The consumption of liquid diet 24h pre-experimental trials improves adherence compared to solid diet in athletes

Dr Alaaddine El-Chab, Dr Charlie Simpson, Dr Helen Lightowler

Department of Sport, Health Sciences and Social Work, Oxford Brookes University, Gipsy Lane, Oxford, OX3 0BP

Liquid *versus* solid pre-packaged meals

Corresponding author: Dr Helen Lightowler, Oxford Brookes University, Gipsy Lane, Oxford, OX3 0BP, hlightowler@brookes.ac.uk, +44 1865483245

Abstract

Discrepancies in energy and macronutrient intakes between tests are apparent even when a solid pre-packaged diet (Sdiet) is used to standardise dietary intake for pre-experimental trials. It is unknown whether a liquid pre-packaged diet (Ldiet) leads to improved adherence, resulting in lower variability in energy and macronutrient intakes. This paper assesses the ability of athletes to replicate a diet when an Ldiet or Sdiet was used as a dietary standardisation technique. In a crossover design, thirty athletes were randomly assigned to either Sdiet or Ldiet. Each diet was consumed for two non-consecutive days. Participants were instructed to consume all the meals provided and to return any leftovers. The coefficient of variation (CV) was calculated for each nutrient for the two methods and reported as the average CV. The Bland-Altman plots show that differences between day 1 and 2 in energy and macronutrient intakes for both diets were close to zero, with the exception of some outliers. The %CV for Sdiet was higher than Ldiet (5% and 3% for energy; 5% and 3% for carbohydrate; 5% and 2% for protein; and 5% and 3% for fat, respectively). There was a strong positive correlation for energy and all macronutrients between day 1 and day 2 for both methods ($r>0.80$; $p<0.05$). Ldiet is an effective technique to standardise diet pre-experimental trials and could be used as an alternative to Sdiet. Furthermore, Ldiet may lead to additional improvements in the compliance of participants to the diet and also decrease the cost and time of preparation.

Keywords: dietary standardization, replicate, repeatability

21 The consumption of liquid diet 24h pre-experimental trials improves adherence compared to
22 solid diet in athletes

23

24 **Introduction**

25 A feature of good quality research is that experimenters control dietary intake of their
26 participants during the trial preparation period with the purpose of minimising the effect of
27 different dietary components (e.g. carbohydrate and caffeine) known to have an impact on the
28 outcomes of the study (Bishop et al., 2001; Black et al., 2005; Desbrow et al., 2012; Walsh et
29 al., 2006). Studies with a crossover design require participants to replicate their diet prior to
30 every subsequent trial by using a dietary standardisation technique such as standardised diet
31 (solid pre-packaged diet; Sdiet), 24-hour dietary recalls or food records. The standardised diet
32 technique has been shown to be the best method, minimising the variability in energy and
33 macronutrient intakes between two visits (El-Chab et al., 2016; Jeacocke & Burke, 2010). An
34 investigation conducted by our research group showed that athletes vary their dietary intake
35 when they are asked to reproduce their freely selected diet (e.g. 24-hour dietary recall and
36 food record) in comparison to a standardised diet provided by the researchers (El-Chab et al.,
37 2016). However, despite the good level of compliance by the majority of participants, the
38 results of our previous study have shown that the Sdiet technique still contains discrepancies
39 in dietary intake in several participants.

40 According to Jeacocke and Burke (2010), only 13% of studies published in the International
41 Journal of Sport Nutrition and Exercise Metabolism from 2004 to 2009 used Sdiet 24-hours
42 prior to each experimental trial. The unpopularity of the Sdiet could be due to the high cost
43 and its burden on researchers. Jeacocke and Burke reported that the average cost per
44 participant per trial is between £7.20 and £9.60. This may have a noticeable increase on the

budget of a study, especially when a large sample size and/or multiple trials are required. Moreover, the preparation of the Sdiet may be time consuming with an average time spent per participant between 2.5-3.25 hours including developing the diet, grocery shopping, food weighing and packaging.

Therefore, in an attempt to improve the compliance to the diet and reduce the cost and time of preparation, we propose a new method to standardise dietary intake during the period before experimental trials. This method is characterised by the provision of a liquid pre-packaged diet (Ldiet) instead of an Sdiet. The Ldiet method requires mixing different products together (e.g. meal replacement powder and milk), making the process more efficient and less burdensome. The Ldiet can be cheaper than the Sdiet and, most importantly, can make it easier for participants to consume due to less food preparation. In light of the above, the aim of this study was to assess the reproducibility of a liquid pre-packaged diet and a solid pre-packaged diet when used as dietary standardisation techniques.

Materials and Methods

Participants

Thirty moderately-trained male athletes from four different disciplines (rowing, triathlon, cycling and football) participated in this study. Two participants withdrew from the study, one for personal reasons and one for feeling nauseous during the Ldiet. The remaining 28 participants were (mean ± SD) 28 ± 7 years of age, 74.6 ± 9.5 kg in body mass and 1.79 ± 0.08 m in height. Participants were recruited from sports clubs in Oxfordshire by contacting their respective coaches. Eligibility criteria included athletes aged between 18-45 years, involved in a team or endurance type activity, training ≥ 5 hours per week, not allergic or intolerant to the food provided and free of metabolic disorders (e.g. diabetes, cardiovascular

disease, or hypertension). This study was conducted according to the guidelines laid down in the Declaration of Helsinki and was approved by the University Research and Ethics Committee (UREC) at Oxford Brookes University. Written informed consent was obtained from all participants prior to taking part in the study.

Design

Participants completed five visits to the laboratory at Oxford Brookes University. On visit 1, after taking anthropometric measurements using a stadiometer (Seca, Birmingham, UK) and a weighing scale (Tanita, Middlesex, UK), participants were randomly assigned to one of the following conditions: 1) solid pre-packaged diet (Sdiet) or 2) liquid pre-packaged diet (Ldiet). Therefore, participants were either given Sdiet on Visits 1 and 2 (separated by 24h) and Ldiet on Visits 3 and 4 (separated by 24h) or *vice versa*. Participants were allocated using a computer-generated list of random numbers (Microsoft Excel, Redmond, Washington, USA). Participants were instructed to consume all the meals provided and informed to return all left-overs at the next visit. They were also asked to record on a food diary sheet any deviation from the diet. For both the Sdiet and Ldiet, the difference in energy intake between visits and macronutrient intakes between visits was measured. The actual food consumed was determined by subtracting the amount of left-over food (if any) from the amount of food provided to the participant; this was then added to the amount of additional food/drink consumed and recorded on the food diary sheet (if any).

The energy and macronutrient content of the Sdiet and Ldiet were identical according to each participant's daily nutrient requirements and food preferences. Both diets provided 6.0 $g.kg^{-1}$ of carbohydrate, 1.6 $g.kg^{-1}$ of protein and 1.0 $g.kg^{-1}$ of fat of the total energy intake. A sample Sdiet is shown in Table 2. It is important to note that participants were free to consume the

food in any order. The Ldiet consisted of Dymatize Super Massgainer Powder (Dymatize, Bedford, Texas, USA) mixed with whole milk (mean ± SD: 1.8 ± 0.3 L) and was offered in three flavours (chocolate, vanilla or strawberry) according to each participant's taste preference. The drinks were prepared and provided by the principal investigators. Participants did not receive any advice on timing and quantity of drinks to consume throughout the day. Individual energy requirement was calculated using the Mifflin-St Jeor equation (Mifflin et al., 1990) and the short form of the International Physical Activity Questionnaire (Ipaq, 2002) to determine estimated basal metabolic rate and physical activity level. Nutritics software (Nutritics LTD, Dublin, Ireland) was used to construct the 24-hour menu for the Sdiet and to analyse the energy and macronutrient content of the additional food consumed by participants on testing days.

Statistical analyses

Statistical analyses were performed using SPSS v.22 (IBM corp., Armonk, NY, USA). All data were checked for normality of distribution. All data were normally distributed therefore paired-sample *t* tests were used to compare the mean energy and macronutrient intakes between day 1 and day 2 for each method. Data were analysed using the Bland & Altman (Bland & Altman, 1986) technique for assessing agreement between the two days of measurements for each condition. A range of agreement was defined as mean difference ±2 SD. The Pearson test was used to measure the correlation between day 1 and day 2 in nutrient intake for each method. In addition, the coefficient of variation (CV = 100 x mean/SD) was calculated for each nutrient for the two methods and reported as the average CV. The sample size was calculated using the equation published by Hopkins (Hopkins, 2000) and the data published by El-Chab *et al.* (2016) which showed that 28 participants were needed. A *P* value

118 < 0.05 was considered as significant. All values are presented as mean ± SD unless stated
119 otherwise.
120

121 **Results**

122 The results, as shown in Table 1, indicate that the mean energy and macronutrient intakes on
123 day 1 and day 2 for both dietary standardisation techniques were not significantly different.
124 Intakes for energy and macronutrients on day 1 and day 2 were compared using Bland-
125 Altman plots with 95% limits of agreement (LOA), as shown in Figures 1–4. As can be seen
126 in Figures 1-4, the differences between day 1 and 2 in energy and macronutrient intakes in
127 Sdiet and Ldiet were distributed around the mean which was close to zero with the exception
128 of some outliers. Outliers were defined as any points that are above mean + 2SD and any
129 points below mean – 2SD. The Bland-Altman plots show that for energy and all three
130 macronutrients, there was no evidence of greater differences between days as intakes
131 increased. The limits of agreement in the Sdiet for all nutrients were wider, almost twice in
132 some variables, compared to the Ldiet. Three participants on the Sdiet differed in their
133 carbohydrate intake between day 1 and day 2 by more than 100g compared to only one
134 participant on the Ldiet.
135

136 The coefficient of variation (%CV) of energy and macronutrients for the Sdiet were higher
137 than the Ldiet (4.9% and 2.7% for energy; 5.4% and 3.0% for carbohydrate; 5.5% and 2.3%
138 for protein; and 5.1% and 3.0% for fat, respectively). The Pearson test showed that for the
139 Sdiet, energy and macronutrient intakes for day 1 were very strongly correlated with those on
140 day 2 (r: 0.85 for energy, r: 0.85 for carbohydrate, r: 0.80 for protein and r: 0.93 for fat). The
141 relationship of energy and macronutrient intakes between day 1 and day 2 for the Ldiet was
142 very strong; however, the values were higher than in the Sdiet except for fat (r: 0.94 for

143 energy; r: 0.96 for carbohydrate; r: 0.96 for protein and r: 0.92 for fat). All correlations were
144 significant in both the Sdiet and Ldiet ($P < 0.01$).

145

146 **Discussion**

147 This study sought to determine the reproducibility of an Sdiet and Ldiet in athletes. The mean
148 energy and macronutrient intakes on day 1 and day 2 for both techniques were not
149 significantly different. However, within-subject differences may be obscured by traditional
150 statistical analysis (Weissgerber et al., 2015). Further analysis showed that both techniques
151 led to good compliance to the diet given as shown in the Bland and Altman plots where most
152 differences between day 1 and day 2 in energy and macronutrient intakes were around the
153 mean which was close to zero. This is supported by the strong correlation between nutrient
154 intake on day 1 and day 2 in both techniques. However, some discrepancies were apparent in
155 some participants, mainly in the Sdiet. More participants in the Sdiet (11%) differed in their
156 carbohydrate intake between day 1 and day 2 by more than 100 g than in the Ldiet (4%). An
157 implication of this is the possibility that these differences in carbohydrate intake can increase
158 signal noise and reduce the ability to detect small worthwhile changes. Nevertheless,
159 researchers are expected to check the compliance of their participants even when the gold
160 standard (i.e. pre-packaged diet) has been used. They could either use a checklist or simply
161 ask their participants to return any leftovers. This way, these discrepancies in energy and
162 macronutrient intakes could be avoided. However, in case of a large sample size, checking
163 the compliance of participants might become impractical and therefore the Ldiet becomes the
164 best choice.

165 The results of %CV confirm that the Sdiet and Ldiet are both effective techniques to
166 standardise dietary intake leading to only slight variations in nutrient intakes, although the

Ldiet had a smaller %CV compared to the Sdiet making it an ideal technique for studies with small sample size and/or looking for small worthwhile changes. When compared to the %CV of food record and dietary recall techniques obtained from our previous study, the %CVs of the Sdiet and Ldiet were at least two-folds smaller (food diary: 10-19%; dietary recall: 7-12%; El-Chab et al., 2016). The inter-subject variability in energy and carbohydrate intakes reported in this study was wide. It seems possible that this variability may be due to the difference in the type of athletes recruited who have different nutrient requirements and their body weight. For example, the carbohydrate intake of a cyclist weighing 63.0 kg was 366 g and of another cyclist weighing 99.2 kg was 652 g. This variation could increase the width of the confidence interval; therefore, it is suggested to recruit subjects with similar characteristics to reduce the between-subjects variability (Hopkins et al., 1999).

Cost and time of preparation were two of the main limitations of the Sdiet. Comparing the two techniques, the average cost of the Sdiet per participant per trial was £6.60 compared to £4.90 for the Ldiet. This does not cover the cost of labour, plastic bags and bottles, software package and other consumables. To put this in context, the average cost of the Sdiet for 30 participants undergoing two trials is £396.00 compared to £294.00 for the Ldiet. In addition, the average time spent preparing the solid pre-packaged diet was longer than preparing the liquid pre-packaged diet (20 minutes and 8 minutes, respectively). The greater time and cost may be prohibitive to carrying out a larger study which makes Ldiet advantageous.

Finally, two limitations need to be considered. The energy expenditure on the day preceding each visit was not measured; therefore, it was not possible to examine whether the changes in dietary intake were associated with any changes in physical activity. However, participants were asked to keep their physical activity level as close as possible prior to each trial. The study is also limited by the lack of information on participant's appetite in each trial. This

piece of information would have given us an indication on whether participants had increased hunger during a particular diet, thus increasing the risk of misreporting.

This study confirms that the Ldiet is an effective technique to standardise diet pre-experimental trials and could be used as an alternative to Sdiet. Furthermore, the Ldiet may lead to additional improvements in the compliance of participants to the diet and also decrease the cost and time of preparation. More research is needed to assess the ability of other population groups (e.g. obese, sedentary, women) to reproduce these two forms of diets. Future research is encouraged to monitor energy expenditure the day before and measure appetite during each of the experimental trials.

200 **ACKNOWLEDGEMENTS**

201 The authors' contributions are as follows: C. Simpson and H. Lightowler contributed to the
202 study design and interpretation of the findings; A. El-Chab was the principal investigator and
203 contributed to the study design, data collection, data analyses and interpretation of the
204 findings and wrote the manuscript. All authors read and approved the final version of the
205 manuscript. The authors have no financial or personal conflicts of interest to declare.

206

207 **References**

208 Bishop, N., Walsh, N., Haines, D., Richards, E., & Gleeson, M. (2001). Pre-exercise
209 carbohydrate status and immune responses to prolonged cycling: II. Effect on plasma
210 cytokine concentration. *International Journal of Sport Nutrition & Exercise Metabolism*,
211 *11*(4), 503.

212 Black, S. E., Mitchell, E., Freedson, P. S., Chipkin, S. R., & Braun, B. (2005). Improved
213 insulin action following short-term exercise training: role of energy and carbohydrate
214 balance. *Journal of Applied Physiology*, *99*(6), 2285–93.

215 Desbrow, B., Biddulph, C., Devlin, B., Grant, G. D., Anoopkumar-Dukie, S., & Leveritt, M.
216 D. (2012). The effects of different doses of caffeine on endurance cycling time trial
217 performance. *Journal of Sports Sciences*, *30*(2), 115–20.

218 El-Chab, A., Simpson, C., & Lightowler, H. (2016). The reproducibility of a diet using three
219 different dietary standardisation techniques in athletes. *European Journal of Clinical*
220 *Nutrition*, *70*(8), 954–958.

221 Hopkins, W. G. (2000). Measures of reliability in sports medicine and science. *Sports*
222 *Medicine*, *30*(1), 1–15.

223 Hopkins, W. G., Hawley, J. a, & Burke, L. M. (1999). Design and analysis of research on

224 sport performance enhancement. *Medicine and Science in Sports and Exercise*, *31*(3),
225 472–85.

226 Ipaq. (2002). *International Physical Activity Questionnaires Ipaq : Short Last 7 Days Self-*
227 *Administered Format*.

228 Jeacocke, N. a, & Burke, L. M. (2010). Methods to standardize dietary intake before
229 performance testing. *International Journal of Sport Nutrition and Exercise Metabolism*,
230 *20*(2), 87–103.

231 Martin Bland, J., & Altman, D. (1986). Statistical methods for assessing agreement between
232 two methods of clinical measurement. *The Lancet*, *327*(8476), 307–310.

233 Mifflin, M., St Jeor, S., Hill, L., Scott, B., Daugherty, S., & Koh, Y. (1990). A new predictive
234 equation for resting energy expenditure in healthy individuals. *Am J Clin Nutr*, *51*(2),
235 241–247.

236 Walsh, M. C., Brennan, L., Malthouse, J. P. G., Roche, H. M., & Gibney, M. J. (2006). Effect
237 of acute dietary standardization on the urinary, plasma, and salivary metabolomic
238 profiles of healthy humans. *The American Journal of Clinical Nutrition*, *84*(3), 531–9.

239 Weissgerber, T. L., Milic, N. M., Winham, S. J., & Garovic, V. D. (2015). Beyond bar and
240 line graphs: time for a new data presentation paradigm. *PLOS Biology*, *13*(4), e1002128.

241

242 Table 1. Mean energy and macronutrient intakes of trained athletes (N=28) on day 1 and day
243 2 of solid and liquid diet consumption

Method	Day 1	SD	Day 2	SD	P value
Solid diet					
Energy (kcal)	2970	613	2997	645	0.67
Carbohydrate (g)	463	108	455	118	0.49
Protein (g)	127	32	127	27	0.90
Fat (g)	72	22	74	26	0.30
Liquid diet					
Energy (kcal)	3139	621	3140	623	0.98
Carbohydrate (g)	475	122	475	123	0.99
Protein (g)	131	26	132	26	0.51
Fat (g)	77	18	77	18	0.78

244

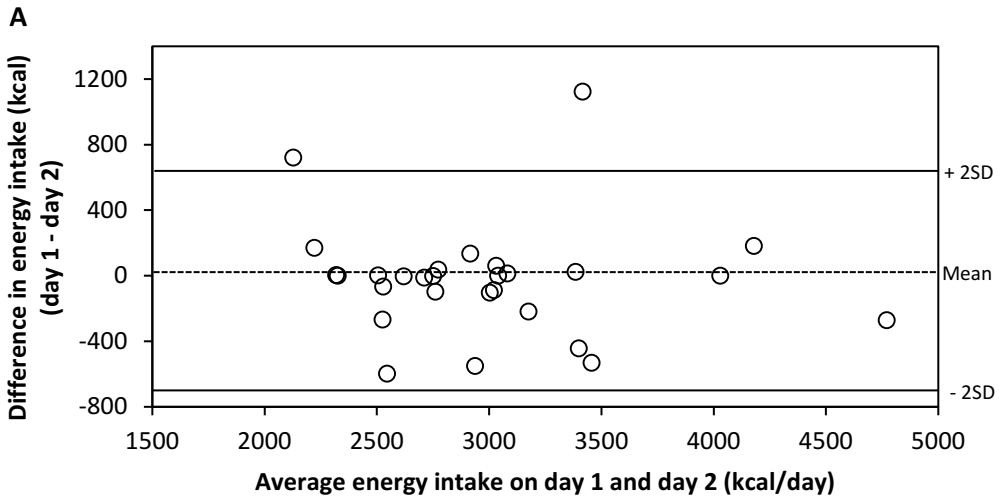
245

246 Table 2. Sample diet* for a 70 kg participant receiving solid pre-packaged meals

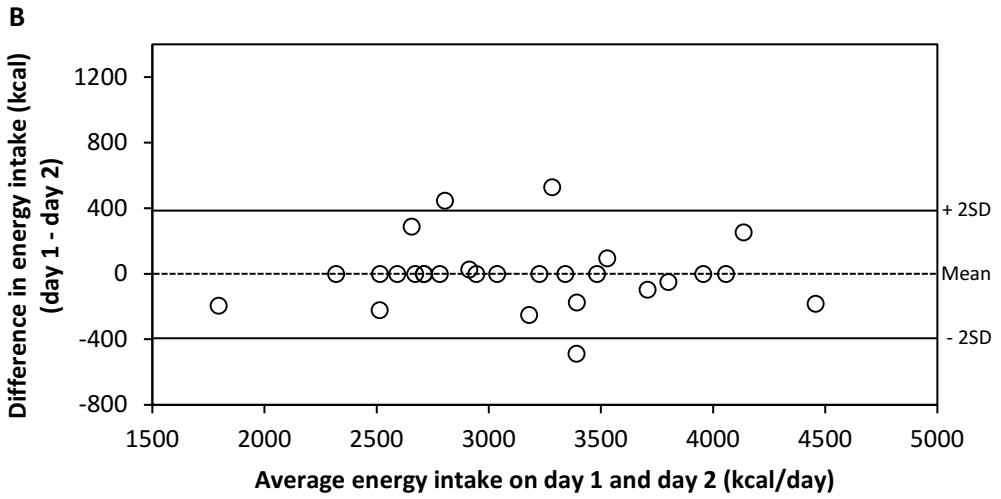
	Food	Amount
Meal 1	Cornflakes	60 g
	Whole milk	500 ml
Meal 2	White bread	223 g
	Cheese	90 g
	Beans	250 g
	Butter	8 g
	Tomato	135 g
Meal 3	Pasta	160 g
	Tomato sauce	190 g
Snacks	Apple	292 g
	Banana	320 g

*Dietary composition: energy = 2730 kcal; carbohydrate = 419 g; protein = 115 g; fat = 69 g.

247



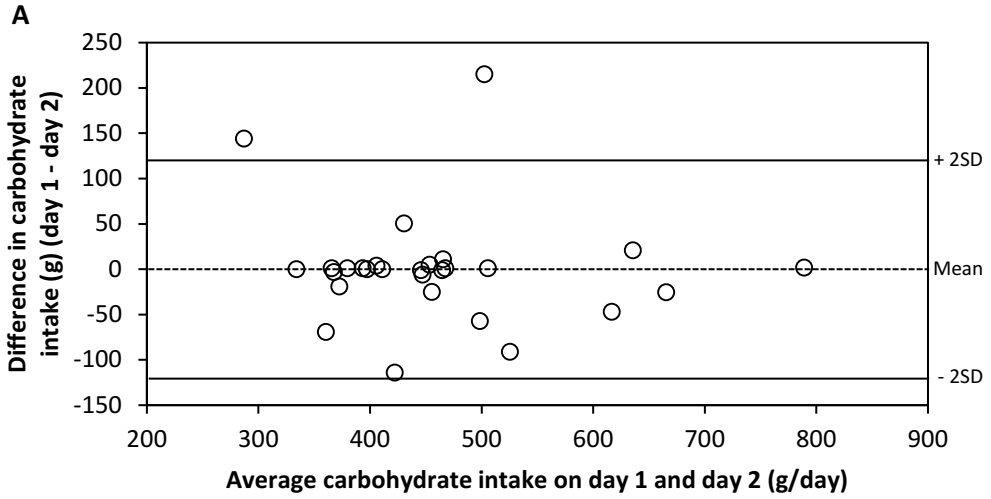
248



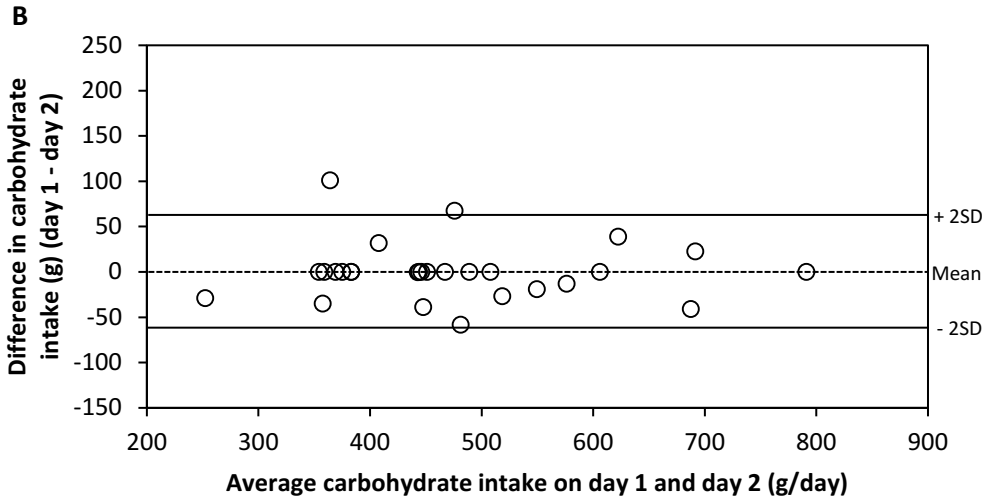
249

250 Figure 1. Comparison of the amount of energy consumed on day 1 and day 2 for the solid (A)

251 and liquid (B) diet techniques.



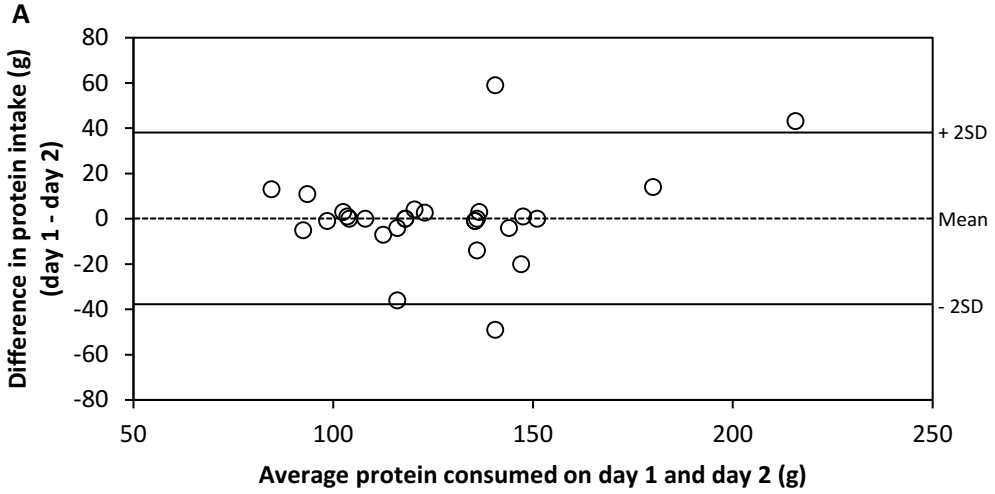
252



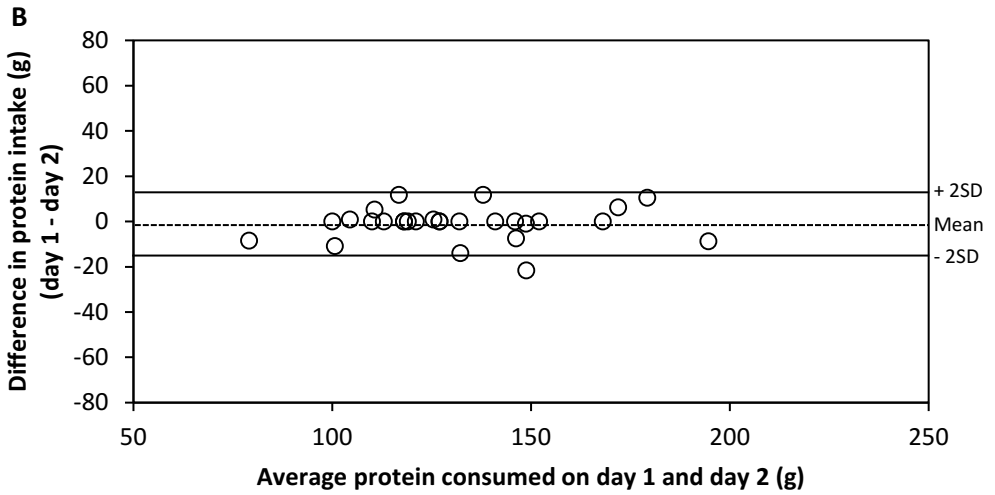
253

254 Figure 2. Comparison of the amount of carbohydrate consumed on day 1 and day 2 for the
255 solid (A) and liquid (B) diet techniques.

256

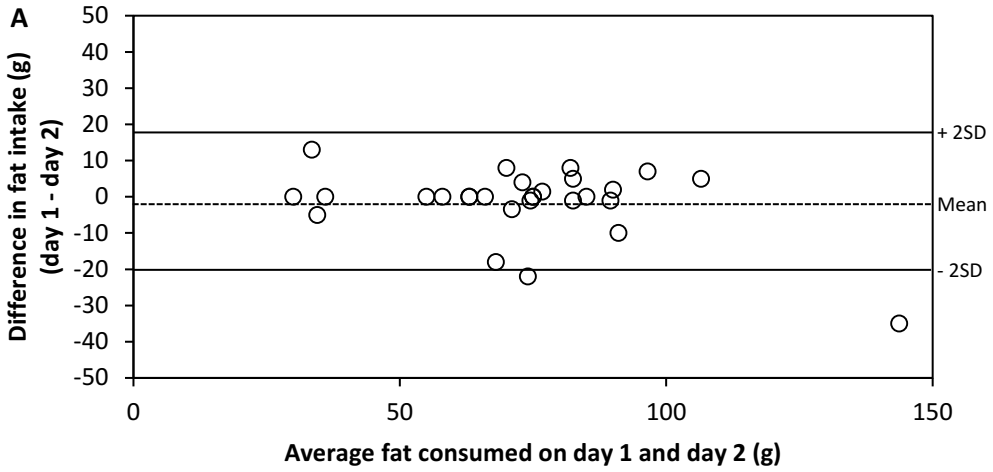


257

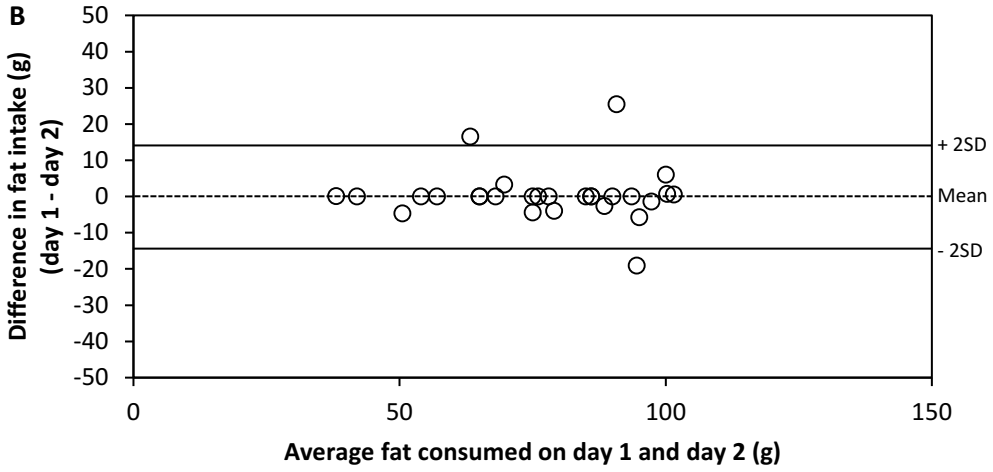


258

259 Figure 3. Comparison of the amount of protein consumed on day 1 and day 2 for the solid (A)
260 and liquid (B) diet techniques.



261



262

263 Figure 4. Comparison of the amount of fat consumed on day 1 and day 2 for the solid (A) and
264 liquid (B) diet techniques.