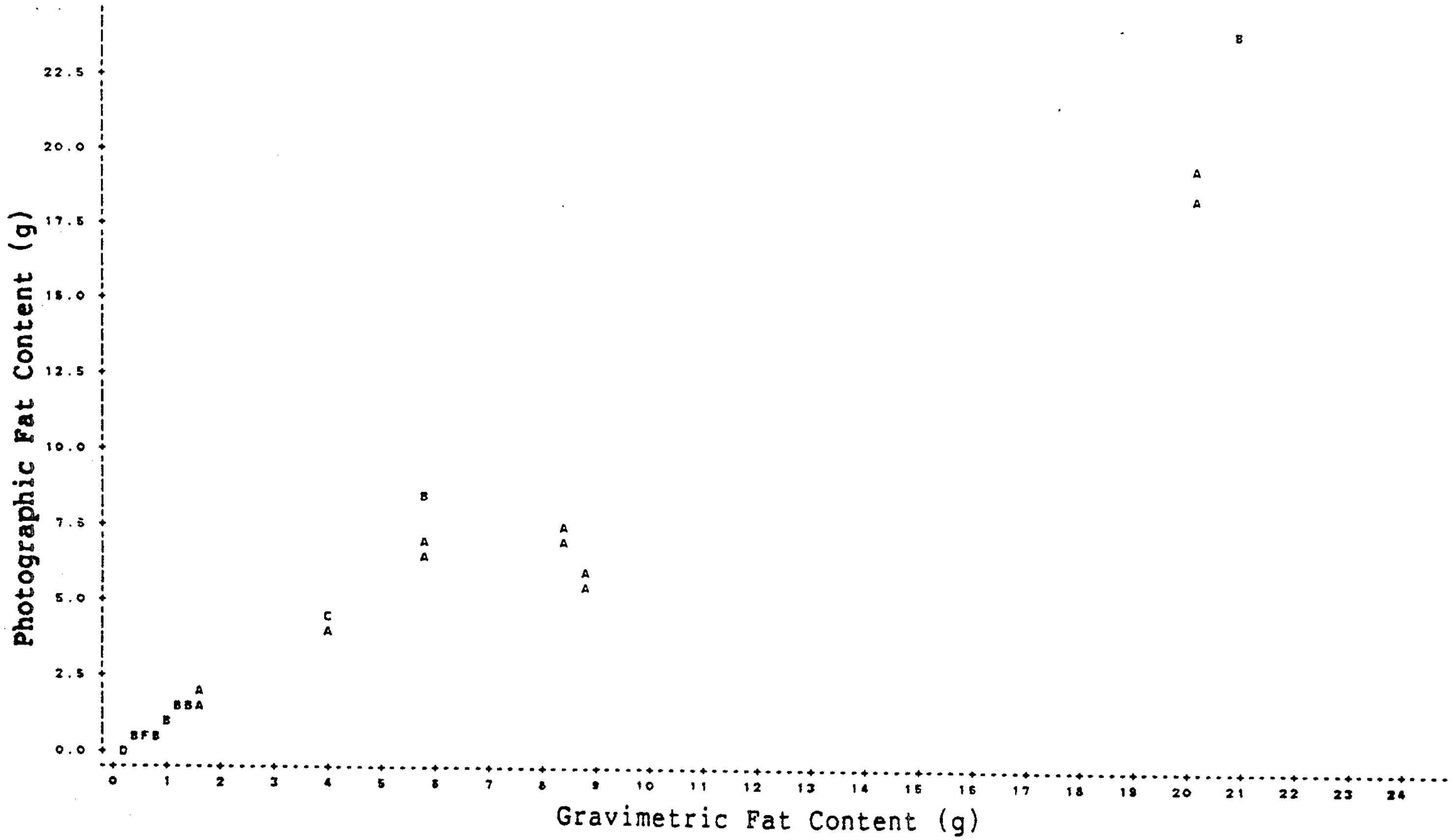


Figure 18: Plot of photographic fat content estimates against gravimetric fat contents for 10 food items with published density figures, N=38
(A=1 observation, B=2 observations, C=3.observations, D=4 observations, F=6 observations)

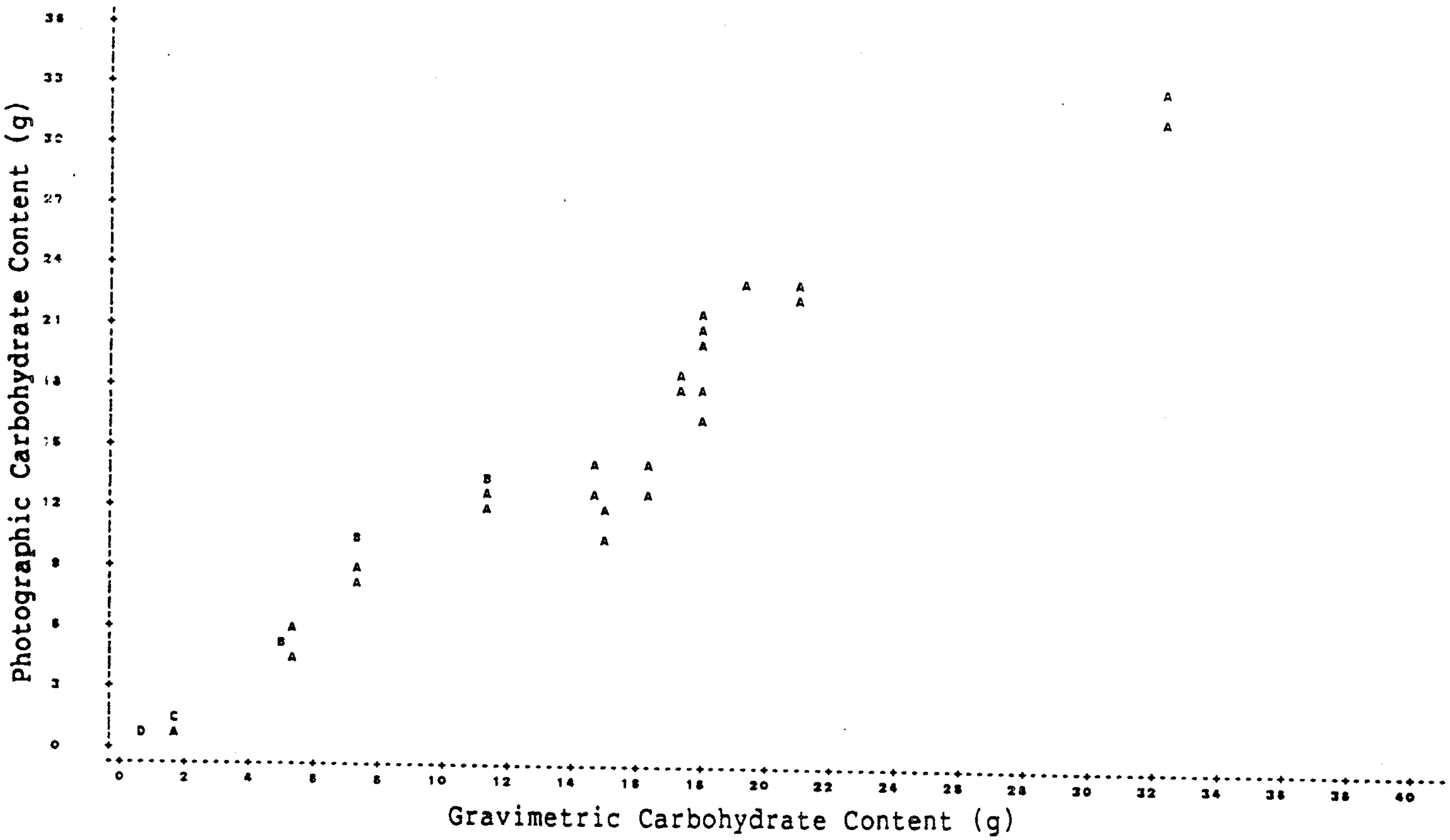


Figure 19: Plot of photographic carbohydrate content estimates against gravimetric carbohydrate contents for 10 food items with published density figures, N=38
(A=1 observation, B=2 observations, C=3 observations, D=4 observations)

4.2.5 Food Density/Consistency Groupings

Twenty foods were divided into four density/consistency groups. The mean photographic volume estimates, weight estimates and nutrient content estimates as percentages of gravimetric values are shown for each group in Table 20.

TABLE 20

Mean photographic estimates as percentages of gravimetric values for four density/consistency groups

Density/ Consistency Group	N	Volume	Weight	Energy	Protein	Fat	Carbo-hydrate
1[2]	32	107.41	107.71	108.53	110.58	109.70	121.71
		(21.2)[1]	(20.6)	(19.84)	(22.42)	(19.7)	(85.22)
2[3]	20	89.20	89.18	89.11	89.11	89.07	89.11
		(15.91)	(14.91)	(15.01)	(15.01)	(14.93)	(15.01)
3[4]	12	92.66	92.68	92.68	92.36	92.36	92.63
		(11.43)	(11.47)	(11.47)	(10.87)	(10.88)	(11.42)
4[5]	12	121.27	121.23	121.23	121.23	121.23	121.23
		(12.4)	(11.65)	(11.65)	(11.65)	(11.65)	(11.65)

[1](s.d.)
[2]Solid foods -- no visible air spaces with density < 1
[3]Solid foods -- visible air spaces with density < 1
[4]Liquid foods -- with density ≥ 1
[5]Semi-solid foods -- with density ≥ 1

A one-way analysis of variance procedure was applied to the individual food data to determine the effect of density/consistency group on the photographic volume estimates (N=76). The effect was found to be significant (F=10.64;p=0.0001). A pairwise comparison of the group means using Scheffe's procedure indicated a significant difference between semi-solid foods and solid foods with visible air spaces, semi-solid foods and liquid foods, and between solid foods with visible air spaces and solid foods with no visible air spaces.

A paired t-test was performed on the differences between the photographic estimates and the gravimetric values for each of the four density/consistency groupings. The results are shown in Table 21. For solid foods with visible air spaces and semi-solid foods all differences were significant. For solid foods with no visible air spaces, only the differences in weight were significant. No differences were significant for liquid foods.

The photographic record method does not appear to perform consistently across the density/consistency groups tested. The method seems to overestimate for semi-solid foods and to underestimate for solid foods with visible air spaces.

TABLE 21

Paired t-test of differences between photographic estimates and gravimetric values for four density/consistency groupings

Density/ Consistency Group	N	Volume	Weight	Energy	Protein	Fat	Carbo-hydrate
1[2]	32	-1.80 (0.082)[1]	-2.36 (0.025)	-0.78 (0.44)	-0.97 (0.34)	-0.10 (0.92)	-1.40 (0.17)
2[3]	20	2.98 (0.008)	2.65 (0.016)	2.92 (0.009)	2.97 (0.008)	2.56 (0.019)	2.77 (0.01)
3[4]	12	2.14 (0.055)	2.09 (0.06)	2.07 (0.06)	2.00 (0.07)	2.07 (0.06)	2.15 (0.054)
4[5]	12	-4.72 (.0006)	-5.03 (.0004)	-6.41 (.0001)	-7.88 (.0001)	-3.08 (0.01)	-5.13 (.0003)

[1](probability)
[2]Solid foods -- no visible air spaces with density < 1
[3]Solid foods -- visible air spaces with density < 1
[4]Liquid foods -- with density ≥ 1
[5]Semi-solid foods -- with density ≥ 1

Chapter V

DISCUSSION

In an attempt to develop a photographic food record method for possible use in survey situations, this study looked at the calculation of three dimensions from a single two-dimensional representation. Since standard mathematical theory requires at least three photographs with a defined relationship in order to determine the volume of any object, compromises were made to the method developed in this study. Thus, the technique of volume calculation studied was unique. The development of the technique for the photographic record method entailed the investigation of nine variables. The statistical testing of these variables either confirmed or denied the assumptions and theory put forth by the conceptual model.

Results of acceptable accuracy for survey work should be obtained regardless of the position of food items with respect to the camera lens at the time of recording, since no significant effects on the photographic volume estimates were found to occur due to object position. This method should not increase respondent burden by requiring the food items to be precisely positioned prior to photographing. The angle between the camera and the light source (angle A) seems to have little effect on the final volume estimate. For further studies , an angle between 15^0 and 60^0 should suffice. From observation and experience, an angle of approximately 30^0 is suggested. This angle provides fewer obscured points at the front of a recorded object and thus, decreases the investigator burden and subjectivity during measurement of photographic records. A contour line width of 1.0 mm should function well and be less time-consuming to analyze. If a small food item were to contain very few slices as defined by the method of this study, it should be possible to measure slices from both the left and the right sides of the dark shadow band, provided the dark and light bands are truly equal in width. Thus, the need for a smaller contour line width would be obviated.

The practical significance of the significant interactions found between contour line width and angle A and between contour line width and object position can be questioned due to the narrow range between the two line width means at the 15^0 level of both angle A and object position. For this reason, it is expected that these interactions will not be of practical importance for photographic volume estimations.

Important implications regarding the analysis of slide records can be drawn since the effects of magnification of slide records of a right rectangular block were not significant. The equipment configuration needed for slide record measurement will be more flexible if the adherence to a specific magnification factor is not required. The reproducability, or inter-operator reliability, of the photographic record method appears to be strong since different investigators have provided results that were not statistically different. The fact that investigators were given 2-3 hours of technical instruction without the theoretical basis of the measurements, shows that little training should be required and that investigators can successfully carry out the mechanics of the method without being fully cognizant of the theory. An approximate training time for interviewers has been given as two hours (Batt, 1979). While not clearly stated, it has been assumed that this applies to interviewers giving instructions regarding the keeping of a three-day food record. Adelson (1960) has stated that interviewers for a 24-hour recall require longer instruction and perhaps, need a stronger background in food habits and better judgement than interviewers using a record method. The photograpgic record method, then, appears to require less training time and less knowledge of food habits than other common dietary methodologies.

This study suggested that the photographic record method consistently estimated the volume of food items with absolute volumes falling within the 100 mL to 400 mL range. When this range was expanded to include 50 mL for right rectangular block objects, size had a significant effect on photographic volume estimates. Further investigation of object sizes under 100 mL for different shapes would be needed to determine the validity of the photographic record method on smaller objects.

Heights of the right cylinder and right wedge objects varied more than those of the right rectangular block and sphere objects. This factor needs to be further investigated to perhaps explain the differences encountered between object shapes in this study. Underestimation of photographic volume determinations for the 400 mL size of both the right cylinder and the right wedge objects could be partially responsible for the significant interaction found between object shape and object size. This, too, could be due to the possible effect of object height. Further investigation into the effect of object shape and object height should assist in clarifying these results, also. Since the sample size was small for the examination of the reference object height, the validity of these results is questionable. Further investigation with a larger sample size and perhaps, more than the three reference object heights used in this study is required before any conclusive statements can be given regarding the effect of reference object height.

In an attempt to reduce error in volume estimation, three different concepts were used for calculation of volume for standard object data. The three formulae tested in this study did not produce similar estimates of object volume. Figures 20,21 and 22 illustrate the manner in which each formula determines volume. The Arithmetic Mean is the simplest of the three to calculate and the least sensitive to object shape, and thus ,volume. This was evidenced by the high standard deviations found for volume estimates with this formula. The formula determines a volume estimate based on a rectangular representation of all object shapes (see Figure 20). The Triangular Mean formula is more sensitive to object shape. It is influenced by differences in slice area size. An outline of the object shape is estimated by joining the means of slice areas with straight lines (see Figure 21). Simpson's formula is the most sensitive of the three to changes in object shape. It estimates volume by approximating curves (see Figure 22). Upon examination of mean volume estimates and the associated standard devitions, it appears that of the three formulae tested, Simpson's formula would be best applied to the irregular shapes encountered with food items.

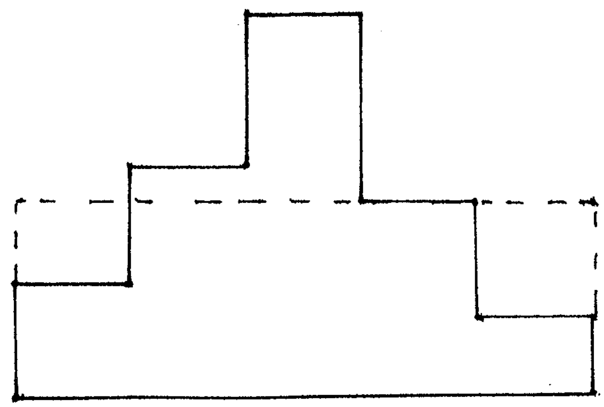


Figure 20: Volume determination by Arithmetic Mean formula

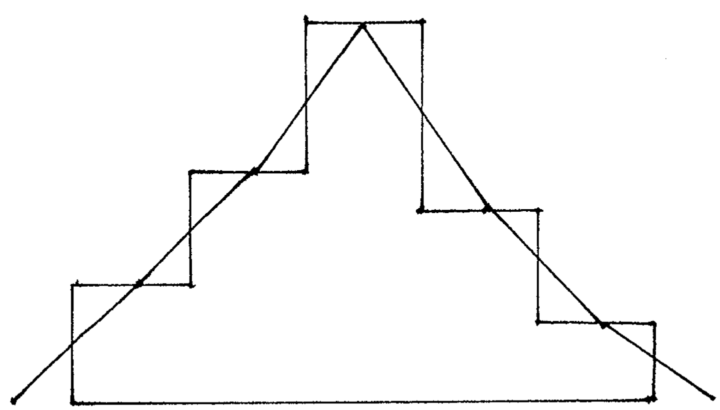


Figure 21: Volume determination by Triangular Mean formula

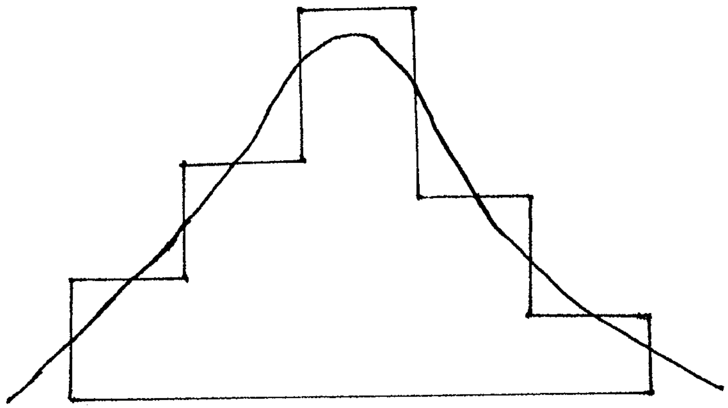


Figure 22: Volume determination by Simpson's formula

Direct validity of the photographic record method was tested by applying paired t-tests to the differences between absolute volumes and estimated volumes. Significant differences were found for the series of slides obtained to test object shape but not for the slide series of a wooden right rectangular block or of individual food items. It is possible that some unidentified factor was present only in the shape series slides and that it resulted in an underestimation of object volume. Perhaps, as noted earlier, the wide variation in object heights was partially responsible for these results. Such variation was not as evident with the other slide series. The shape series slides were recorded with a fixed object position, whereas in the wooden right rectangular block series the object was recorded at three different positions. Object position in the individual food series was randomly assigned, thus covering a wider range of possible positions. It is possible, then, that the fixed position affected the volume estimates of the shape series records. As well, the sample size of the shape series records was smaller than that found in either the wooden right rectangular block series or the individual food series. Further investigation is required to determine the factor or factors responsible for the underestimation of volume found with the shape series slide records.

It appears that the photographic food record method is able to estimate the mean nutrient content of groups of individual food items, since no significant differences were found between estimated nutrient contents and the corresponding gravimetric values for the 20 food items in this study. The standard deviations are higher than found with standard objects. This was as expected due to the greater irregularity of food shapes. Further investigation is needed to determine how this method functions with records of several foods on the same plate, as would be encountered in survey situations.

Similar results for nutrient content estimates were found with both the experimentally determined density figures and the published density figures. Thus, published density figures could be utilized which are more common in survey settings. This method was limited by the density information available in current food composition tables and databases, since the published density figures represent a range of moisture contents for any one food item. This would be a source of variation of the photographic record method and any other method.

The consistency of a food item affects both the density and shape of that food item. For this reason, the 20 food items used in this study were divided into four density/consistency groups. It was found that the photographic record method was not consistent for all groups. Solid foods with visible air spaces and semi-solid foods showed significant differences between photographic estimates and actual values. The solid foods with visible air spaces included such foods as muffins and toast.

It is possible that the estimation by the investigator of the obscurred portion of these food items was not as accurate as desired, thus, adversely affecting the volume estimation. It is interesting to note, however, that this group also included french fries, noodles, scrambled eggs and kernel corn, all of which form highly irregular shapes. The volume estimates of these foods, though, were extremely close to the physical volumes. Due to their consistency, semi-solid foods were held in bowls. Occasionally, difficulty was encountered by the investigator in identifying the point at which the bottom of the bowl and the food met. It is possible that the overestimation of the three semi-solid foods in this study was due to inclusion in the volume estimate of a portion of the dish holding the food items. Alternatively, since no significant differences were apparent for the three liquid foods used in this study, the overestimation may have been due to the inverted mound shape of the food items. Given previous indications of possible problems with cylindrical shaped objects, it was unexpected that the liquid foods gave such good results. For solid foods with no visible air spaces, a significant difference was encountered only between estimated and gravimetric weight. This could be due to experimentally determined density figures for these food items. Volumes of some of these foods could not be measured via water displacement. Therefore, formulae for volume determination of standard geometric shapes were imposed on foods such as brownies and cookies. Such rough estimations may not have been as accurate as desired. It is possible that more extensive training of investigators when measuring semi-solid foods and slightly irregular bread products would result in significantly better volume estimations. Further validation studies should attempt to use food items with published density figures and those that can be subjected to water displacement.

Given the 76 photographic estimates of 20 different food items commonly consumed in Canada and the assumption that the average person consumes 12-15 food items per day, this study can represent one-day records from a group of 5 or 6 individuals or one 5-6 day record from an individual, albeit a limited diet.

For this study, in terms of energy, the photographic estimate was not significantly different from the gravimetric energy content. Studies using the 24-hour recall method have shown energy intake estimates that were significantly different from the actual energy intakes (Campbell and Dodds, 1967; Acheson, et al., 1980). This difference can be attributed to the inability of subjects to remember all food items consumed or to accurately estimate food quantities. Many researchers consider that the estimated and weighed food record and the 24-hour recall give comparable results of mean intakes for groups of people though absolute agreement is not always found for individuals (Young, et al., 1952; Adelson, 1960; Pekkarinen, 1970; Gersovitz, et al., 1978; Todd, et al., 1983). It is reasonable, then, to expect the photographic food record method to give more accurate estimates of energy intake when compared with the estimated and weighed record methods. This, however, bears further investigation.

Based on statistical analysis for significant differences between the nutrient content values from weighed records and from photographic records, small differences were found between the photographic record method developed in this study and that developed by Elwood and Bird (1983). While correlation coefficients for the association between gravimetric and estimated nutrient contents of the 20 food items in this study are higher than those found by Bird and Elwood (1983), neither study showed significant differences between weighed nutrient values and estimated nutrient values. Though estimated nutrient intake results were comparable for these two methods, it is possible that the method used in the study presented here required less training for the analysis of slide records, due to the greater objectivity of this method. As well, this greater objectivity may have been the source of the virtually constant variation noted with the photographic nutrient content estimates of this study. While the standard deviations for the nutrient estimates varied from 17.3% to 25.6% in the study by Bird and Elwood (1983), the range for this study was 19.7% to 21.1%. Thus, the photographic food record method developed in this study appears to yield a more consistent estimate of nutrient content than the method tested by Bird and Elwood (1983), due to the lesser degree of subjectivity involved in the estimation of food volume. The reproducability of volume estimates determined by different investigators was demonstrated in this study. The study conducted by Bird and Elwood (1983) did not mention any attempt to test the reliability of that method.

Chapter VI

CONCLUSIONS

In this study, no relationship was found between photographic volume estimates of a right rectangular block object and the independent variables of object position, angle A (angle between the camera and the light source), contour line width, level of photograpgic slide record magnification and investigator responsible for measurement of slide records. Therefore, it was concluded that errors due to the variation in measurement of co-ordinates, horizontal angle and reference object that may arise from changes in these independent variables, had no significant effect on photographic volume estimation. The reproducability of volume estimate determinations has been shown by six investigators. Object size showed no significant effect on photographic volume estimates regardless of object shape for the size range of 100 to 400 mL. For right rectangular blocks in the range of 50 to 400 mL, size had a significant effect. It was concluded that photographic volume estimates were not significantly affected by object size in the range of 100 to 400 mL, which are similar to common food portion sizes. A relationship between object shape and photographic volume estimate was found, but object height may have been a confounding factor. The significantly different effects of integration formulae suggest that Simpson's formula may function best for irregular shaped objects, such as food items. Inconclusive results were found for the effect of reference object height due to the small sample size. Thus, errors associated with variation in measurements made of the comparison object due to differing heights of the comparison object were not defined.

Significant differences between photographic estimates and absolute values were not found for either the wooden right rectangular block slide series or the individual food slide series but were identified for the shape slide series. It is possible that object height, fixed object position or the smaller sample size of the shape slide series may have caused this difference. From these tests of direct validity for the photographic record method, it appeared that the method can be used to quantitate energy and nutrient intakes.

This study has shown a strong relationship between photographic volume estimates with the subsequent weight and nutrient content estimates and the corresponding gravimetric values for 20 individual food items. Similar values were found using both experimentally determined density figures and published density figures. The consistency of food items had a significant affect on the photgraphic estimates. It is possible, again, that the object height and shape were partially responsible for this result. It is possible, too, that further training of investigators may result in less variation of photographic volume estimates of food items and thus, decrease the possible effects of the thickness of containers and reflection from glass containers.

The overall performance of the photographic record method developed in this study shows promise as an alternate method for estimating individual food consumption. Since object shape was found to have a significant affect on photographic volume estimates of standard objects, further investigation may determine if this effect is due to differing heights of the recorded objects or to another image characteristic. Further investigation will determine the effect reference object height may have on photographic volume estimates. Study of various shaped objects with volumes less than 100 mL, will determine the error associated with smaller items when estimating volume with the photographic record method. In terms of actual foods, this study dealt solely with individually recorded food items. Since, in a survey situation, plates hold several food items, further investigation will be needed to determine if the estimation of portions of food items obscured by other food items on the same plate, significantly affects the photographic food volume estimates. Field testing, including comparative studies with other record methods, will then further indicate the usefulness of such a tool in actual survey work.

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Appendix A

PHOTOGRAPHICALLY RECORDED INDIVIDUAL FOOD ITEMS

Density/Consistency Group	Food Item
Solid -- no visible air spaces Density < 1	Cheddar cheese* Mashed potato* Orange* Hamburger patty Pork chop Apple Brownie Cookie
Solid -- visible air spaces Density < 1	Kernel corn* Scrambled eggs* Noodles* Muffin Toast French fries
Liquid Density ≥ 1	Skim milk* Tomato juice* Tea
Semi-solid Density ≥ 1	Cream soup* Yogurt* Oatmeal

*Foods with published density figures (Health and Welfare, 1984)

Appendix B

STATISTICAL MODELS TESTED FOR INTERACTION BETWEEN ANGLE A, OBJECT POSTITION AND CONTOUR LINE SIZE

Three-way analysis of variance procedure for object position, angle A and contour line width -- Full Model, N=72

Source	df	F value	Probability
Angle A	2	0.32	0.7291
Line Width	1	2.95	0.0919
Position	2	1.61	0.2094
Angle A*Line Width	2	6.22	0.0037
Angle A*Position	4	0.96	0.4374
Position*Line Width	2	3.47	0.0385
Angle A*Position* Line Width	4	0.55	0.6974
Error	53		
Total	71		

Three-way analysis of variance procedure for object position, angle A and contour line width -- Modified Model, N=72

Source	df	F value	Probability
Angle A	2	0.33	0.7214
Line Width	1	3.04	0.0861
Position	2	1.66	0.1979
Angle A*Line Width	2	6.43	0.0029
Position*Line Width	2	3.58	0.0338
Error	62		
Total	71		

Appendix C

LINEAR REGRESSION ANALYSIS AND TWO-TAILED T-TESTS FOR DIFFERENCES BETWEEN SAMPLE REGRESSION LINE AND THE LINE Y=X FOR 20 INDIVIDUAL FOOD ITEMS WITH EXPERIMENTALLY DETERMINED DENSITIES

Slope and intercept values for sample regression lines for 20 food items with experimentally determined density figures (N=76)

Photographic Estimate	Intercept	Slope
Volume	7.0449	0.9573
Weight	6.8064	0.9744
Energy	9.1668	0.9291
Protein	-0.0447	1.0028
Carbohydrate	0.3750	1.0031
Fat	0.0751	0.9851

T-test results for 20 food items with experimentally determined density figures (N=76)

Photographic	Ho: intercept=0		Ho: slope=1	
Estimate	t-value	probability	t-value	probability
Volume	0.95	0.3435	-0.8119	>0.3
Weight	1.20	0.2325	-0.563	>0.5
Energy	1.77	0.0802	-1.977	>0.1
Protein	-0.29	0.7740	0.134	>0.5
Carbohydrate	0.55	0.5871	0.0719	>0.5
Fat	0.39	0.6966	-0.705	>0.4

Appendix D

LINEAR REGRESSION ANALYSIS AND TWO-TAILED T-TEST FOR DIFFERENCES BETWEEN SAMPLE REGRESSION LINE AND THE LINE Y=X FOR 10 INDIVIDUAL FOOD ITEMS WITH PUBLISHED DENSITY FIGURES

Slope and intercept values for sample regression lines for 10 food items with published density figures (N=38)

Photographic Estimate	Intercept	Slope
Energy	-0.8010	1.0248
Protein	0.0156	1.0218
Carbohydrate	0.2392	1.0116
Fat	0.1193	0.9525

T-test results for 10 food items with published density figures (N=38)

Photographic	Ho: intercept=0		Ho: slope=1	
Estimate	t-value	probability	t-value	probability
Energy	-0.12	0.9031	0.446	>0.5
Protein	0.42	0.6785	-1.156	>0.2
Carbohydrate	0.43	0.6704	0.300	>0.5
Fat	0.06	0.9506	0.664	>0.5