Digital food photography technology improves efficiency and feasibility of dietary intake assessments in large populations eating ad libitum in collective dining facilities

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ABSTRACT

Background: Accurate assessment of dietary intake continues to challenge researchers, especially in field, or non-laboratory settings.

Objective: In this study, digital food photography (DFP) methodology was used to assess nutritional intake (NI) of Soldiers participating in the US Army’s Ranger Selection and Assessment Program (RASP).

Methods: During this high-intensity six-week course, Soldiers complete simulated operational missions, perform various military tasks, and importantly, eating time is severely limited. Therefore, this study provided an opportunity to evaluate the utility of DFP methods for accurate assessment of energy balance in conditions where consumption of large numbers of subjects must be completed in a very short periods of time (<20 min). NI of 131 male, enlisted Soldiers (21 ± 4 years, 178 ± 7 cm, and 78 ± 8 kg) enrolled in the RASP course was assessed in their garrison dining facility using DFP utilizing visual estimation of pre- and post-meal photos of participant meals concurrently with photos of weighed, standardized portions. Total daily energy expenditure (TDEE) was assessed using doubly-labeled water (2H218O) in a sub-group of 19 volunteers.

Results: During the study, data loss (i.e., missing meal photos) was less than 5% per meal, and during the visual estimation process discrepancies in food identification averaged less than 10% per meal, while approximately a third of serving size estimations required a third party adjudication prior to finalization and calculation NI.

Conclusions: We conclude that the use of DFP allows an adequately reliable approach for quantifying NI in real-world scenarios involving large numbers of participants who must be assessed very rapidly, and researchers must have a small footprint.

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1. Introduction

Assessing dietary intake of people eating ad libitum continues to present researchers with a challenge. The utility of self-reported dietary intake methods such as food record diaries, food frequency questionnaires and 24-hour recall interviews have all been shown to be limited due to misreporting of nutritional intake (NI) by study participants, especially by obese participants (Archer, Hand, & Blair, 2013; Bray, 2008). Furthermore, while dietary assessment by direct observation and visual estimation of portions served and plate waste is accurate (Dubois, 1990; Gittelsohn, Shankar, Pokhrel, & West, 1994), these methods are slow, very labor intensive, and lack historical reference to resolve data collection inconsistencies or errors at a later date (e.g. one time occurrence to capture data). Thus, traditional visual estimation is not ideal for settings where dietary intakes of large numbers of study participants must be assessed while they dine simultaneously in a short
meal period, without interference by investigators, such as during military group feeding in garrison dining facilities (DFAC) or workplace cafeterias.

The use of digital food photography (DFP) methods have been shown to allow valid and reliable dietary assessment and evaluation of energy and nutrient intake in both children (Martin et al., 2007, 2010; Williamson et al., 2007) and adult (Williamson et al., 2003, 2004) populations, while decreasing participant burden and other problems associated with traditional food data collection. The DFP method of assessing dietary intake is fast, as it only requires only photographs of the participant’s food tray, less onsite staff and equipment during data collection, and provides a permanent record (photo) that can be re-examined and re-estimated when an estimate seems in error. Still photographs captured with video cameras allow participants to present their plate for photography, prior to consumption and again after meal completion. Later, two or more trained technicians, or estimators, view the stored video images of participants’ plates to compare the food item images against images of weighed standards of the same foods in appropriate DFAC serving sizes to derive a portion size estimation. Crombie et al (Crombie et al., 2013), used DFP to assess dietary intakes in a military population during the lunchtime meal. Efficient NI of 200 Soldiers per day for five consecutive days in 10 unique DFACs on Fort Bragg, NC (~1000 individual meals) were recorded and assessed. In the previous study by Crombie et al (Crombie et al., 2013), meal duration was not constrained. Therefore, whether this approach remained useful in settings where dinnertime is very high was not clear. The objective of this study was to evaluate the feasibility of digital photography methods for accurate assessment of energy balance in conditions where consumption of large numbers of subjects must be completed in a very short period of time (<20 min). We attempted to characterize the energy balance through onsite dietary assessment of a military population eating under severe time limitations in the DFAC environment.

2. Methods

2.1. Participants

Participants were 131 male enlisted Soldiers of the rank of sergeant and below, who were enrolled in Ranger Selection and Assessment Program (RASP) at Fort Benning, GA in October 2012. All Soldiers enrolled in RASP were briefed and interested participants were consented during a report period prior to initializing data collection the first week of this six-week course that selects Soldiers for assignment to the 75th Ranger Regiment. In addition to classroom instruction and daily physical fitness training which included calisthenics and 3–8 mile group runs, RASP participants completed weapons familiarization courses and ranges, land navigation, marches under load, and other military task trainings. The study was reviewed and approved by the US Army Research Institute of Environmental Medicine Human Use Review Committee, and all study investigators adhered to US Army Regulation 70–25 and US Army Medical Research and Material Command regulation 70–25 on the participation of volunteers in research.

2.2. Demographics and anthropometrics

Height was measured to the nearest 0.1 cm using a portable stadiometer, and body weight to the nearest 0.1 kg using a calibrated digital scale with participants wearing shorts and a t-shirt with stocking feet. Mean age, height, weight and body mass index (BMI) was matched between the overall group and a select cohort. A representative sub-group of 19 were asked to participate in the measurement of total daily energy expenditure (TDEE), estimation of body composition using circumference-based equations (abdomen and neck circumferences measured to nearest 0.1 cm) in accordance with Army Regulation 600–9 (U.S. Department of the Army, 2013).

2.3. Total daily energy expenditure

Estimated TDEE was used as a method of comparison for the DFP method (e.g. assumption that energy expenditure equals energy intake in weight-stable individuals) and to characterize the energy requirements of the study population. TDEE was determined in a subgroup of participants using the doubly labeled water (DLW) technique utilized previously in our lab (DeLany et al., 1985; Margolis et al., 2013). Briefly, participants (16 received DLW dose, 3 were controls) were fasted four hours prior to, and eight hours following their consumption of DLW on day one. Baseline urine samples were obtained prior to dosing with DLW (0.23 g H218O kg TBW–1 and 0.15 g H216O kg TBW–1) on day one; and second void urine samples were obtained on days two through six to assess the elimination rates of the isotopes. Energy expenditure was calculated by regression analysis using an assumed Respiratory Quotient (RQ) of 0.86 (DeLany et al., 1985).

2.4. Digital food photography

Energy intake was determined using the DFP method described in previous studies (Martin et al., 2007; Williamson et al., 2003, 2004). Briefly, this method captures foods selected and consumed by individuals using a digital video camera pre- and post-meal consumption. After obtaining their tray of food, participants reported to one of three DFP stations (Fig. 1A) to have their tray photographed. Each station contained a video camera (Sony, Handycam HDR-XR100) and data collector. Participants were able to go to any available DFP station for tray photography, regardless of whether it was a pre- or post-tray photo (Fig. 1B). Video cameras were mounted on tripods placed 29 inches (73.7 cm) from the plate (or tray) and angled at approximately 45° and the view adjusted to assure total capture of the participant’s tray to standardize the apparent size of all foods and maintain consistency across photographs. Participants were assigned study-specific numbers at the study start and instructed to place the number (e.g. cards were pre-printed with study number) on their tray at each photograph opportunity to aid in tracking participants’ and in matching pre-with post-meal photos later. Participant’s study numbers were visible on the photo capture, enabling the photos, when imported into the Food Photo system, to be imported and organized by participant number. Meal periods were approximately 20 min from arrival to departure of all participants. Due to meal time constraints volunteers that consumed 100% of food selected (pre-meal photo) were instructed to report to assigned data collector for visual confirmation of post-tray consumption (100% consumed). Data collectors then manually logged (written account) of NI recorded at 100% eliminating the need and time taken to photograph an empty tray. When no pre-meal tray photo was taken, data collectors reconstructed the meal using traditional food recall methods (e.g. paper recording) with a participant interview at the time of the post-meal tray return.

Data were collected over five days, three meals per day, with the exception of one field training day when participants consumed the Meal-Ready-to-Eat (MRE) ration and one week day when the DFAC closed early (e.g. no dinner meal was served). During all DFAC meals participants self-selected food items and were provided one of two beverage choices (e.g. water or carbohydrate electrolyte beverage).
Prior to the meal, all DFAC food and beverages choices available to participants was weighed and then photographed, creating a library of standardized reference portions of all available menu items. Digital photographs of reference portions, pre- and post-meal photographs were captured and incorporated into software designed for estimation of food portion sizes in digital photographs (Food Photo, version 2.0, PBRC, 2008) (Fig. 1C). Using the software, trained staff (estimators) were able to simultaneously view photos of the (weighed) reference portions, food selection (pre-meal photo) and plate waste (post-meal photo) of each food and beverage (Fig. 2). Total nutritional intake (NI) was defined as the difference between estimations of pre- and post-meal photographs. The trays were viewed by two estimators, food assessments (item or portion) differing by more than 10% underwent a third review (final adjudication) by a study dietitian with additional expertise in food photography and food composition and provided the final NI estimate. The estimation process utilized was described earlier (Crombie et al., 2013), and final estimates were averaged and analyzed using the USDA Food and Nutrient Database for Dietary Studies version 4.1 (2010, Beltsville, MD). To assess nutrient adequacy, measured nutrient intakes were compared to the Military Dietary Reference Intakes (MDRIs) for each nutrient (U.S. Department of the Army, 2013). MDRIs closely mirror the Dietary Reference Intakes (DRIs) specific for the age-group of the U.S. population, with slight alterations to meet the unique needs of the military population.

2.5. Statistical analysis

The acceptability of the DFP method was assessed using inferential statistics. Estimates of TDEE and NI were initially examined quantitatively and graphically for outliers that could bias the analyses. Outliers were defined as values that were >3 times the IQR above the upper quartile or below the lower quartile. Comparisons between the full cohort and DLW subgroup were made using independent samples t-tests. Statistical analyses were conducted using SPSS v 21.0 (SPSS Inc., Chicago, IL). All tests were deemed statistically significant at \( P < 0.05 \). Data are presented as mean ± SD unless otherwise noted.

3. Results

The 131 enrolled participants were 21 ± 4 years old, 78 ± 8 kg body mass, 178 ± 7 cm tall, and had a BMI of 24.8 ± 2.1 kg/m². There were no differences between the DLW subgroup compared to the entire study cohort (\( P > 0.05 \) ) for age (21.3 ± 3.4 vs. 21.6 ± 4.3 yrs), body weight (78.6 ± 8.4 vs. 77.2 ± 9.1 kg), height (177.9 ± 7.3 vs. 176.2 ± 6.5 cm) or BMI (24.8 ± 2.2 vs. 24.8 ± 2.3 kg/m²).
respectively. Mean TDEE for participants in the subgroup was 4264 ± 342 kcal/d and they lost on average 0.25 ± 0.34 kg over the 6-d study.

The participants consumed, on average, 99% of meals, with minimal plate waste. Energy intake averaged 2918 ± 332 kcal/d from DFAC meal intake and nutritional supplements provided to participants outside the DFAC (nutritional shake, nutritional bar, and electrolyte beverage; total contribution/day: 630 kcal and 30 g protein). Mean daily intakes of calories and select nutrients as compared to the Military Dietary Reference Intakes (MDRIs) population are presented in Table 1. Overall the distribution of participant’s NI was adequate except for carbohydrate, dietary fiber, selenium and vitamin D. Noteworthy, even without supplementation, protein intakes increased to 1.5 g/kg (data not shown), and with supplementation, protein intakes increased to 1.9 g/kg.

The DFP method resulted in a 99% success rate; matching 1253 of 1270 pre-meal and post-meal food trays over the 5-day observation period (Table 2). Data lost (both pre- and post-photos missing) per meal was less than 5%, and typically less than 2%. Overall accuracy of correctly matching the photographed food item on a participant’s plate to that of the standard, weighed food item is shown in Table 3. The quality of the images was also acceptable, as only 10% of food items required adjudication by a third dietitian to correct food item identification errors (Table 3). The magnitude of error in estimating the serving size and thereby the nutritional contribution of each food is represented in Table 4. Of the third of foods that were categorized as a mismatch for serving size (>10% discrepancy between the two estimators), most inaccuracies of serving size estimations fell within the mismatch range of 15–25% error (13%) (e.g. one estimator may have recorded 0.5 cup of oatmeal, while the second recorded 0.66 cup) and just 12% fell within a mismatch range 25–50% discrepancy of serving size estimate (e.g. 0.5 cup recorded vs. 0.75 cup). Foods that were amorphous in nature (e.g. oatmeal, gravy, sauces) were the items most frequently requiring arbitration.

4. Discussion

The use of DFP removes much of the participant burden when it comes to quantifying NI. DFP allows for the rapid and accurate capture of nutritional intakes in the field environment, especially in evaluation of large groups with time constraints, thereby minimizing disruption of normal activities, which is a key attribute when studying workplace cafeteria settings or military personnel engaged in training.

The DFP method served as an effective and efficient tool for assessing NI of the participants enrolled in this fast-paced RASP training course. Even with course-specific time constraints on eating (<10 min per meal per participant), participants consumed over 99% of food provided for each meal period. Although consumption was near 100% it could not match the participants’ mean TDEE of 4264 ± 342 kcal/d during the first week of the course. Measured TDEE exceeded the MDRI for energy (3250 kcal/d) as well as recommendations of up to 125% of the MDRI for energy (4062 kcal/d) for individuals participating in prolonged, high intensity activities (U.S. Department of the Army, 2017). Similar to previous studies of specific military populations, TDEEs have been estimated to exceed even these higher energy intake recommendations during intense training scenarios (Margolis et al., 2013, 2014; Tharion et al., 2005). Mean carbohydrate intake was less than desired, meeting just two-thirds of the recommended daily intake over the 5-day study. The lack of carbohydrate intake accounted for a large portion of the energy imbalance measured. Surprisingly, even with the marked energy deficit, participants consumed adequate protein (1.9 g/kg), and this may have helped to offset loss of lean mass due to energy deficit. Protein intake levels of two (1.6 g/kg) and three (2.4 g/kg) times the RDA (0.8 g/kg) have been observed to be more effective in attenuating the loss of lean mass often seen during periods of energy deficit when compared to the RDA (Pasiakos et al., 2013a). However, consuming protein at three times the RDA, was no more effective than twice the RDA, as the excess protein was oxidized for energy (Pasiakos et al., 2013b). Long-term, for sustaining performance during training or under

### Table 1
Average daily energy and nutrient intake.

| Nutrient (unit) | Intake | % MDRI |
|----------------|--------|--------|
| Energy (Kcals) | 2919 ± 331 | 90 |
| Protein (g)    | 148.8 ± 14.9 | 146 |
| Carbohydrate (g) | 339 ± 55 | 66 |
| Total Fat (g)  | 108 ± 13 | 96 |
| Calcium (mg)   | 1580 ± 178 | 158 |
| Dietary Fiber (g) | 16.8 ± 5.6 | 50 |
| Iron (mg)      | 23.5 ± 3.3 | 235 |
| Magnesium (mg) | 438 ± 50 | 104 |
| Phosphorous (mg) | 2547 ± 222 | 364 |
| Potassium (mg) | 3797 ± 454 | 119 |
| Selenium (mg)  | 205 ± 25 | 85 |
| Sodium (mg)    | 5397 ± 710 | 108 |
| Zinc (mg)      | 23.6 ± 2.0 | 157 |

### Table 2
Daily photographs captured per meal.

| Meal   | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 |
|--------|-------|-------|-------|-------|-------|
| Breakfast | 260/262 (99) | 262/262 (100) | 254/256 (99) | 244/246 (99) | 234/244 (96) |
| Lunch   | 260/262 (99) | 262/262 (100) | 246/256 (96) | 242/246 (98) | 242/244 (99) |
| Dinner  | 262/262 (100) | 262/262 (100) | 246/256 (96) | 242/246 (98) | D / FAC closedd |
| Total   | 782/786 (99) | 786/786 (100) | 746/768 (97) | 486/492 (99) | 476/488 (98) |

Data are presented as either total number of photographs taken per meal/total number of photographs expected per meal or as total of daily photographs taken/total number of daily photographs expected (% of total photographs captured).

a Photographs per day reflect total number of soldiers who presented at one or more meals. Not all soldiers appeared at all meals due to duty assignments.

b All soldiers were engaged in a field exercise and did not eat lunch in the DFAC.

c The DFAC was closed for dinner weekly on day.
Of the foods that required adjudication (e.g., margarine or 50% error) proved to be most labor intensive and the greatest source of error. Weighted food item. Estimation of food portion or serving size matching food items on participant’s trays to that of the standard, real-time data collection. Overall there was 90% accuracy between that were assessed for 131 participants in approximately 240 min of population. Overall less than 5% of data was lost over the 12 meals.

Magnitude of discrepancy between estimators in food item serving size by meal. Table 4

| Meal      | # food items to score | # of food records requiring adjudication and 100% | w/food item mismatch | w/serving size mismatch |
|-----------|-----------------------|-------------------------------------------------|----------------------|------------------------|
| Breakfast | 3312                  | 1350 (41)                                       | 352 (11)             | 998 (30)               |
| Lunch     | 1985                  | 834 (42)                                        | 170 (9)              | 664 (33)               |
| Dinner    | 1905                  | 892 (47)                                        | 192 (10)             | 700 (37)               |
| Total     | 7201                  | 3076 (43)                                       | 714 (10)             | 2364 (33)              |

Table 3 Distribution of digital food photography inaccuracies requiring arbitration.

| Meal      | # food items recorded | # scored food item records | Mismatch between 10 and 15% | 15 and 25% | 25 and 50% | 50 and 75% | 75 and 100% | > 100% |
|-----------|------------------------|-----------------------------|-----------------------------|------------|------------|------------|-------------|--------|
| Breakfast | 3312                   | 35 (1)                      | 68 (3)                      | 23 (1)     | 126 (2)    |            |             |        |
| Lunch     | 1985                   | 351 (11)                    | 626 (13)                    | 294 (15)   | 907 (13)   |            |             |        |
| Dinner    | 1905                   | 370 (11)                    | 222 (11)                    | 257 (14)   | 849 (12)   |            |             |        |
| Total     | 7201                   | 182 (6)                     | 98 (5)                      | 96 (5)     | 376 (5)    | 102 (0)    | 22 (1)      | 57 (1) |

Data are presented as total number of food item records with mismatched serving size portion (% of total records captured).

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5. Conclusions

Unlike assessing NI using only visual estimation, where the foods are estimated by one data collector, DFP allows for increased accuracy by incorporating viewing and intake estimation by two or more individuals, who compare the food to estimate to photos of weighed, standardized servings. Another advantage of this type of data collection is that photographs of both the foods consumed and the standards they are compared to are kept on file, and can be reviewed for clarification when questions arise, or for use in subsequent studies. It should be noted that while the method is efficient for on-site data collection, estimation following collection is more time consuming. However, it is time well spent in the challenging area of accuracy in dietary assessment especially in large group settings.

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