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## ABBREVIATIONS

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AMPM	Automated Multiple Pass Method
ANS 08/9	New Zealand Adult Nutrition Survey 2008/9
BMI	Body Mass Index
BMR	Basal Metabolic Rate
CVD	Cardiovascular Disease
cm	Centimetre
DALY	Disability-Adjusted Life Year
DH	Diet History
DLW	Doubly Labelled Water
EI	Energy intake
g	Gram
FFQ	Food Frequency Questionnaire
FR	Food Record
HbA1c	Glycosylated Haemoglobin
IOTF	International Obesity Taskforce
HRC	Health Research Council
HRQL	Health Related Quality of Life
kcal	Kilocalorie
kg	Kilogram
kJ	Kilojoule
LERs	Low Energy Reporters
MJ	Megajoule
MP24	Multiple Pass 24-hour Recall
MP24+SC	Multiple Pass 24-hour Recall plus SenseCam
mpFR	mobile phone Food Record
MUFA	Monounsaturated Fat
NCDs	Non-communicable diseases
NIHI	National Institute for Health Innovation
NDNNS	National Diet and Nutrition Survey

NHANES	National Health and Nutrition Examination Survey
N.Z.	New Zealand
NZEO	New Zealand European
NZFCD	New Zealand Food Composition Database
NNS97	New Zealand National Nutrition Survey 1997
OECD	Organisation for Economic Co-operation and Development
PDA	Personal Digital Assistant
PICTURE	Passive Image Capture to Record Everyday Events
PUFA	Polyunsaturated Fat
REE	Resting Energy Expenditure
RFBM	Remote Food Photography Method
SAFA	Saturated Fat
SC	SenseCam
SD	Standard Deviation
SEM	Standard Error
TEE	Total Energy Expenditure
U.K.	United Kingdom
U.S.	United States of America
USDA	United States Department of Agriculture
WHO	World Health Organization
Yrs	Years



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# CHAPTER 1. THESIS INTRODUCTION

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This thesis investigates the use of wearable cameras to (1) reduce the reporting bias for dietary energy intake (EI) associated with traditional self-reported dietary assessment, and (2) passively record and assess contexts of dietary behaviours. Dietary assessment methods are commonly used for monitoring population health and nutritional status, researching diet-disease relationships, informing public health interventions, guiding and evaluating health and nutrition policies, and informing clinical decisions and advice.<sup>1-7</sup> However, due to the complexity of eating behaviours, reporting errors, and difficulties in objectively measuring dietary intake, traditional dietary assessment methodologies are inherently flawed. Currently no method exists that accurately assesses the dietary intake of an individual or a population in free-living settings.<sup>8-10</sup> This is of concern, as rates of non-communicable diseases (NCDs) around the world are predicted to rise over the next decade,<sup>11-13</sup> and the major NCDs (including, cardiovascular disease, diabetes, obesity, stroke, and certain cancers), are all associated with poor diet.<sup>3-5, 14</sup>

The need for improved methods of dietary assessment is well recognised.<sup>8, 9, 15, 16</sup> Walter Willet, Professor of Nutrition Epidemiology at Harvard University, School of Population Health, describes the need for better research methods to study diet-disease relationships: *“our knowledge of many of these relationships will depend largely on epidemiologic data, and for many relationships indefinitely”. For this reason it is crucial to refine maximally our methods of data collection, analytic procedures, and interpretation of findings*.”<sup>17(p19)</sup> The implications sub-optimal methods and the associated measurement error is that it often attenuates the estimated disease relative risk (causes bias towards 1) and reduces the statistical power to detect an effect. Therefore an important relationship between diet and disease may therefore be obscured.<sup>18</sup>

One of the most common methods of dietary assessment is the 24-hour dietary recall, a retrospective method usually conducted by a skilled interviewer (in person or over the telephone), but can be completed solely by a participant using an automated website or software package.<sup>2, 19-22</sup> The 24-hour dietary recall is the method chosen for national nutrition surveillance programmes in New Zealand and a number of other high income countries including the United States of America (U.S.) and Australia.<sup>23-25</sup> Additionally, the 24-hour dietary recall method is a popular method used in a wide-range of small and large-scale nutrition research, and in clinical

and community settings.<sup>1</sup> The important role the 24-hour dietary recall plays in nutrition monitoring and assessment therefore means efforts to improve the method should be undertaken. Computer-assisted systems help to ensure correct methodical procedures are followed, and sophisticated portion size tools have improved portion size estimations.<sup>19, 20, 26, 27</sup> However, these developments have not addressed key limitations of 24-hour dietary recalls, the reliance on self-report and memory.<sup>1, 8, 28</sup>

Five reviews over the past nine years have summarised, described, and evaluated the strengths and weaknesses of various technologies and computer-assisted systems for dietary assessment.<sup>16, 19, 29-31</sup> The reviews found technology-assisted methods are preferred by participants and can reduce the burden of research, but none has thoroughly examined image-assisted methods of dietary assessment and the use of wearable cameras.<sup>16, 19, 29-31</sup> Image-assisted dietary assessment is an emerging field of nutrition research, and encompasses any method that uses images/video of eating episodes to assist self-report used in traditional methods, or uses images/video as the primary record of dietary intake.

The central tenet of this thesis is to examine the feasibility and validity of image-assisted methods of dietary assessment, and to identify and minimise limitations of the 24-hour dietary recall method, using wearable cameras (image-assisted 24-hour dietary recall). Wearable cameras may improve 24-hour dietary recalls since images have been shown to enhance memory recall and provide an objective record of daily events.<sup>32, 33</sup> As such, the use of wearable cameras and self-report are potentially complementary; the wearable camera images provide visual prompts to augment memory recall<sup>32, 33</sup> and provide a visual representation to assist portion size estimation,<sup>32, 33</sup> while participant self-report provides specific details on dietary intake that are decipherable from the images (hidden ingredients). More accurate and complete recall of dietary intake during the measurement period should reduce the magnitude of measurement error.<sup>8, 34</sup> Additionally, wearable camera images may provide a novel method to passively and objectively assess the context of dietary behaviours in free-living settings.<sup>35-39</sup> Developing methods to better assess and understand the determinants of dietary behaviours is important to inform nutrition policies and interventions to positively change dietary behaviours.<sup>40-44</sup>

The thesis objectives are as follows:

1. To evaluate self-reported dietary energy intake in the 2008/9 Adult Nutrition Survey and determine the prevalence of low energy reporters
2. To undertake a systematic review of existing evidence for image-assisted methods of dietary assessment
3. To explore the feasibility of using wearable cameras to assist an interviewer-administered 24-hour dietary recall
4. To validate a wearable camera image-assisted 24-hour dietary recall using the criterion measure doubly labelled water
5. To assess the utility of wearable cameras to objectively record and reliably assess environmental and social contexts of eating episodes

It was hypothesised that images captured by wearable cameras would reduce self-report bias for dietary EI compared to self-report alone by providing additional information to augment memory recall, and enhance self-report.

A brief overview of this thesis is as follows: Chapter Two provides general background on nutrition-related disease relevant to this thesis. The prevalence of nutrition-related disease, and risk factors, the associated cost and impact of nutrition-related disease, and recent national and global trends in dietary intake and body size will be discussed. Chapter Three provides an overview of dietary assessment. The traditional methods of dietary assessment, and associated sources of measurement error and validity, are discussed.

Five modules of research were conducted as part of this PhD and these form Chapters Four to Nine. Chapter Four is a retrospective analysis of EI data reported in the 2008/9 New Zealand Adult Nutrition Survey (ANS 08/9). The aim was to estimate the prevalence of low energy reporters (LERs) by gender, age, body size, and ethnicity in the most recent national nutrition survey. Chapter Five is the first systematic review of existing evidence for image-assisted methods of dietary assessment. The review included all relevant studies and technologies, and provides the first comprehensive examination of image-assisted methods of dietary assessment. Chapter Six describes a feasibility study that explores wearable cameras to enhance dietary self-report in the 24-hour dietary recall method (image-assisted 24-hour dietary recall).

Results from the feasibility study informed the design of a subsequent larger study called PICTURE “Passive Image Capture to Record Everyday Events”, that validated wearable camera image-assisted 24-hour dietary recalls, using the criterion measure doubly labelled water (Chapter Seven). The study assessed the degree to which wearable cameras altered self-reported intake and how this affected measurement bias. Chapter Eight describes a body of work that uses the dietary intake data and images captured during the validation study (Chapter 7) to explore the potential use of visual images for research into human eating and nutrition behaviours in free-living settings. Chapter Nine discusses the findings of all the research undertaken investigating image-assisted methods of dietary assessment, summarises the potential of wearable cameras to reduce dietary reporting bias for dietary EI and assess context of dietary behaviours, and makes recommendations for future studies and development of image-assisted methods of dietary assessment.

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# CHAPTER 2. THE BURDEN OF NUTRITION-RELATED DISEASE AND TRENDS IN DIETARY INTAKE

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## 2.1. Overview

The following section provides an overview on the global burden of nutrition-related disease, and trends in dietary intake and body size in New Zealand (N.Z.). The studies and reports included in this section were obtained from searches of MEDLINE (1946 to September 2014), Web of Science, Google Scholar, and PubMed (to September 2014). The most recent national data available were used to describe the prevalence of nutrition-related disease and associated risk factors at the time of writing. Data regarding nutritional epidemiology and trends in population dietary intake (sections **2.2** and **2.3**) provide the rationale for the objectives of the thesis (Chapter One).

The chapter is structured as follows:

- **Section 2.2** Epidemiology of nutrition-related disease
- **Section 2.2.1** Prevalence of nutrition-related disease, and associated risk factors
- **Section 2.3** Trends of dietary intake and body size
- **Section 2.4** Cost of nutrition-related disease
- **Section 2.5** Summaries of sections **2.2** to **2.4**

## 2.2. Epidemiology of nutrition-related disease

Epidemiology provides evidence that bears directly on the health of the population<sup>45</sup> and is defined by the World Health Organisation (WHO) as the study of the distribution and determinants of health-related states or events (including disease) and the application of this study to the control of diseases and other health problems.<sup>46</sup> Nutritional epidemiology specifically focuses on diet-disease relationships, and the monitoring of the nutritional status of populations.<sup>47</sup>

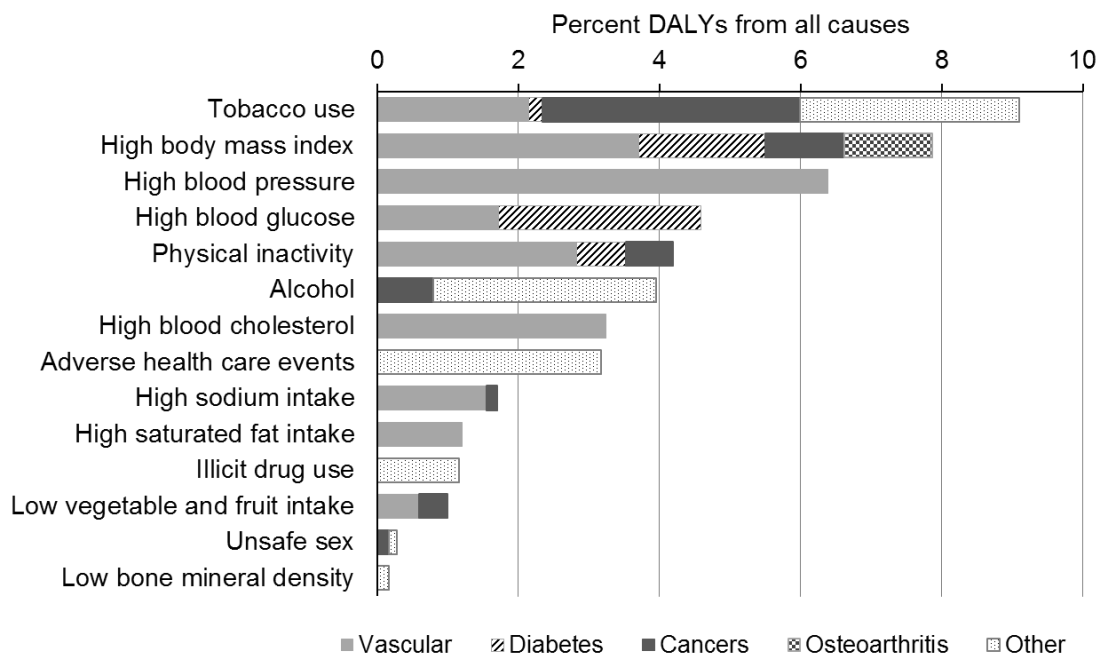
Globally approximately 34.5 million out of 52.8 million deaths (almost two thirds) annually are due to non-communicable diseases (NCDs).<sup>48</sup> When health loss is considered, 1.1 billion annual disability-adjusted life years can be attributed to NCDs.<sup>5</sup> The disability-adjusted life year (DALY) is a measure of overall disease burden, and can be thought of as the number of years lost due to ill-health, disability or early death. Predominant global nutrition-related NCDs, which include cancer (not all related to nutrition), cardiovascular disease (CVD), obesity, and diabetes mellitus, have reached epidemic proportions.<sup>6</sup> Globally the top five nutrition-related risk factors are high blood pressure, high blood glucose levels, overweight and obesity (high body mass index, BMI), high cholesterol, and low fruit and vegetable intake (middle and high income countries only).<sup>4</sup> Combined, these risk factors account for approximately 24.8 million (71%) of deaths from NCDs worldwide annually.<sup>4</sup> Regarding health loss, these major risk factors account for approximately 540 million or 50% of DALYs attributable to NCDs.<sup>4,5</sup> Additionally, diets high in salt account for 61 million DALYs, and diets low in seafood omega-3 fatty acids, poly unsaturated fatty acids, and diets high in trans fatty acids account for 51.5 million or 2.9% of DALYS attributable to NCDs.<sup>4,5</sup>

### ***New Zealand***

New Zealand is ethnically and culturally diverse, with a population of approximately four million residents (N=4,541,420 at 3rd July 2014)<sup>49</sup> and a median age of 38 years.<sup>50</sup> Information from the most recent census in 2013 indicates the population is ageing slowly, with a substantial proportion (14.3%) aged 65 years or older.<sup>51</sup> Europeans are the largest ethnic group (74.0%), followed by Maori (14.9%), Asian (11.8%), Pacific peoples (7.4%), and other ethnic groups (3.7%, note people could select more than one ethnicity therefore values do not add up to 100). The majority of the population have a formal qualification (79.1%), and one in five (20.0%) have a bachelor's degree or higher. The average household disposable income is \$25,495 NZD (\$21,773 USD) which falls

slightly below the average household disposable income (\$23,938 USD) for countries that belong to the Organisation for Economic Co-operation and Development (OECD).<sup>52</sup>

In N.Z., the burden of nutrition-related disease is comparable to that described globally.<sup>53</sup> Cancer (17.5%), coronary heart disease (9.3%) overweight and obesity (7.9%) and diabetes (3.0%) are major attributable causes of total estimated DALYs.<sup>54</sup> **Figure 1** shows the dietary risk factors high blood pressure, high cholesterol, overweight and obesity, inadequate fruit and vegetable intake, and high salt intake are attributable for approximately 24.8% of total DALYs.<sup>54</sup>



**Figure 1 Attributable burden (percentage of DALYs) for selected risk factors in New Zealand, 2006.**

Figure taken from Health Loss in New Zealand. A report from the New Zealand Burden of Diseases, Injuries and Risk Factors Study, 2006–2016<sup>54</sup>

### 2.2.1 Prevalence of nutrition-related disease in New Zealand

This section briefly discusses the prevalence of the four major nutrition-related NCDs in N.Z.; cancer, CVD, obesity, and diabetes.<sup>54</sup> Cancer is the largest cause of death but it is common to report the annual incidence of cancer using an age-standardised rate for the total population rather than the prevalence. In 2009, the incidence of cancer in N.Z. was 344/100,000 people.<sup>55</sup> With respect to CVD the most recent data for N.Z. are reported for all persons rather than adults,

therefore the prevalence 7% appears relatively low.<sup>56</sup> However, 2005 projections from the 2003/4 Auckland Diabetes Heart and Health study suggested 20% of adults aged  $\geq 35$  years are likely to have CVD.<sup>57</sup> Regarding obesity, the prevalence amongst N.Z. adults aged  $\geq 15$  years is 28%, which is one of highest rates the world.<sup>58-60</sup> Compared with all other nations in the OECD, N.Z. has the fourth highest mean BMI.<sup>60</sup> Regarding diabetes (type 1 and type 2), the most recent data available are from the Adult Health Survey 2011/12, which indicated that the prevalence of diabetes is 5%.<sup>58</sup> However, blood analytes measured in the Adult Nutrition Survey 2008/9 (ANS 08/9) indicated that 6.9% of adults aged  $\geq 15$  years had a proportion of glycosylated haemoglobin (HbA1c) of  $\geq 6.5\%$ , which is indicative of diabetes.<sup>61</sup>

### **2.2.1.1. Prevalence of nutrition-related risk factors**

As discussed above, high blood pressure, high cholesterol, inadequate fruit and vegetable intake, and high salt intake are the leading nutrition-related risk factors in N.Z. attributable to total annual DALYs.<sup>54</sup> The only national data for prevalence of high blood pressure (adults  $\geq 15$  years) is based on self-reported use of medication for hypertension (16%), reported in the 2012 N.Z. Adult Health Survey.<sup>58</sup> However, data from the 2003/4 Auckland Diabetes, Heart and Health Study ( $\geq 35$  years) that measured blood pressure indicated 22% of N.Z. European (NZEO) (n=2021), 37% of Maori (n=1006), and 38% of Pacific people (n=996) had high pressure (population estimates not reported).<sup>62</sup> Similarly, the most recent data on the prevalence of high cholesterol (10%) is based on self-reported use of medications to reduce cholesterol reported in the 2012 N.Z. Adult Health Survey,<sup>58</sup> which is substantially lower than the 68% of NZEO adults (n=2021) with high cholesterol measured (total cholesterol  $\geq 5$ mmol/L) in the Auckland Diabetes, Heart and Health Study (2003/4).<sup>63, 64</sup> With respect to fruit and vegetable intake, the most recent data available is based on self-reported intake in the 2012 N.Z. Adult Health Survey with 41% not meeting recommendations for fruit (2 servings) and 32% not meeting recommendations for vegetables (3 servings).<sup>58</sup> For sodium (principally from salt) intake, the most recent available data are from the ANS 08/9 which used measured urinary sodium.<sup>65</sup> At 3500mg/day N.Z. adults consume more than twice the recommended suggested target for reducing chronic disease (1600mg/day) set by the N.Z. Ministry of Health and the Australian Government.<sup>66</sup>



### 2.3. Trends in dietary intake

For N.Z. adults, dietary intakes of key nutrients associated with nutrition-related disease are sub-optimal compared with recommendations (presented in **Table 1**). It is important to note that data regarding dietary intake are obtained using self-reported methods of dietary assessment, and thus prone to bias (discussed in section 3.5).<sup>2, 8, 9</sup>

Energy intake is an important factor in nutrition-related disease, as it is the surrogate measure of the total quantity of food intake with many nutrients (macronutrients, mineral and B vitamins) highly correlated with its intake.<sup>8, 67</sup> It is difficult to compare EI with recommended intakes as age, body composition, and levels of physical activity all affect energy demands.<sup>68</sup> Furthermore, substantial under-reporting of EIs observed in national nutrition survey data make it difficult to accurately monitor and interpret trends in EI.<sup>69-73</sup> However, with this in mind reported EIs for N.Z. adults decreased substantially for men and slightly for women (statistically non-significant) between 1997 and 2008/9.<sup>65, 74</sup> Regarding saturated fat intake, N.Z. adults have substantially reduced their intake over the past decade but with 13% of total energy provided by saturated fat it is still greater than recommendations.<sup>65</sup> Trends for sodium intake are more difficult to assess as urinary sodium was not assessed in the 1997 national nutrition survey. However, data from a urinary excretion study (n=700) in 1998 suggests sodium intake has remained stable at ~3500mg/day over the past decade.<sup>65, 75</sup> The inadequate intake of fruit and vegetables in N.Z. was discussed above in section 2.2.1.1. Data from 2003-2012 suggest that the inadequate intake of fruit and vegetables have remained relatively stable over the past nine years.<sup>58, 61, 76</sup>

**Table 1 Intakes of major nutrients and fruit and vegetables associated with nutrition-related disease in New Zealand**

Characteristic	Method of Assessment	Recommendations/ classifications	Mean daily intake			Change**
			1997*	2008/9*		
<b>Energy</b>						
≥15yrs	1x 24-hour dietary recall	7.7MJ to 18.6MJ/day (Men)	12.0MJ	10.7MJ		▼
		6.1MJ to 15.3MJ/day (Women)	8.0MJ	7.6MJ		NC
<b>Saturated Fat</b>						
≥15yrs	1x 24-hour dietary recall	≤12% of total energy <sup>77</sup>	15% of total energy	13%		▼
<b>Sodium</b>						
≥15yrs	Urinary sodium	Recommended Upper Level = 2300mg/day Suggest dietary target for reducing chronic disease = 1600mg/day <sup>66</sup>	3464mg/day (1998, ≥18yrs) <sup>^</sup>	3500mg/day		NA
<b>Fruit &amp; Vegetable intake</b>						
≥15	self-reported	Recommended servings/day Fruit ≥ 2 vegetables ≥ 3	2003/4 <sup>#</sup> 45% not meeting recommendations for fruit 31% not meeting recommendations for vegetables	2006/7 <sup>#</sup> 40% not meeting recommendations for fruit 36% not meeting recommendations for vegetables	2011/12 <sup>#</sup> 41% not meeting recommendations for fruit 32% not meeting recommendations for vegetables	NA

\*\* **NC** = no statistical difference, **▼** = significant decrease, **▲** = significant increase, **NA** = not applicable.

\*Data taken from the 1997 National Nutrition Survey<sup>74</sup> and the 2008/9 Adult Nutrition Survey of N.Z.<sup>65</sup>

<sup>^</sup>Sodium intake was not assessed in the 1997 National Nutrition Survey therefore data was taken from a N.Z. urinary excretion study conducted in 1998 (n=700).<sup>75</sup>

<sup>#</sup>Data taken from the N.Z. Health Surveys.<sup>58, 61, 76</sup>

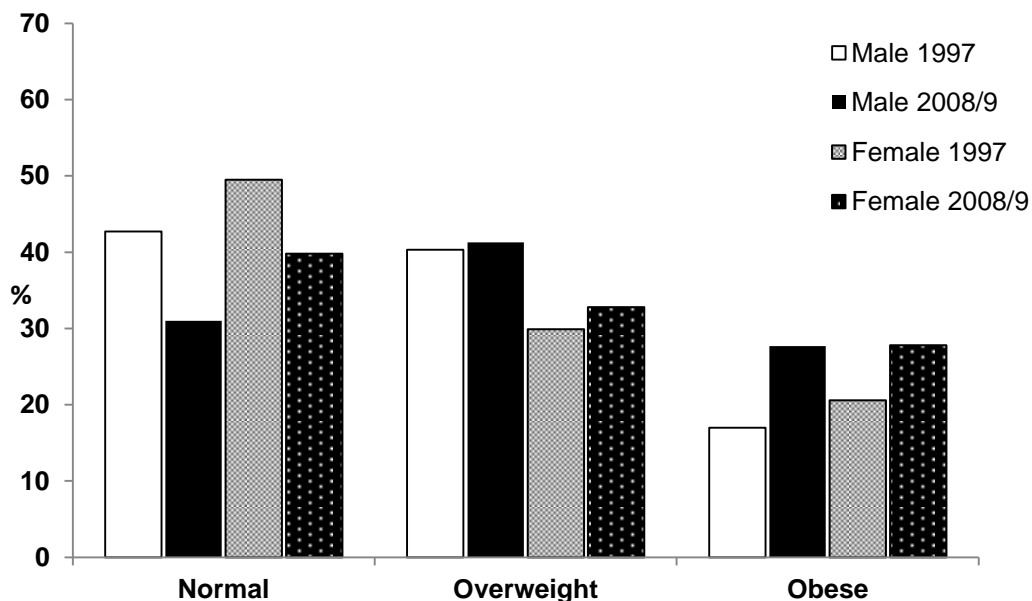
### 2.3.1 Trends in body size

Trends in body mass and obesity in N.Z. are presented in **Table 2** and **Figure 2**. Mean body weight and prevalence of overweight and obesity in N.Z. adults have increased substantially between national nutrition surveys. <sup>65</sup> This indicates N.Z. adults are in positive energy balance, despite decreases in reported EIs. <sup>65</sup> Body size data from the 2011-12 N.Z. Health survey suggests the trend is continuing (Male obese = 28.1%, female = 28.8%). <sup>51</sup> Similarly, data for the U.S. and U.K show an increasing BMI trend, and are predicted to rise further. <sup>78</sup>

**Table 2 Physical characteristics of New Zealand Adults in 1997 compared to 2008/9**

Body Weight	1997	2008/9	Change
Male	80.4kg	85.1kg	▲
Female	68.7kg	72.6kg	▲

Data taken from the 1997 National Nutrition Survey <sup>74</sup> and the 2008/9 Adult Nutrition Survey of N.Z. <sup>65</sup>



**Figure 2 Body size of New Zealand adults aged ≥15 years in 1997 compared to 2008/9. Data taken from the 1997 National Nutrition Survey <sup>74</sup> and the 2008/9 Adult Nutrition Survey of N.Z. <sup>65</sup>**



## 2.4. Cost of nutrition-related disease

The costs associated with nutrition-related disease in N.Z. are considerable.<sup>79</sup> Economic costs can be direct or indirect. Direct costs include hospital costs (inpatient and outpatient), allied health professional costs, general practitioner visits, residential/aged care, pharmaceuticals and laboratory costs, or any other directly related cost. Indirect economic costs or productivity losses are the costs associated with lost opportunities or an impaired ability to work.<sup>80</sup> There is limited information regarding direct and indirect costs of nutrition-related disease in N.Z., with the majority of information sourced from a recent study by Lal et al.<sup>81</sup> The direct and indirect cost of nutrition-related diseases are presented in **Table 3**. Costs per capita were calculated using population estimates corresponding to the year of source data and the 12-month average exchange rate for the N.Z. Dollar (NZD). Overall the total direct costs for the five types of cancer, CVD, obesity, and diabetes were estimated by Lal et al<sup>81</sup> were \$1.6 billion annually.

**Table 3 Summary of estimates for direct and indirect costs of nutrition-related diseases in New Zealand**

Source	Direct Costs (Million \$NZD)	Indirect Costs (Million \$NZD)	Total Costs (Million \$ NZD)	Cost per capita*
<b>Cancer</b>				
Lal et al <sup>81</sup> (2006)				
Colorectal	58	-	58	Direct cost =\$14
Breast	46	-	46	Direct cost =\$11
Endometrial	5	-	5	Direct cost =\$1
Kidney	8	-	8	Direct cost =\$2
<b>Cardiovascular Disease</b>				
Lal et al <sup>81</sup> (2006)				
Ischaemic heart disease	371	-	371	Direct cost =\$89
Hypertensive heart disease	4	-	4	Direct cost =\$1
<b>Obesity</b>				
Lal et al <sup>81</sup> (2006) (overweight and obesity)				
	624	-	-	Direct cost = \$149
New Zealand Government <sup>82</sup> (2004)				
	460	370	830	Direct and indirect costs =\$203
<b>Diabetes</b>				
Lal et al <sup>81</sup> (2006) Type 2 only				
	526	-	526	Direct and indirect costs =\$125
PriceWaterhouseCoopers and Diabetes New Zealand <sup>83</sup> (2008) Type 2 only				
	600	-	-	Direct Cost = \$140

\*Population counts are taken from the estimated populations in June for the corresponding year<sup>50</sup>  
Costs are approximate.

## **2.5. Summary**

The prevalence of nutrition-related disease (cancer, CVD, obesity, and diabetes) and associated risk factors (blood pressure, cholesterol, inadequate fruit and vegetable intake, high salt intake) in N.Z. is already high, but is predicted to rise further. At present there is a vast economic, personal and social burden attributed to nutrition-related disease. Dietary data indicates N.Z. adults are in positive energy balance (increasing in weight), are consuming higher than recommended intakes of saturated fats and sodium, and are consuming inadequate servings of fruit and vegetables, which further contribute to nutrition-related disease. In contrast to these trends, self-reported EI data for N.Z. adults has reduced for males and remained stable for females.



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# CHAPTER 3. TRADITIONAL METHODS OF DIETARY ASSESSMENT

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## 3.1. Overview

The following section provides an overview of the traditional methods of dietary assessment and their associated strengths and limitations. This section also includes information on the common sources of error in dietary assessment, validity of the traditional methods of dietary assessment, and discusses the implications of measurement error. The sources for this information were obtained from MEDLINE (1966 to September 2014), Web of Science, Google Scholar, and PubMed (to September 2014). The limitations of the traditional methods of dietary assessment, and implications of measurement error, provide the rationale for investigating the use of wearable cameras to reduce the reporting bias for dietary EI.

This literature overview is structured as follows:

**Section 3.2** provides an overview of the traditional methods of dietary assessment

**Section 3.4** summarises the common sources of error in dietary assessment

**Section 3.5** describes methods used to assess validity, common results from reviews of validation studies, and discusses the implications of measurement error

**Section 3.6** summarises sections **3.2** to **3.5**

## 3.2. Dietary assessment

The traditional methods of dietary assessment have been primarily designed to estimate the quantity and/or frequency of food consumption, and are essential to evaluate individuals' or populations' dietary intake and nutritional status.<sup>2, 84</sup> Four traditional methods of dietary assessment have been used extensively in nutrition research and in clinical and community settings: 24-hour dietary recall, food record (FR), food frequency questionnaire (FFQ), and the diet history interview (DH).<sup>1, 2, 84</sup> Each method has specific strengths and limitations, making them appropriate for use in different situations (discussed in sections **3.2.1** to **3.3.3**). However, all methods rely on self-report without the ability to verify intake objectively (at the time of assessment). Therefore, both unintentional and intentional misreporting can contribute undetected to measurement error.<sup>84</sup>

Although traditional methods of dietary assessment are primarily designed to record dietary intake, the 24-hour dietary recall and FR can also be used to collect additional limited information on the context of eating episodes (meals and snacks), such as time and location (e.g. food eaten at home vs. at work).<sup>85, 86, 87, 88</sup> Context describes the interrelated conditions in which something exists or occurs,<sup>89</sup> but at present there is no standard terminology for defining context or classes of contextual variables for dietary intake.<sup>42</sup> Both lab-based and real-world studies investigating human eating and nutrition behaviours have shown that many contextual factors affect dietary intake; such as meal time, location, effort required (e.g. distance of food away from table), cost, décor, ambient music, plate size, television viewing, social interaction, positive and negative cues (e.g. suggestions provided regarding the popularity of a food), meal frequency, and meal duration.<sup>41, 42</sup> Equally, contextual information can also reveal where and when certain foods are likely to be obtained or consumed.<sup>90</sup> As such, information on contexts is now recorded in some large-scale dietary surveillance programmes in conjunction with details of the foods and beverages consumed.<sup>85, 86, 91</sup>

### 3.2.1 24-hour dietary recall

The 24-hour dietary recall is a retrospective method of dietary assessment usually conducted by a skilled interviewer (in person or over the telephone), but it can be completed solely by a participant using an automated website or software package.<sup>2, 19-21</sup> This flexibility makes the 24-



hour dietary recall suitable for a range of participants including those with low literacy and people with mental and physical disabilities.<sup>1</sup>

Typically, the interviewer follows a standardised format to prompt participants to recall all foods and beverages consumed over the previous 24-hours. The 24-hour period is usually reviewed multiple times to elicit further information from the participant, and this is referred to as the multiple pass 24-hour dietary recall (MP24). As described above, dietary recalls also allow some contextual information on each eating episode to be recorded, such as location (discussed in section 3.2).<sup>11</sup> The retrospective nature of dietary recalls places a reduced burden on participants compared to the FR, as there is no need to record any information prior to the assessment, and this therefore reduces the possibility of participants to change their dietary behaviour.<sup>1</sup>

Research-specific software is not required to conduct the 24-hour dietary recall interview but is commonly used in large-scale research to help standardise data collection and reduce the burden of analysis.<sup>23, 86, 92</sup> The United States Department of Agriculture (USDA) developed the Automated Multiple Pass Method (AMPM)<sup>24, 86</sup> for use in The National Health and Nutrition Examination Survey (NHANES), which uses five distinct steps (see **Figure 3**). The first step asks participants to recall all the foods and beverages consumed for the previous day. The second step encourages additional information with a “forgotten foods” list to prompt recall of unreported foods. Successive passes gather additional details, such as time and occasion, food brand, portion size, method of cooking, and condiments added. A final review is then conducted to check all the information is correct.

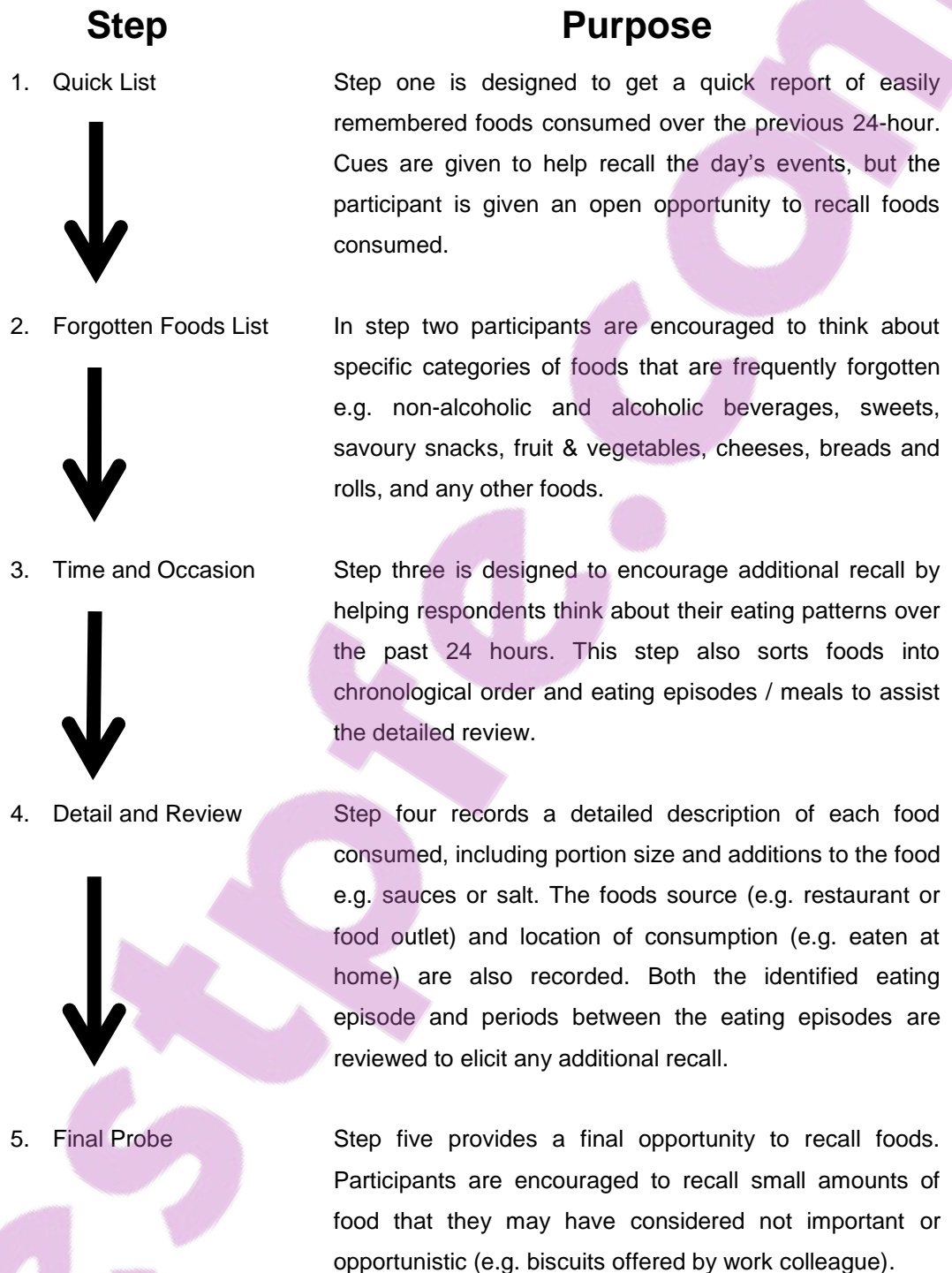
Nutrition surveillance programmes in N.Z. and Australia incorporate the MP24 and have adopted the method using bespoke software but differ slightly in the number of steps and details collected at each successive step.<sup>25 23, 93</sup> In N.Z., the LINZ24 MP24 software developed by the University of Otago has been used in two previous adult national nutrition surveys (NNS97 and ANS 08/9).<sup>23, 94</sup> The LINZ24 system was also adapted for use in the 1995 Australian National Nutrition Survey,<sup>93</sup> but Australia recently developed their own system based on the USDA AMPM for the most recent Australian Healthy Survey 2011/13.<sup>25</sup>

Software has also been developed to assist 24-hour dietary recalls for a range of both large and small scale research. An early example is EPIC-SOFT developed for the European Prospective Investigation into Cancer and Nutrition, used to standardise the 24-hour dietary recall procedures across 23 different research centres in 12 European countries.<sup>92</sup> Similar to other software, EPIC-

SOFT assists an interviewer to follow the structured method and consists of a quick list followed by detailed steps and probing questions to gather further details.<sup>92</sup> For small scale research some nutrient analysis software packages, used to convert foods into energy and nutrients (discussed in section **3.4.1**), include a 24-hour recall feature to assist researchers. More recently, web-based systems have been developed (for both large and small scale research), such as the National Cancer Institute ASA24, which can be easily modified for any country.<sup>20</sup>

#### **3.2.1.1. Limitations of the 24-hour dietary recall**

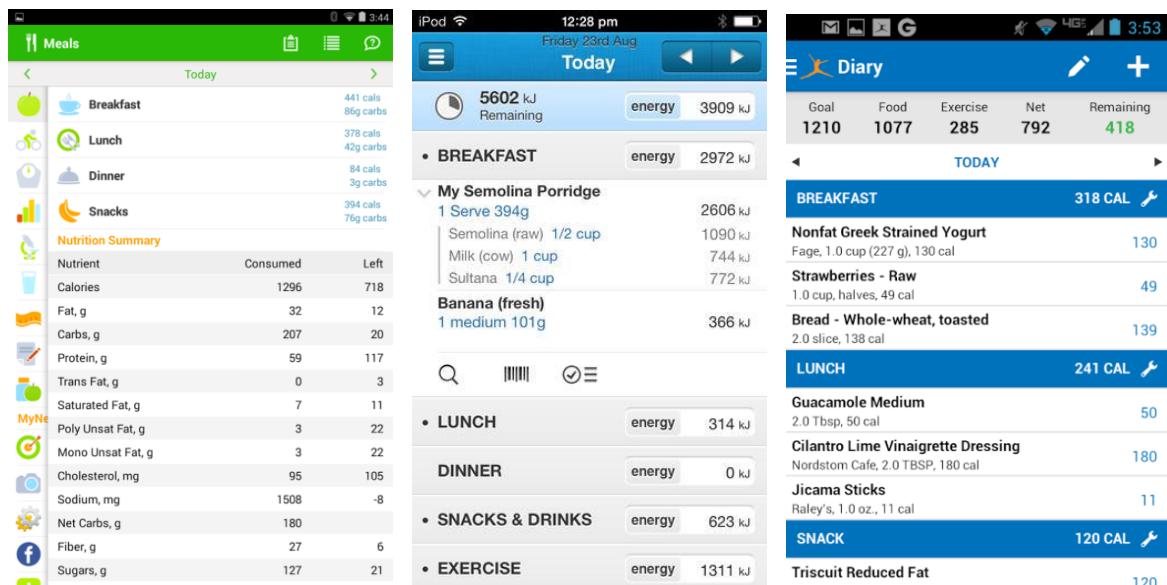
Due to the wide variation in an individual's daily dietary intake, use of a single 24-hour recall is only appropriate to describe the average dietary intake of a group, not individuals.<sup>1, 95</sup> As a retrospective method, the portion size of foods and beverages must be estimated, and details regarding the brand and variety may be forgotten or misreported. Moreover, the accuracy of the recall can be affected by interviewer bias and social desirability bias (discussed in section **3.4**).<sup>2,</sup>  
<sup>96</sup> Overall, the data obtained from the 24-hour recall method usually under-estimates dietary intake, especially amongst the elderly, women and overweight/obese respondents (specific details regarding the validity of the 24-hour dietary recall are presented in section **3.5**).<sup>8, 9, 70, 73, 97</sup>



**Figure 3 Outline of United States Department of Agriculture five step multiple pass 24-hour dietary recall method.** <sup>86</sup>

### 3.3. Food record

The FR is a self-reported prospective record of all food consumed by a person over a given time period (usually 3 to 7 days), and is used widely in community and clinical settings, and small and large-scale nutrition research.<sup>1,2</sup> Typically, participants are required to record everything they eat or drink for 1 to 7 days. Quantities of foods and beverages recorded are either weighed or estimated (using portion size guides) and training is usually provided to ensure thorough records are kept.<sup>1</sup> Traditionally, FR's were completed by participants using pen and paper in booklets. An example of the FR booklet used for the National Diet and Nutrition Survey (NDNS) in the United Kingdom (U.K.) is presented in **Figure 5**.<sup>98</sup> However, electronic food records have been developed for hand-held devices, personal digital assistants (PDAs), smartphones and tablet computers.<sup>99-101</sup> More recently consumer friendly FR apps have been developed for smartphones, such as MyNetDiary, Easy Diet Diary, and My Fitness Pal shown in **Figure 4**.



**Figure 4** Screenshots food record software applications for handheld devices, MyNetDiary, Easy Diet Dairy, and My Fitness Pal.

As the FR is the only method of dietary assessment which attempts to record dietary intake prospectively (at the time food is consumed), the FR has been referred to as the gold standard measure (seven-day weighed FR) and is used as a reference method to validate other methods of dietary assessment.<sup>1</sup> However, the data obtained from the FR is far from optimal, as discussed in section 3.3.1.1.

As described above in section 3.2, the prospective nature of the FR makes it suitable to record the context of eating episodes, and is the recommended choice in research of human eating and nutrition behaviours in free-living settings.<sup>85, 87, 88</sup> Moreover, since 2008 the NDNS has included an extra column in the FR booklet for participants to record contextual information on the location (where?), whether there was social interaction (with whom?), whether television was viewed (TV on?), and seating position (at table?) of the eating episode (see **Figure 5**).<sup>85</sup>

Day: Thurs		Date: 29 <sup>th</sup> June 2014		
Time	Where? With whom? TV on? At table?	Food & drink Description	Brand Name	Portion size or quantity eaten
<b>6am to 9am</b>				
6:30am	Kitchen Alone No TV Not Table at	Filter Coffee, decaffeinated Milk (fresh, trim) Sugar white	Nescafe Anchor	250ml 10ml 1 tsp
7:30am	Kitchen Partner TV on At Table	Filter coffee with milk and sugar Cornflakes Milk (fresh, trim) Toast, Multigrain Marmite	As above  Kellogg's Anchor Tip Top Sanitarium	As above  Bowl (3/4 cup) ½ cup 1 Slice 1 heaped tsp
12:00	At work Alone No TV At Desk	Banana Yoghurt  Coke	Fresh Yoplait – Lite berry Zero	Medium 1 tub  1 x355ml can
<b>9am to 12 noon</b>				

**Figure 5 Example of an estimated food record booklet, adapted from the NDNS with an additional column for contextual information: Where? With whom? TV on? At table? <sup>85</sup>**



### 3.3.1.1. Limitations of the food record

Similar to the 24-hour dietary recall the FR is self-reported without any means to objectively verify dietary intake (at the time of assessment). Moreover, 1-day FRs like 24-hour dietary recalls are only appropriate to describe the average dietary intake of a group, not individuals, due to the wide variation in an individual's daily dietary intake.<sup>1,95</sup> A selection bias (non-response) is possible as participants must be literate, and a high burden is placed on participants due to the level of detail, concentration, and time required for completion of the FR correctly.<sup>1, 102</sup> Investigations have demonstrated that the quality of the data obtained from FRs diminishes over successive days of assessment.<sup>2, 102</sup> Early studies using electronic food records revealed the majority of participants record their meals between 3-6 hours after consumption, thus the FR can still be prone to similar limitations of retrospective methods i.e. memory lapses, and incorrect estimation of portion sizes.<sup>103</sup> The prospective design of the FR is also prone to respondent biases such as changes in dietary behaviour, under-recording of food intake, and forgetting to record foods.<sup>104</sup> Together, these limitations affect the quality of the data obtained when using FRs, and often result in under-estimation of dietary intake.<sup>8, 9</sup> Specific details on validity of the FR method are presented in section 3.5.

### 3.3.2 Food frequency questionnaires

Food frequency questionnaires assess the frequency with which certain foods are consumed over a standard period of time (e.g. one month), using questions such as "how often over the past month did you eat fish"? A limited number of possible responses are available. The FFQ was traditionally an interviewer-led or self-administered paper-based questionnaire, but can be completed by a parent or caregiver proxy, or conducted over the telephone, or the internet.<sup>2</sup> A FFQ designed to assess the full diet usually contains approximately 120-180 pre-specified food items (questions) but can be shortened to focus on specific nutrients and food groups.<sup>105, 106</sup> The frequency at which certain foods are consumed can be used to rank individuals according to nutrient intake, or monitor changes in usual intake, and semi-quantitative FFQs that incorporate portion size questions also allow estimates of energy and nutrient intakes to be derived.<sup>1, 107</sup> The strength of the FFQ is therefore its ability to assess a participant's habitual intake of foods, and is also better suited to capture intake of episodically consumed foods/seasonal foods such as, strawberries or mandarins. Further, being a retrospective method, it does not influence dietary

behaviours like the FR (though participants can still misreport intake).<sup>1</sup> Moreover, FFQ has a low participant burden compared to the FR, and the limited number of pre-specified responses make the FFQ easy to analyse compared to other methods.<sup>1, 2</sup> These attributes make the FFQ a popular choice in dietary surveillance programmes, diet-related intervention studies, and prospective and retrospective research investigating diet and disease relationships.<sup>2, 107</sup>

### **3.3.2.1. Limitations of food frequency questionnaires**

Food frequency questionnaires lack accuracy compared to other methods, as many details regarding dietary intake are not captured by the limited possible responses. Respondent biases and memory lapses are problematic, as it can be challenging to estimate how frequently certain foods are consumed, especially with foods only eaten occasionally.<sup>1</sup> Further inaccuracies result from incomplete lists of foods in the questionnaire, and FFQ must be tailored and validated for specific population groups, otherwise it may not contain the most appropriate and commonly consumed foods for the population assessed. Therefore, data obtained from the FFQ method should only be considered an approximation.<sup>1, 2</sup> Additionally, information on context cannot be recorded as the FFQ captures information on habitual dietary intake, not specific eating episodes.

### **3.3.3 Diet history**

The DH method is usually conducted by a skilled interviewer and comprises a range of questions, which can vary depending on the exact technique used, to assess an individual's historical and habitual dietary intake.<sup>108-110</sup> However, computer-assisted systems for automated self-report have also been developed.<sup>111</sup> The DH typically obtains information on commonly consumed meals and snacks, cooking methods, and the frequency with which certain foods and food groups are consumed.<sup>1, 2</sup> The major strength of the DH is the assessment of habitual intake, rather than daily intake, as assessed by the 24-hour recall and FR. Therefore, the DH is a popular method for dietitians and nutritionists in clinical and community settings,<sup>1</sup> but in recent years has become less common in nutrition research, and is not commonly used in dietary surveillance programmes due to the limitations discussed below.

#### **3.3.3.1. Limitations of a diet history**

Substantial interviewer biases may arise due to the variability of skills and techniques used to obtain dietary intake information, and the lack of standardisation can make comparisons between

studies challenging.<sup>1, 96</sup> Respondent biases are also problematic as many judgements are required regarding the frequency of consumption of different meals or food.<sup>1</sup> Social desirability biases may affect reported intake during the interview, and, as it is a retrospective method, lapses in memory may cause further errors.<sup>2, 96</sup> The validity of different DH techniques is also hard to assess as there is no independent reference measure for habitual intake.<sup>1, 28</sup> Additionally, information on context cannot be obtained as the DH assesses habitual dietary intake, not details of specific eating episodes.

### **3.4. Sources of error in dietary assessment**

There are many potential sources of error in dietary assessment that can be random or systematic.<sup>96</sup> Random errors occur with all respondents/participants but can be minimised by increasing the number of observations and/or days diet is assessed.<sup>8, 84</sup> In contrast, systematic errors may be associated with particular respondent/participant characteristics (e.g. among people with obesity), with certain foods (e.g. socially undesirable snack foods), or with specific interviewers conducting the dietary assessment.<sup>84</sup>

Extensive work has been conducted to help minimise the potential sources of error in dietary assessment. These include standardising data collection with software and websites,<sup>19</sup> and developing sophisticated portion size guides<sup>22, 27</sup> or food atlases (books that contain images of commonly eaten foods in various portion sizes).<sup>112</sup> However, the traditional methods still rely on self-report without the ability to verify intake,<sup>112, 113</sup> therefore systematic biases in dietary studies are problematic.<sup>1, 84, 114</sup> The common sources of measurement error are briefly described below.

#### **Non-response bias**

Non-response or selection bias may arise from use of a sample that does not reflect the population of interest. This can occur due to restraints of the research design, recruitment method, or resources.<sup>96</sup> Moreover, the associated burden of dietary recording for participants can cause a reduced response rate,<sup>115, 116</sup> and therefore people who do choose to participate may not reflect the population of interest.

#### **Respondent bias**

Respondent bias may occur if a participant provides socially desirable answers to avoid criticism (social desirability and approval biases), under or over-reports food intake, or changes dietary



behaviours during the period of assessment, thereby altering dietary intake. The psychosocial and behavioural characteristics related to respondent bias have been extensively reviewed with a range of characteristics commonly associated with bias: lower leisure physical activity, increased social desirability, fear of a negative evaluation, body size dissatisfaction, recent weight loss, fluctuation of body weight, attempted weight loss in previous 12 months, eating restraint, and eating disinhibition (overeating/loss of self-control over hunger).<sup>28</sup>

### **Interviewer bias**

Interviewer bias may result if different interviewers use different techniques to probe for information to varying degrees, intentionally omit questions (to save time), or record responses incorrectly.<sup>96</sup> Thorough training regimens and audits of interviewer techniques can be used to ensure interviewer bias is minimised.<sup>117</sup> Furthermore the development of computer-assisted methods commonly used in large-scale research has helped to minimise interviewer bias.<sup>26, 86</sup>

### **Incorrect portion size**

Errors in portion size can arise in all methods of dietary assessment as participants may fail to record estimate and/or record the portion size correctly. Other errors may arise due to misconceptions of what is considered a “normal” portion size, and differences in food characteristics and volume make some foods more difficult to estimate accurately than others, such as single foods items and complex mixed dishes.<sup>96, 118 27</sup> Reduced accuracy in portion size estimation has also been shown among obese people.<sup>119</sup>

### **Supplement usage**

Food and nutrient databases usually contain a limited number of dietary supplements, but due to the number of products on the market and the large differences in dosage and ingredients, supplement intake is inherently hard to assess. The errors associated with supplement intake affect both macronutrients (e.g. protein powders or oil-based supplements) and micronutrients (e.g. vitamin and mineral products).

### **Coding errors and mixed dishes**

Coding errors are errors that arise when converting foods into nutrients due to the limited number of foods present in nutrient databases (the coding errors are discussed below in section 3.4.1.1.). Mixed dishes are problematic to assess as the specific ingredients and portions may be unknown.

### **3.4.1 Converting food to nutrients using a food composition database**

The dietary intake data (e.g. foods and beverages) recorded during dietary assessments is converted into energy and nutrient values using food composition databases. Food composition databases are usually country specific and provide the macronutrient (energy protein, carbohydrate, and fat) and micronutrient (e.g. vitamins and minerals) values of local foods. The values for every food and nutrient are derived by chemical analysis or can be estimated from other databases.<sup>120</sup> The first nutrition composition tables (paper-based) were published in 1896 by Atwater et al.<sup>121</sup> More recently, electronic formats are available for many countries and are often freely available to view online, or can be accessed and manipulated using nutrition-specific software for nutrient analysis.

There are a range of software packages available to analyse dietary intake data, but these are usually region-specific or only have access to a select number of food composition databases. The software accesses the appropriate database and codes foods and beverages weight/volume with the corresponding macronutrient and micronutrient values. In N.Z., the most common nutrient analysis software is FoodWorks (Xyris software, Queensland, Australia) and was used for the PICTURE study reported in Chapter 7. FoodWorks accesses the electronic version of the N.Z. Food Composition Database (NZFCD) called FoodFiles.<sup>122</sup> The NZFCD is N.Z.'s most comprehensive food composition database and contains information on nutrient data for 59 nutrient components of 2710 commonly consumed foods. The NZFCD is maintained by the N.Z. Institute for Plant and Food Research Limited in partnership with the Ministry of Health. In the U.K., WISP (Tinuviel Software, Warrington, United Kingdom) is a common nutrient analysis software and was used for the UK-based feasibility study reported in Chapter 6. WISP accesses the Composition of Foods Integrated Data Set, which is maintained by the Institute of Food Research in partnership with the Biotechnology and Biotechnology Sciences Research Council. The dataset contains nutrient information for 3423 foods and was last updated in 2002.<sup>123</sup> An updated version is scheduled for 2014.<sup>123</sup>

### **3.4.1.1. Sources of error associated with food composition databases**

Although food composition databases are the only method researchers can use to derive nutrient intakes from dietary data, there are several limitations of food composition databases that need to be acknowledged. Firstly, food databases only contain a limited number of foods, and thus may not contain all foods consumed by respondents. In such circumstances a similar food must be chosen. Secondly, there is a constant change in the food supply as manufacturers produce new products and reformulate existing products. Therefore, it is a challenge to keep the databases current and many manufactured foods are not included. Thirdly, seasonal variations, changes to agricultural practices and natural variability in natural and manufactured products can change the nutrient composition of foods.<sup>120, 124</sup> Fourth, coding errors may result when mixed dishes are reported (or recorded) due to the ingredients in the mixed dishes being different than the ingredients used in the food composition database. Lastly, different food composition databases vary in how foods are described, grouped and analysed. Therefore, it is difficult to make comparisons across databases and/or countries.<sup>125</sup>

## **3.5. Validity in dietary assessment**

Validity describes the degree to which a method of dietary assessment measures what it is intended to measure. Errors that affect the validity of dietary assessment methods are usually systematic.<sup>84, 126</sup> The relative or concurrent validity of a method can be assessed by comparing the method of interest with another method of dietary assessment, usually FR and 24h-hour dietary recall.<sup>84, 127</sup> However, caution must be taken when interpreting results from concurrent validation studies as no method of dietary assessment can accurately assess dietary intake in free-living settings, therefore correlated errors are almost certainly present.<sup>8-10, 18</sup>

### **3.5.1 Biomarkers**

Biomarkers provide an independent and objective measure to assess the validity of specific nutrients as assessed by dietary assessment.<sup>144, 191</sup> At present, the DLW method to assess total energy expenditure (discussed further in section **3.5.2** below), 24-hour urinary nitrogen to assess protein intake, and 24-hour urinary potassium to assess potassium intake are routinely used to validate the results of dietary assessment methods.<sup>128</sup> 24-hour urinary nitrogen is the most well-known biomarker, and is used to validate protein intake at the group level.<sup>129</sup> Metabolic studies

have demonstrated a moderate correlation between protein intake, and urinary nitrogen excretion when dietary intake is controlled.<sup>130</sup> However, its use relies on the assumption that participants are in nitrogen balance. In other words, nitrogen is not accumulated in the body due to the growth or repair of tissue, or lost due to starvation. Due to the daily variation in nitrogen excretion, multiple 24-hour periods of urine collection are usually conducted to validate protein intake estimated from dietary assessment.<sup>130, 131</sup> 24-hour urinary potassium is a suitable biomarker to assess dietary data as it is abundant in a wide range of foods and 24-hour urinary potassium is highly correlated with dietary intake.<sup>128</sup> Other urinary biomarkers (sodium and iodine), plasma biomarkers (Vitamin C,  $\beta$ -carotene, Vitamin E, and Vitamin D), serum selenium, and folacin are also used. However, these biomarkers are only weak to moderate correlates of intakes and some of the plasma biomarkers can also be affected by smoking and alcohol intake, particularly for those which are prone to oxidation (e.g. Vitamin C, tocopherols,  $\beta$ -carotene, folate), and are therefore better used as a measure of nutrition status.<sup>132</sup>

### 3.5.2 Use of doubly labelled water to assess total energy expenditure

Doubly labelled water contains two (doubly labelled) isotopes  $^2\text{H}$  and  $^{18}\text{O}$ . The isotopes occur naturally in the environment<sup>133</sup> but are concentrated for use in the DLW method, which allows them to be measured as they are turned over. Special attention to DLW water is given in this section as it is the biomarker used to validate EI in the PICTURE study (Chapter Seven). Total energy expenditure is usually assessed for a period of 7 to 15 days using the DLW method, though longer durations are possible.<sup>134</sup> A baseline urine sample is collected before a weight-specific loading dose of DLW ( $^2\text{H}_2\text{O}$  and  $\text{H}_2^{18}\text{O}$ ) is ingested orally by participants (approximately 60 to 130ml). The baseline urine sample is used to control for background levels of the isotopes  $^2\text{H}$  and  $^{18}\text{O}$  that occur naturally in the environment.<sup>133</sup> After the loading dose, urine samples are collected periodically (approximately 3 to 7 samples collected) over the testing period to measure the isotopes as they are eliminated. The isotopes are measured using ratio isotope mass spectrometry.<sup>8, 133</sup>

The labelled hydrogen deuterium ( $^2\text{H}$ ) exists in the body as water ( $^2\text{H}_2\text{O}$ ), and the labelled oxygen ( $^{18}\text{O}$ ) exists in the body as water ( $\text{H}_2^{18}\text{O}$ ) and carbon dioxide ( $\text{C}^{18}\text{O}_2$ ).<sup>135 133</sup> The  $^2\text{H}$  is eliminated through water losses in urine, respiration and sweat, and the  $^{18}\text{O}$  is eliminated through the same water losses (urine, respiration and sweat) and also as carbon dioxide in expired air (**Figure 6**).

<sup>133</sup> Total energy expenditure can be derived as the isotopes (<sup>2</sup>H and <sup>18</sup>O) are turned over at different rates. The rate of turnover is used in calculations to determine carbon dioxide production, which in turn is used to derive total energy expenditure. <sup>135</sup> <sup>133</sup> <sup>136</sup> Total energy expenditure can be used to validate EI data at a group level as the first law of thermodynamics states that energy is conserved. Therefore the energy put into a system (EI) is equal to the energy used (energy expenditure) and/or stored by the system (change in body mass). <sup>137</sup> More specific details of the methods and calculations used in this thesis are presented in the methods section of the PICTURE validation study (see section 7.5).

The DLW method was first developed in the early 1950's <sup>138</sup> but its application as a method to objectively assess total energy expenditure in free-living individuals was not demonstrated until 1982 by Schoeller and Van Santeen. <sup>139</sup> The DLW method was later validated, with comparisons to direct (whole-room calorimetry) and indirect calorimetry demonstrating non-significant differences (<1%) between methods. <sup>140</sup> It is therefore considered an accurate method to assess total energy expenditure in free-living individuals. <sup>137, 141, 142</sup> The DLW method has been used extensively as the gold standard method to evaluate EI data at a group level in nutrition research. <sup>8-10, 143</sup> However, DLW is very costly (approximately \$1000 NZD per participant excluding analysis) so is predominantly only used in studies with small of sample sizes between 5 - 50 participants; <sup>9</sup> although some larger DLW studies (N = 450+) have also been conducted. <sup>26, 131</sup>

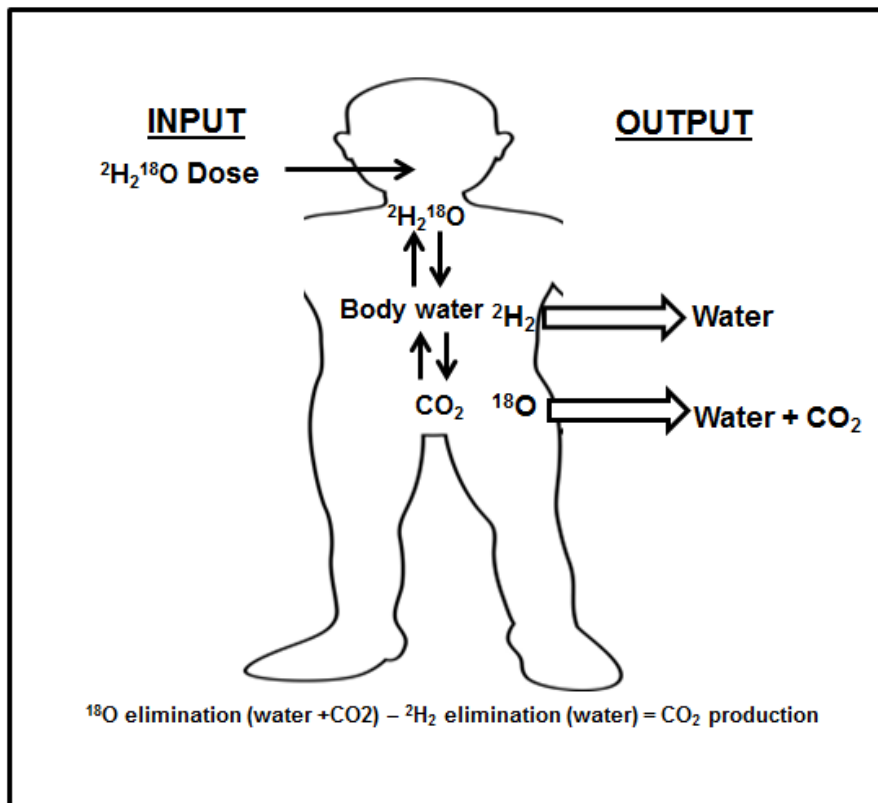


Figure 6 Elimination of doubly labelled water to assess total energy expenditure

### 3.5.3 Validity of dietary energy intake data

Studies that have evaluated EI data have demonstrated both over- and under-reporting of energy; However, only under-reporting is of major significance (only 3-4% of participants over-report).<sup>8-10, 144</sup> Under-reporting is systemic among all methods of dietary assessment and population groups, however, people of older age,<sup>70, 73, 145, 146</sup> women,<sup>70, 145, 147-149</sup> indigenous ethnicities,<sup>73, 150, 151</sup> and people with higher body weight, BMI, or waist circumference,<sup>73, 146, 152-155</sup> and people with higher energy expenditure (e.g. athletes) tend to under-report to a greater extent than others.<sup>134, 156-158</sup>

Five reviews between 1990 and 2008 have extensively compared EI data from dietary assessment methods to the DLW method, and have repeatedly demonstrated widespread under-reporting across all methods of dietary assessment.<sup>8-10, 137, 143</sup> The first review was conducted by Schoeller et al<sup>137</sup> in 1990, and included ten DLW studies. Large differences between studies in the under-reporting bias was found (+25% to -75%), especially in participants with obesity; they concluded that traditional methods of dietary assessment are not appropriate for obesity research. In 2001 Trabulsi et al<sup>143</sup> reviewed 23 DLW studies, which revealed under-reporting reporting was greater than 20% of total EI in 16 of the 23 studies and greater than 25% of total EI in 12 of the 23 studies. Compared to the DLW, no method of dietary assessment was more accurate than others. Hill et al<sup>10</sup> also conducted a review in 2001 and examined 40 DLW studies of adults, obese people, and athletes. Similarly, substantial levels of under-reporting were evident for all methods of dietary assessment for most population groups, but participants with obesity and athletes typically under-reported to a greater extent.<sup>10</sup>

Livingstone et al<sup>8</sup> reviewed 63 DLW studies in 2004, and also found a substantial under-reporting of EI. A comparison between the traditional methods of dietary assessment found all methods under-estimated EI to a similar extent. In 22 studies using weighed FR, 25 studies using estimated weighed food records, four using the DH, and six studies using 24-hour dietary recalls, EI was under-estimated by 16% ( $\pm 10\%$ ,  $\pm 14\%$ ,  $\pm 14\%$ , respectively).<sup>8</sup> Additionally, in six studies using FFQs, EI was underestimated by 13% ( $\pm 12\%$ ).<sup>8</sup> Livingstone et al<sup>8</sup> concluded that studies in which EI was reported and EE was measured using the doubly labelled water technique conclusively demonstrate widespread bias to the underestimation of EI. Polsuna et al<sup>9</sup> conducted the most recent review in 2008 and compared both the prevalence of under-reporting of EI (16 studies) and the magnitude of EI was underestimated (11 studies) using the 24-hour recall, weighed FR, and estimated FR. No differences were found between the 24-hour dietary recall,

weighed FR, and estimated FR for the prevalence of underreporting (31.0%; range 21.5%-67.5%, 33.3%; 14.0%-38.5%, and 31.0%; 11.9%-44%, respectively), or underestimation of EI (13.4% range 12.8%-14.0%; 18.0% range 10.4%-20.2%, and 12.2% range 7.2%-20.%, respectively).<sup>9</sup>

### 3.5.4 Implications of measurement error

In epidemiology the terms “measurement error” and “misclassification” refer to a discrepancy between the true value of a variable and its measured value.<sup>159</sup> There are a number of implications of measurement error: (1) nonsignificant associations in studies of diet and disease relationships (masked by attenuation and discussed further below),<sup>18, 34, 159, 160, 161</sup> (2) under-reporting that results in serious over-estimates of nutrient inadequacies,<sup>162</sup> and (3) differential under-reporting, which hinders the usefulness of dietary guidelines.<sup>163</sup>

Gibson<sup>96(p121)</sup> states that “*the existence of both random and systematic measurement errors in dietary assessment is a major challenge to the design of all types of nutritional assessment. The existence of such errors in dietary assessment can have serious consequences when interpreting data*”. With respect to the validity of dietary intake data presented in section 3.5.3 above, Willet<sup>164(p4)</sup> notes “*we assume that all errors apply equally to all cases and non-cases in an epidemiological study, that is, errors are random in relation to disease. Systematic differences in measurement error between these two groups, that is measurement errors that are biased with respect to disease, have serious consequences that are usually not amenable to correction*”.

Moreover, measurement error with respect to EI requires special consideration, as an inaccurate assessment of EI can have important implications including<sup>8, 165</sup> (1) the level of EI may be the primary determinant of disease, (2) most nutrients are positively correlated with EI thus differences in individual EI can cause variation in the intake of specific nutrients unrelated to dietary composition, and (3) EI may be associated with a disease but not its direct cause, thus the effects of specific nutrients may be distorted or confounded by EI.<sup>165</sup>

An example that demonstrates the implications of measurement error has been presented by Kipnis et al.<sup>18</sup> Data from a U.K. FFQ validation study were used to model the attenuation effect of measurement error; the analysis revealed that measurement error in the FFQ could lead to a 51% attenuation of the true nutrient effect for protein, and require a 2.3 times larger sample size than previously calculated i.e. the measurement error would substantially increase the chance of null findings. Kipnis et al.<sup>34</sup> further demonstrated the attenuating effect of measurement error in the



Observing Protein and Energy Nutrition Study (OPEN), a large biomarker validation study (n=484) in part designed to explore the implications of measurement error. The analysis revealed that the FFQ led to severe attenuation (reduced statistical power), and that the use of a 24-hour recall for a reference method for an FFQ could under-estimate attenuation by up to 60%.

Due to the implications of measurement errors, statistical approaches in handling the data and adjusting EI have been developed and intensively studied.<sup>161, 166-176</sup> However, the relative merits of the different method of energy adjustment have been vigorously debated, as assumptions regarding the nature of the data must be made, and adjustments cannot eliminate selective/systematic underreporting of foods.<sup>177 164 178-183</sup>

### **3.6. Summary**

There are many potential sources of error in dietary assessment, from the initial recording of intake to the conversion of food intake data into nutrient data. Traditional methods of dietary assessment are used widely in research but are self-reported without any objective means to verify intake. Findings of DLW studies have consistently demonstrated systematic under-reporting of EI, which is systemic among all methods of dietary assessment and population groups (though certain groups misreport to a greater extent). Such measurement error increases the chance of null findings in nutrition research towards the null hypothesis thereby masking relationships between nutrients and disease. Despite the development of sophisticated software and structured methodology to ensure consistent and thorough assessment of diet, the primary methodologies to assess dietary intake have remained the same. Livingstone and Black note that if dietary assessment is to be improved, we need to understand which foods and meals are misreported.<sup>8</sup> Therefore, research needs to address the problems of self-reporting bias, and not just improve the procedures of data collection; otherwise, the issues associated with dietary assessment will remain.

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# CHAPTER 4. UNDER-REPORTING REMAINS A KEY LIMITATION OF SELF-REPORTED DIETARY INTAKE: AN ANALYSIS OF THE 2008/09 NEW ZEALAND ADULT NUTRITION SURVEY

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## 4.1. Introduction to publication

The findings of the Adult nutrition Survey (ANS 08/9) published in November 2011 indicated the level of under-reporting of dietary EI may have increased substantially compared to the 1997 National Nutrition Survey (NNS97). Measured body weights increased by 4-5kg for men and women, but self-reported EIs were lower for men (10.7MJ, 95%CI 10.4-11.1MJ vs. 12.0MJ, 95%CI 11.7-12.2MJ) and women (7.6MJ, 95%CI 7.5-7.8MJ vs. 8.0MJ, 95%CI 7.8-8.1MJ) compared to the NNS97.<sup>65</sup> Determining the prevalence of under-reporting for dietary EI in the general population would reveal the importance of improving dietary assessment methods. This chapter (Chapter Four) is a reformatted version of the manuscript entitled “Under-reporting remains a key limitation of self-reported dietary intake: an analysis of the 2008/09 New Zealand Adult Nutrition Survey” in the *European Journal of Clinical Nutrition*, 2013, Volume 68, Issue 2, Pages 259-264. DOI: 10.1038/ejcn.2013.242. The most recent impact factor available was 2.756 (2013). A few minor revisions were made to this reformatted manuscript at the request of the thesis examiners. The chapter presents results from a retrospective statistical analysis undertaken on the datasets of the 2008/09 New Zealand Adult Nutrition Survey. The study was conducted to address Objective One of this thesis, which was to evaluate self-reported dietary EI in the 2008/9 Adult Nutrition Survey and determine the prevalence of low energy reporters.

## 4.2. Author contribution

Luke Gemming was involved in developing the research question, application for access to ANS 08/9 datasets, development of methods, and procedures completed to analyse the data. He also wrote the paper for publication.

# **UNDER-REPORTING REMAINS A KEY LIMITATION OF SELF-REPORTED DIETARY INTAKE: AN ANALYSIS OF THE 2008/09 NEW ZEALAND ADULT NUTRITION SURVEY**

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### 4.3. Abstract

**BACKGROUND/OBJECTIVES:** The most recent New Zealand Adult Nutrition Survey 2008/09 (ANS 08/9) revealed a decrease in reported EIs compared to the previous 1997 National Nutrition Survey (NNS97). Conversely, measured body weights increased over the same period. We conducted an analysis on the ANS 08/9 datasets to evaluate reported EIs.

**SUBJECTS/METHODS:** Analysis was conducted on data from 3919 (1715 men and 2204 women aged  $\geq 15$  yrs) survey participants who completed the 24-hour dietary recall in the ANS 08/9. Under-reporting was assessed using the ratio of reported EI to estimated resting metabolic rate ( $EI:RMR_{est}$ ), and a cut-off limit of  $<0.9$  ( $EI:RMR_{est}$ ) was used to identify low energy reporters (LERs). Results were examined by gender, body size, age and ethnicity.

**RESULTS:** The mean  $EI:RMR_{est}$  (SEM) was 1.34 (0.02) for men, and 1.23 (0.02) women. Overall, 21% of men and 25% of women were classified as LERs. There was a greater prevalence of LERs among people with overweight (25%), or obesity (30%) than people with normal body weight (16%,  $p < 0.001$ ). The oldest age group ( $\geq 65$  yrs) had a greater prevalence of LERs (33%) compared to all other age groups (19-24%,  $p < 0.001$ ). Pacific people had a greater prevalence of LERs (33%) compared to Maori (26%,  $p = 0.007$ ) and European (23%,  $p < 0.001$ ). Compared with the NNS97, a substantial increase in the prevalence of LERs was evident in most subgroups.

**CONCLUSIONS:** Under-reporting of EI will continue to be a major limitation of nutrition surveys without technological innovation. Care should be taken when interpreting EI data.

**KEYWORDS** Nutrition Assessment, Low Energy Reporters, Under-Reporting, Dietary Surveys, 24-hour Dietary Recall

## 4.4. Introduction

Under-reporting of total energy intake (EI) is a common and acknowledged source of measurement error in dietary assessment.<sup>8, 9</sup> Many factors contribute to under-reporting, but respondent biases (e.g. social desirability) and memory lapses are probable sources not easily addressed.

The gold standard method to assess the validity of EI data post hoc is with the doubly labelled water (DLW) technique to accurately measure total energy expenditure.<sup>8, 135, 140</sup> However, due to the prohibitive expense of DLW, under-reporting is most commonly assessed in large samples by estimating basal metabolic rate (BMR) and applying Goldberg cut-off values.<sup>9, 184</sup> The Goldberg cut-offs were derived using evidence from whole-body calorimetry and DLW studies, and take into account typical physical activity levels (PAL) to assign minimum EI to BMR values (EI:BMR).<sup>184, 185</sup> The cut-off values assess if the EI data recorded is a plausible measure of EI during the measurement period and can be used to estimate the prevalence of low energy reporters (LERs).

In 2011, findings of The New Zealand Adult Nutrition Survey 2008-09 (ANS 08/9), which included a nationally representative sample (n=4258) of adults aged 15yrs and over, were released. The survey used a multiple pass 24-hour dietary recall and, compared with the previous 1997 National Nutrition Survey (NNS97), reported a significant decrease in self-reported EI for men 10.7MJ (95%CI 10.4-11.1MJ) vs. 12.0MJ (95%CI 11.7-12.2MJ), and a non-significant decrease for women 7.6MJ (95%CI 7.5-7.8MJ) vs. 8.0MJ (95%CI 7.8-8.1MJ), respectively.<sup>65</sup> Conversely, a significant rise was recorded in measured mean body weights of approximately 4-5kg for men and women, of all ethnicities, compared with the NNS97.

Controlled feeding, metabolic, and modelling studies have demonstrated a strong relationship between body weight and EI.<sup>186-189</sup> Therefore, to investigate the paradox of decreased EI in parallel with increased body weight we undertook analysis of the ANS 08/9 data using the Goldberg cut-offs, and estimated the prevalence of LERs by gender, body size (normal, overweight, obese), age, and ethnicity. These findings were compared to a previous analysis of the NNS97 dataset, to observe time trends in under-reporting.<sup>73</sup>

## 4.5. Methods

The ANS 08/9 was conducted by the University of Otago, using a computer-based interviewer-assisted three pass (multiple-pass) 24-hour dietary recall method.<sup>23, 65</sup> The study was completed between October 2008 to October 2009, and a total of 4721 participants (2066 men and 2655 women) aged 15yrs and over completed the survey.<sup>23, 65</sup> To permit equivalent comparisons between the ANS 08/9 and the NNS97 we followed a similar methodology to Pikholtz et al<sup>73</sup> to evaluate reported EIs and estimate the prevalence of LERs (surveys compared in the discussion).

The ANS 08/9 datasets which consisted of participant characteristics, anthropometry, and 24-hour recall nutrient data were first merged. Participants were excluded if data from key variables, such as height or weight were missing. Chinese, Indians and the “Other” (ethnic) group (Dutch, Japanese, Tokelauan) were also excluded due to small participant numbers and mixed ethnicity. After these exclusions a total of 3919 participants (1715 men and 2204 women) remained for the analysis.

A body size variable was created by grouping BMI into three categories: normal weight, overweight, and obese. BMI ranges used were those recommended by the World Health organization (WHO) for all adults over 18 years of age as follows: normal weight = BMI < 25 kg/m<sup>2</sup>, overweight = BMI ≥ 25 kg/m<sup>2</sup> to BMI < 30 kg/m<sup>2</sup>, obese = BMI ≥ 30 kg/m<sup>2</sup>.<sup>190</sup> The International Obesity Taskforce (IOTF) cut-offs for children and adolescents were applied for all participants aged 15-18yrs.<sup>191, 192</sup> A second body size variable was created to allow comparison with the NNS97 analysis of under-reporting which used the following ethnic-specific cut-offs for (1) NZ Europeans: normal weight = BMI < 25 kg/m<sup>2</sup>, overweight = BMI ≥ 25 kg/m<sup>2</sup> to BMI < 30 kg/m<sup>2</sup>, obese = BMI ≥ 30 kg/m<sup>2</sup>, and (2) for Maori and Pacific people: normal weight = BMI < 26 kg/m<sup>2</sup>, overweight = BMI ≥ 26 kg/m<sup>2</sup> to BMI < 32 kg/m<sup>2</sup>, obese = BMI ≥ 32 kg/m<sup>2</sup>.<sup>193</sup> Prior to 2006 ethnic specific cut-offs were commonly used in New Zealand as dual x-ray absorptiometry (DEXA) revealed Polynesians (Maori and Samoans) had a significantly greater ratio of lean muscle mass : fat mass compared to New Zealand Europeans.<sup>194</sup> Post 2006 New Zealand aligned national BMI classifications with WHO recommendations to allow comparison with other nations.<sup>195</sup> Ethnicity was self-identified.<sup>23</sup>

Several steps were performed to estimate resting metabolic rate (RMR<sub>est</sub>). Using equations derived by Swinburn et al<sup>194</sup> fat mass (FM, in kg) was calculated from BMI for N.Z. European,

Maori, and Pacific males and females (Samoan equations were used for the whole Pacific ethnic group). Fat free mass (FFM, in kg) was then calculated by subtracting fat mass from weight. Lastly, an equation taken from Bogardus et al <sup>186</sup> was used to calculate  $RMR_{est}$  ( $RMR_{est}$  (kilocalories per day) =  $(22.8 \times FFM) + 489$ ). The unit for energy (kilocalories per day) was converted into kilojoules per day by multiplying by the conversion factor 4.184.

The ratio between reported EI and  $RMR_{est}$  (EI: $RMR_{est}$ ) was calculated by dividing EI by  $RMR_{est}$ . Cut-off values taken from work conducted by Goldberg et al <sup>184</sup> were used to evaluate EI data. Goldberg et al <sup>184</sup> used estimated basal metabolic rate ( $BMR_{est}$ ) predicted from the Schofield equation, <sup>196</sup> where this analysis substituted  $RMR_{est}$  for  $BMR_{est}$  as they are nearly identical. EI: $BMR_{est}$  cut-off values vary according to the sample size and number of days dietary intake is measured. This analysis used the 95<sup>th</sup> percentile lower cut-off value for one-day of dietary intake (as data were from a single 24-hour dietary recall) to classify LERs for individuals and population subgroups (gender, body size, age, and ethnicity). The cut-off values range from 0.9 for one person, to 1.53 for 2000 people (based on one day of dietary intake). <sup>184</sup> Thus the cut-off limit of  $<0.9$  EI: $RMR_{est}$  was used to classify individuals as LERs and higher cut-off values (1.50-1.53 dependant on  $n$ ) were used to assess the mean EI: $RMR_{est}$  for subgroups. Individuals with a  $EI:RMR_{est} \geq 0.9$  were considered adequate reporters for the purpose of this analysis, but likely comprise a mixture of possible LERs, adequate energy reporters (AER), and high energy reporters (HER).<sup>144</sup>

The ANS 08/9 used a multi-stage, stratified, probability-proportional-to-size sample design, and over-sampled Maori, Pacific people, and some age groups with a three-step selection process by meshblocks, dwellings from within each meshblock, and respondents within households. The weights were calculated for every survey participant to ensure no group was under - or over - represented in estimates from the survey. 100 replicate weights were produced for every respondent in the sample. <sup>23</sup> The standard error of the population estimate is based on the variation of the replicate estimates. Weighted means and standard errors of the mean (SEM)  $EI:RMR_{est}$  were calculated using linear regression models with both unadjusted and adjusted analyses, controlling for the effect of important confounders (body size, age, ethnicity). Same survey weighted estimates were calculated for the percentages of LERs, taking into account the unequal selection probabilities. Differences between subgroups were tested using the standard t-test. Since this was a national survey to generate population level estimates, no multiple

comparisons were considered. Statistical package SAS Version 9.3 (SAS Institute Inc, Cary, NC) and R version 2.15 (R Foundations for Statistical Computing, Auckland, New Zealand) were used. Threshold for significance was set at  $\alpha < 0.01$ .

## 4.6. Results

**Table 4** presents the population estimates of important participant characteristics by subgroups, using the data collected from all 3919 participants. The clear differences in age, body weights and BMI between ethnicities have been previously reported.<sup>65</sup> Though, noteworthy ethnic differences include, Europeans 8 - 10yrs older on average than Maori and Pacific people, and more than double the prevalence of obesity among Pacific people compared to Europeans.

The mean EI:RMR<sub>est</sub> (SEM) values are presented in **Table 5** for the total population and subgroups. The mean EI:RMR<sub>est</sub> for all participants of 1.28 (0.01) were below the suggested cut-off value of 1.53 (measurement of one-day; 1 x 24-hour dietary recall) and all subgroups were below the suggested cut-off values which ranged from 1.50 to 1.53 (see **Table 4** legend and Goldberg et al<sup>184</sup> for suggested cut-off values).

Regarding body size, no differences were observed among men but women with overweight, and obesity had a lower mean EI:RMR<sub>est</sub> of 1.18 (0.03), and 1.13 (0.03) compared to women with normal weight 1.28 (0.03) respectively ( $p=0.003$  and  $p<0.001$ , adjusted for age, and ethnicity). Regarding age, the mean EI:RMR<sub>est</sub> for men 1.08 (0.04) and women 1.05 (0.03) aged  $\geq 65$ yrs were lower than all other age groups, 1.26 (0.05) to 1.41 (0.05), and 1.19 (0.03) to 1.31 (0.04) respectively ( $p\leq 0.002$  and  $P\leq 0.001$ , adjusted for ethnicity and body size). With respect to ethnicity there were no significant differences in the group mean EI:RMR<sub>est</sub> among men, or among women.



**Table 4 Baseline characteristics of participants\***

Characteristics	Gender	European	Maori	Pacific	All	
<b>Number</b>	<b>Male</b>	1013	388	314	1715	
	<b>Female</b>	1273	588	343	2204	
<b>Age (yrs), mean (SEM)</b>	<b>Male</b>	46.0 (0.37)	36.7 (0.27)	36.5 (0.38)	44.3 (0.28)	
	<b>Female</b>	47.1 (0.31)	37.8 (0.29)	37.9 (0.39)	45.3 (0.25)	
<b>Height (cm), mean (SEM)</b>	<b>Male</b>	176.1	175.0	176.2	176.0	
		(0.29)	(0.37)	(0.50)	(0.23)	
	<b>Female</b>	162.5	163.4	163.7	162.7	
		(0.25)	(0.33)	(0.37)	(0.21)	
<b>Weight (kg), mean (SEM)</b>	<b>Male</b>	84.6 (0.68)	91.6 (1.26)	98.0 (1.50)	86.3 (0.57)	
	<b>Female</b>	71.7 (0.59)	81.8 (1.04)	88.3 (1.29)	74.0 (0.52)	
<b>BMI (kg/m<sup>2</sup>, mean (SEM))</b>	<b>Male</b>	27.3 (0.21)	29.9 (0.37)	31.5 (0.45)	27.9 (0.18)	
	<b>Female</b>	27.1 (0.23)	30.7 (0.40)	33.0 (0.45)	28.0 (0.20)	
<b>Body Size WHO/IOTF § n (%)**</b>						
<b>Normal</b>	<b>Male</b>	356 (35.1)	74 (19.1)	†27 (8.6)	457 (26.6)	
	<b>Female</b>	525 (41.2)	130 (22.1)	†43 (12.5)	698 (31.7)	
<b>Overweight</b>	<b>Male</b>	421 (41.6)	153 (39.4)	89 (28.3)	663 (38.7)	
	<b>Female</b>	440 (34.6)	170 (28.9)	89 (25.9)	699 (31.7)	
<b>Obese</b>	<b>Male</b>	236 (23.3)	161 (41.5)	198 (63.1)	595 (34.7)	
	<b>Female</b>	308 (24.0)	288 (49.0)	211 (61.5)	807 (36.6)	
<b>Body Size § n (%) **</b>						
<b>Swinburn</b>	<b>Normal</b>	<b>Male</b>	369 (36.4)	104 (26.8)	†43 (13.7)	516 (30.1)
	<b>Female</b>	530 (41.6)	167 (28.4)	58 (16.9)	755 (34.3)	
<b>Overweight</b>	<b>Male</b>	411 (40.6)	163 (42.0)	102 (32.5)	676 (39.4)	
	<b>Female</b>	437 (34.3)	201 (34.2)	112 (32.7)	750 (34.0)	
<b>Obese</b>	<b>Male</b>	233 (23.0)	121 (31.2)	169 (53.8)	523 (30.5)	
	<b>Female</b>	306 (24.0)	220 (37.4)	173 (50.4)	699 (31.7)	

BMI = Body mass index, SEM = standard error of the mean.

\*The unequal selection probabilities have been taken into account.

\*\*Percentages relate to body size in each ethnic and gender subgroup (i.e. male: % normal + % overweight + % obese = 100%).

†Limited sample size within that cell, n<50, and data should be interpreted with caution.

§ See methods for definitions.



**Table 5 Ratio of reported energy intake to estimate resting metabolic rate (EI:RMR<sub>est</sub>)\***

Characteristics		Male	Female	All
<b>All: mean(SEM)</b>		1.34 (0.02)	1.23 (0.02)	1.28 (0.01)
<b>Ethnicity: †</b> <b>mean (SEM)</b>	<b>European:</b>	1.31 (0.02)	1.22 (0.02)	1.27 (0.02)
	<b>Maori:</b>	1.36 (0.04)	1.17 (0.03)	1.26 (0.03)
	<b>Pacific:</b>	1.21 (0.06)	1.19 (0.04)	1.20 (0.03)
<b>Age (yrs): ‡</b> <b>mean (SEM)</b>	<b>15-29:</b>	1.41 <sup>a</sup> (0.05)	1.31 <sup>a</sup> (0.04)	1.35 <sup>a</sup> (0.03)
	<b>30-39:</b>	1.40 <sup>a</sup> (0.05)	1.21 <sup>a</sup> (0.04)	1.29 <sup>a,b</sup> (0.03)
	<b>40-49:</b>	1.38 <sup>a</sup> (0.05)	1.21 <sup>a</sup> (0.04)	1.29 <sup>a,b</sup> (0.03)
	<b>50-56:</b>	1.26 <sup>a</sup> (0.05)	1.19 <sup>a</sup> (0.03)	1.22 <sup>b</sup> (0.03)
	<b>≥65:</b>	1.08 <sup>b</sup> (0.04)	1.05 <sup>b</sup> (0.03)	1.06 <sup>c</sup> (0.02)
<b>Body Size: IOTF §</b> <b>mean (SEM)</b>	<b>normal:</b>	1.34 (0.05)	1.28 <sup>a</sup> (0.03)	1.32 <sup>a</sup> (0.03)
	<b>overweight:</b>	1.30 (0.04)	1.18 <sup>b</sup> (0.03)	1.24 <sup>a,b</sup> (0.02)
	<b>obese:</b>	1.23 (0.03)	1.13 <sup>b</sup> (0.03)	1.18 <sup>b</sup> (0.02)
<b>Body Size: Swinburn§</b> <b>mean (SEM)</b>	<b>normal:</b>	1.32 (0.05)	1.26 <sup>a</sup> (0.03)	1.30 <sup>a</sup> (0.03)
	<b>overweight:</b>	1.30 (0.03)	1.17 <sup>a</sup> (0.02)	1.23 <sup>a,b</sup> (0.02)
	<b>obese:</b>	1.23 (0.04)	1.13 <sup>b</sup> (0.03)	1.18 <sup>b</sup> (0.02)

\*The unequal selection probabilities have been taken into account.

†Adjusted for age and body size (and gender for the last column 'all').

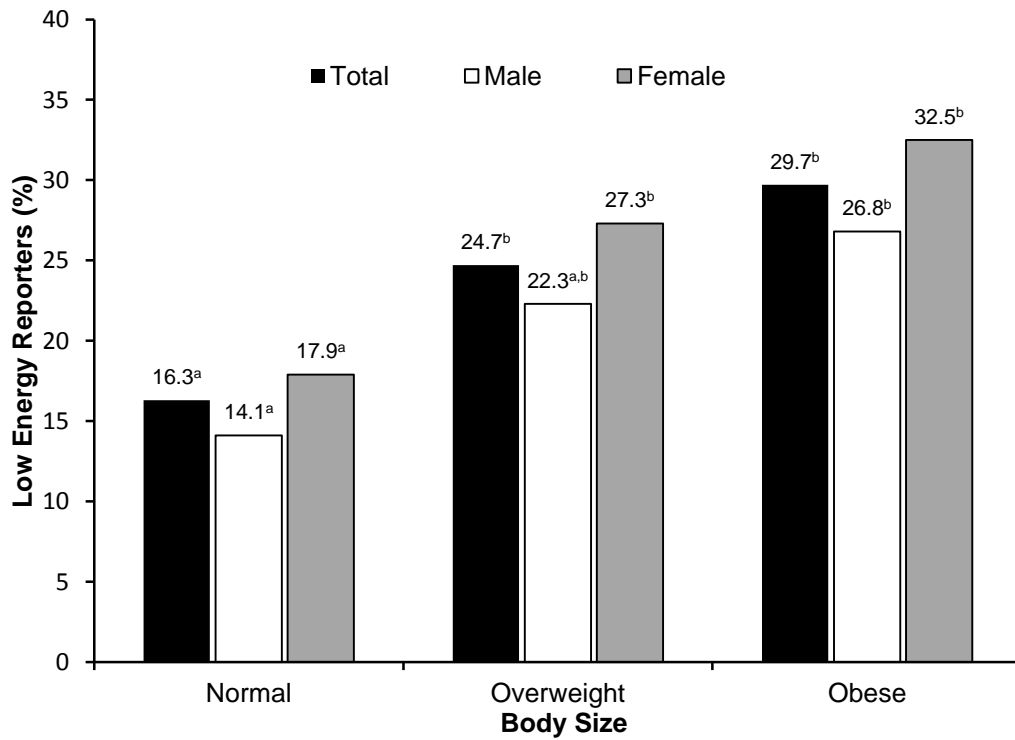
‡Adjusted for ethnicity and body size (and gender for the last column 'all').

§ Adjusted for ethnicity and age (and gender for the last column 'all'). See methods for definitions.

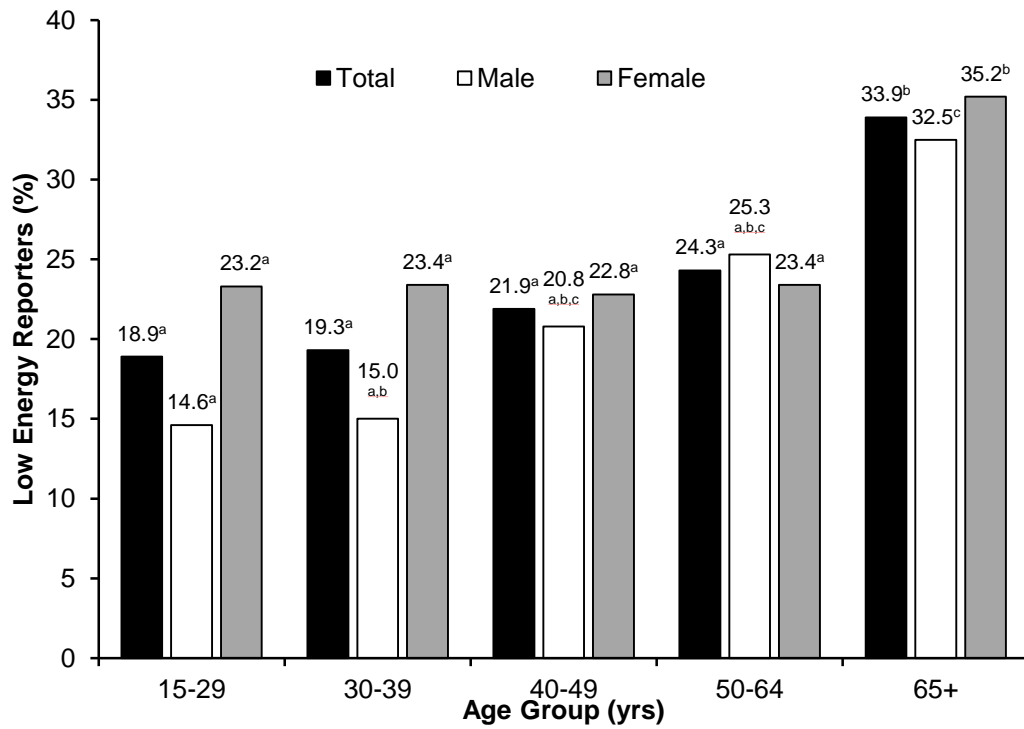
a, b, c, and d = values for each population characteristic in the same column with different superscript letters are significantly different from each other, P<0.01.

Suggested cut-off values taken from Goldberg et al<sup>134</sup> for *n* and one day of dietary intake with 95% confidence limits (Male 1.52; Female 1.52; European 1.52; Maori men 1.51; Maori women 1.52; Pacific people 1.50).

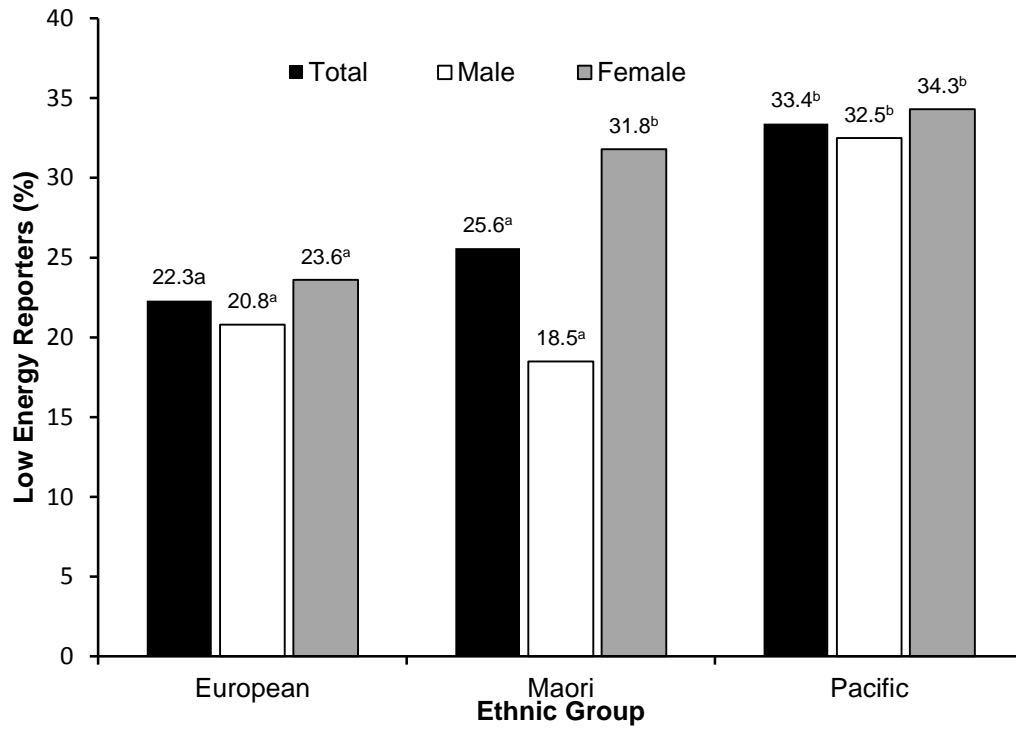
Using the cut-off limit  $<0.9$  applied to individual  $EI:RMR_{est}$  values the overall prevalence of LERs was 23.0%; with men 21.0%, and women 25.0%. The proportions of LERs by subgroups (ethnicity, age and body size) are presented in **Figure 7** to **Figure 9**. **Figure 7** presents the prevalence of LERs using the WHO IOTF classifications for body size (see methods). The prevalence of LERs among men with obesity was 12.7% greater than men with normal body weight ( $p<0.001$ ), and the prevalence of LERs among women with overweight, and obesity was 9.4% and 14.6% greater than women with normal body weight, respectively (both  $p<0.001$ ). **Figure 8** shows the prevalence of LERs among men aged  $\geq 65$  yrs was 17.5% and 20.6% greater than among men aged 15-29 yrs and 30-39 yrs, respectively (both  $p<0.001$ ). Furthermore the prevalence of LERs among women aged  $\geq 65$  yrs was  $\geq 11.8\%$  greater than all other age groups ( $p\leq 0.007$ ). **Figure 9** shows the prevalence of LERs among Pacific men was 11.7% ( $p=0.001$ ) and 14.0% ( $p=0.007$ ) greater than among Maori and European men, respectively. Moreover, the prevalence of LERs among Pacific and Maori women was 10.7% and 8.2% greater than among European women (both  $p=0.003$ ).



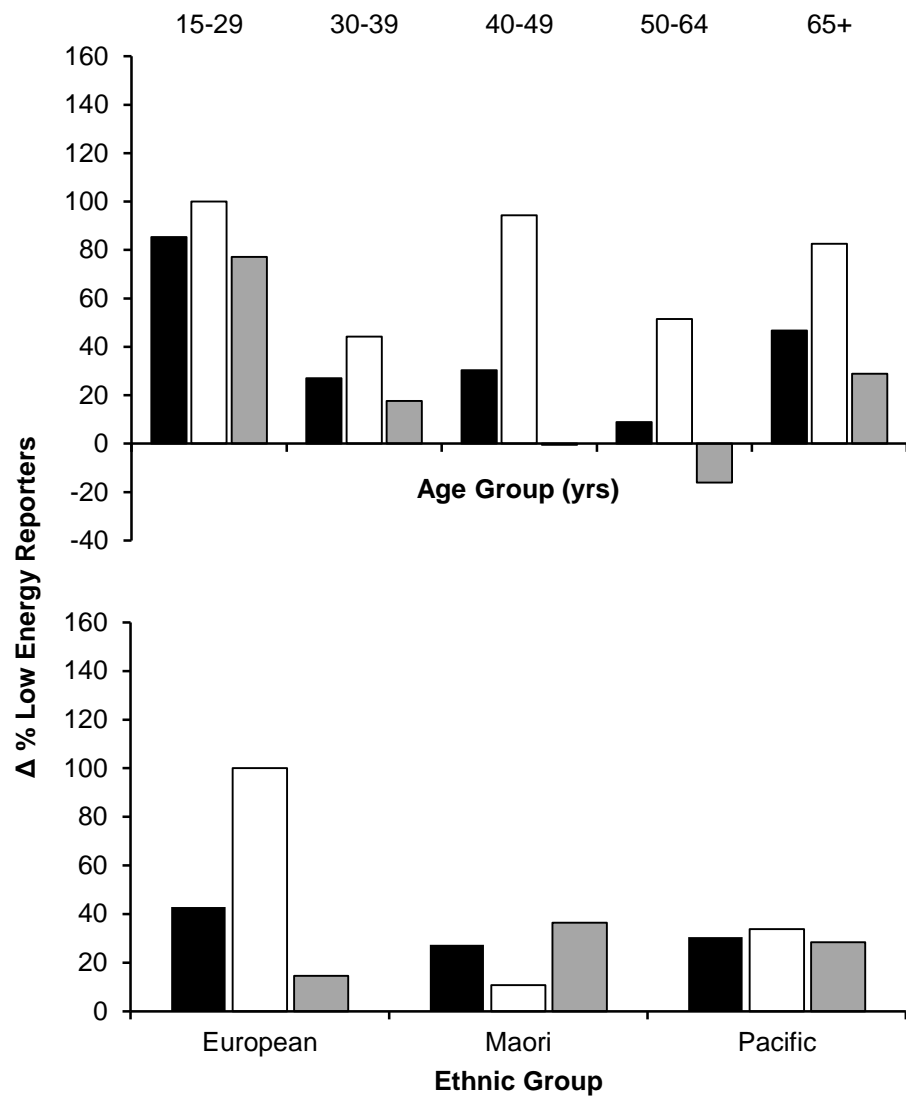
**Figure 7 Percentage of low energy reporters by body size using the WHO & Obesity International Taskforce BMI cut-offs <sup>191</sup> (unadjusted; unequal selection probabilities taken into account). a, b = values for each population characteristic in the same column with different superscript letters are significantly different from each other, P<0.01.**



**Figure 8 Percentage of low energy reporters by age group (unadjusted; unequal selection probabilities taken into account). a, b, c, = values for each population characteristic in the same column with different superscript letters are significantly different from each other,  $P < 0.01$ .**



**Figure 9 Percentage of low energy reporters by ethnicity (unadjusted; unequal selection probabilities taken into account). a, b = values for each population characteristic in the same column with different superscript letters are significantly different from each other,  $P < 0.01$ .**



**Figure 10 Percentage change of low energy reporters in the NZ Adult Nutrition Survey 2008-9 (ANS 08/9) by body size, age, and ethnicity compared to the 1997 NZ National Nutrition Survey (NNS97) (unadjusted; unequal selection probabilities taken into account).**

NNS97 data taken from Pikholtz et al (2004). Swinburn et al (1998) classifications for body size used.

## 4.7. Discussion

This analysis of the 2008/9 New Zealand Adult Nutrition Survey revealed substantial under-reporting of EI. The mean EI:RMR<sub>est</sub> values for the population were substantially below suggested cut-off values and lower than those reported in the NNS97 for both men and women, 1.34 (0.02) vs. 1.51 (0.02), and 1.28 (0.01) vs. 1.40 (0.01) respectively.<sup>73</sup> The greater prevalence of LERs observed among priority ethnic groups, older age groups, and people with overweight and obesity have been reported elsewhere.<sup>70, 145, 147, 197</sup>

Compared with the NNS97 analysis the proportion of LERs increased in nearly all subgroups (differences between surveys presented in **Figure 10**). The overall increase in the prevalence of LERs paralleled an increase in mean population body weight for men and women, for all ethnicities. The increase in mean body weight (~4-5kg) can be calculated to reflect an approximate increase of 400-500kJ in daily EI.<sup>198</sup> This is in marked contrast to the reported decrease in daily EI for men (1300KJ) and women (400KJ) between 1997 and 2008/9.

Notably the proportion of LERs more than doubled among men classified as normal body weight (6.1 to 14.7%), and increased in women with normal body weight from 14.4% to 18.6%. Considering the similarities between surveys this finding suggests the increase in LERs may be due to an increased influence of psychosocial factors (e.g. social desirability) and other behavioural characteristics (e.g. body dissatisfaction) among individuals with normal body weight (in addition to people with overweight and obesity). The relationship between these factors and under-reporting is well established, thus sociocultural changes and events within New Zealand society between surveys offer possible explanations for the differences observed.<sup>28</sup>

Over time, there has been an increase in screen-based activities and a substantial shift in the genre and quantity of television shows and media advertising, many of which portray a slim-body image or health-related content (e.g. reality television focussed on weight loss, cosmetic surgery, makeover, modelling etc.) which are known to influence factors, such as body dissatisfaction, self-esteem, depression, and eating behaviours (all related to under-reporting).<sup>28, 199, 200</sup> There were also two widely publicised nation-wide government led health campaigns (Healthy Eating Healthy Action, 2003; Mission On, 2006) that promoted a healthy lifestyle which, in conjunction with an increased public awareness of nutrition-related health and increased dieting practises may have



influenced people's self-perceptions, and thus increase the likelihood of dietary under-reporting.

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The absence of a method to verify the self-report or assist memory in dietary recalls (during the assessment) dictates that pervasive under-reporting is likely to remain a key issue in large scale dietary surveys.<sup>69-71, 73</sup> However, the recent development of wearable cameras may provide new solutions to enhance self-report and improve accuracy. Two studies recently demonstrated a significant increase self-reported EI when wearable cameras were used data to complement food records,<sup>204</sup> and 24-hour dietary recalls. {Gemming, #983} The images from the wearable camera revealed unreported/records foods and misreporting/reporting errors that substantially added to the estimated energy intake from the traditional method. Moreover, the design of bespoke wearable cameras for the passive and objective assessment of dietary intake and physical activity are under development.<sup>205</sup> If feasible, such technologies would be a welcome addition to improve dietary assessment,<sup>15</sup> though, further testing and validation would be required to evaluate their utility for large scale dietary surveys.

These analyses have several limitations that need consideration. The present study used the same methods used as those utilised by Pikholtz et al<sup>73</sup> to allow comparison between New Zealand's Adult Nutrition Surveys. However, possible selection bias and differences between surveys sample designs must be taken into account.<sup>23, 94</sup> Participants in the NNS97 survey were recruited after participating in the linked New Zealand Health Survey with a response rate of 50%, where participants in the ANS 08/9 survey were recruited independently, had a greater percentage of Maori and Pacific people sampled, and a somewhat higher response rate (61%). Other limitations comprise both limitations of the ANS 08/9 survey methodology, and methods used in the present study to analyse the data. The ANS 08/9 used a single 24-hour dietary recall as primary method to collect nutrient data for the full sample. A single 24-hour recall cannot capture daily, weekly or seasonal intra-individual variation in food intake which must be considered when interpreting data. Regarding the methods used in this analysis, estimated resting metabolic rate was derived from estimated fat-free mass and the Goldberg cut-offs were applied, where the gold-standard for the assessment EI data is with the use of the doubly labelled water technique.<sup>8, 135</sup>

The use of  $RMR_{est}$  was justified in this analysis as the Schofield equation commonly used to estimate BMR was developed for a population of normal weight (up to 84kg). Thus, the Schofield equation could not be assumed valid for the current New Zealand population (due to a high proportion with a BMI  $\geq 35\text{kg/m}^2$ ).<sup>206</sup> Furthermore about 80% of the variance between individual BMR can be explained by fat-free mass,<sup>187, 207, 208</sup> thus New Zealand specific equations for estimation of fat-free mass were used.<sup>194</sup>

Limitations of the Goldberg cut-offs must also be considered. Cut-off values alone cannot distinguish dieting from LERs (if below the cut-offs), and the cut-offs only identify extreme degrees of low energy reporting.<sup>185</sup> Moreover, use of a single cut-off value can be conservative for physically active populations, as people can under-report but not fall below the cut-offs.<sup>144, 185</sup> Information regarding PAL was not recorded in the ANS 08/9, but over half of New Zealand Adults meet physical activity guidelines (self-reported) suggesting the cut-off values used were likely too conservative.<sup>58</sup>

## 4.8. Conclusions

This analysis highlights a systematic bias in self-reported EI data and, the need to interpret EI data with substantial caution. Without technological innovation, under-reporting of EI will continue to be a major limitation of 24-hour dietary recall method used for large scale nutrition surveys.

## Acknowledgements

Access to the data in this study was provided by Statistics New Zealand in accordance with security and confidentiality provisions of the Statistics Act 1994. The results in this paper have been confidentialised to protect individuals from identification.

## Conflict of interest

There were no conflicts of interest.

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# CHAPTER 5. IMAGE-ASSISTED DIETARY ASSESSMENT: A SYSTEMATIC REVIEW OF THE EVIDENCE

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## 5.1. Introduction to publication

There are concerted efforts to use technologies to enhance dietary assessment.<sup>16, 31</sup> One approach is to use images of eating episodes to assist self-report used in traditional methods, or use the images as the primary record of dietary intake. Several of these image-assisted methods have been developed, pilot tested or validated.<sup>209-214</sup> However, no review had examined studies that have evaluated or validated image-assisted methods of dietary assessment among users. This chapter (Chapter Five) is a reformatted version of the manuscript entitled “Image-assisted dietary assessment: A systematic review of the evidence” was published in the Journal of the Academy of Nutrition and Dietetics, 2015; Volume 115, issue 1, pages 64-77 DOI: 10.1016/j.jand.2014.09.015. The latest impact factor available was 3.797 (2013). A few minor revisions were made to this reformatted manuscript at the request of the thesis examiners. The chapter presents the results from the first systematic review to examine the evidence for image-assisted methods of dietary assessment. The review was completed to address Objective Two of this thesis, which was to undertake a systematic review of existing evidence for image-assisted methods of dietary assessment.

## 5.2. Author contribution

Luke Gemming was involved in developing the research question, search strategy, selecting the papers, and extracting the data. He also summarised the information and wrote the paper for publication.



# IMAGE-ASSISTED DIETARY ASSESSMENT: A SYSTEMATIC REVIEW OF THE EVIDENCE

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### 5.3. Abstract

Images captured during eating episodes provide objective information to assist in the assessment of dietary intake. Images are captured using handheld devices or wearable cameras, and can support traditional self-report or provide the primary record of dietary intake. A diverse range of image-assisted methods have been developed and evaluated but have not been previously examined together. Therefore a review was undertaken to examine all studies that have evaluated or validated image-assisted methods of dietary assessment for assessing dietary EI. Identified image-assisted methods that employ similar methodologies were grouped for comparison. English language full-text research articles published between November 1998 and November 2013 were searched using five electronic databases. A search of reference lists and associated websites was also conducted. Thirteen studies, that evaluated ten unique image-assisted methods among adults aged 18 to 70 years, were included. Ten studies used handheld devices and three studies used wearable cameras. Eight studies evaluated image-based food records, two studies explored the use of images to enhance written food records, and three studies evaluated image-assisted 24-hour dietary recalls. Results indicate images enhance self-report by revealing unreported foods and identify misreporting errors not captured by traditional methods alone. Moreover, when used as the primary record of dietary intake, images can provide valid estimates of energy intake. However, image-assisted methods that rely on image analysis can be prone to underestimation if users do not capture images of satisfactory quality before all foods are consumed. Further validation studies using criterion measures are warranted. The validity among children, adolescents, and the elderly as well as the feasibility of using image-assisted methods in large samples needs to be examined. Additional research is also needed to better understand the potential applications and pitfalls of wearable cameras.

## 5.4. Introduction

There is a clear need for improved methods of dietary assessment.<sup>15, 215</sup> Despite advances in computer technologies to standardize methods and streamline analysis through software, traditional methods are still prone to substantial error and bias.<sup>26, 72, 73</sup> A main contributor to bias is reliance on self-report without the ability to verify the dietary information, which typically leads to under-reporting of energy intake (EI), especially problematic in overweight and obese populations.<sup>26, 131, 152-154, 216-219</sup> However, despite the bias, self-report obtains valuable information about the foods people consume.

Due to the limitations of self-report and the perception that images may increase objectivity (a picture is worth a thousand words), various methods of image-assisted dietary assessment have been developed, pilot tested or validated.<sup>209-214</sup> Image-assisted dietary assessment refers to any method that uses images/video of eating episodes to enhance self-report of traditional methods, or uses images/video as the primary record of dietary intake. The images of foods can be captured using any device but two distinct approaches for capturing the image, 'active' and 'passive', have been explored.

Active methods typically require individuals to capture images of foods with handheld devices, such as digital cameras or smartphones. Generally images are captured before and after eating episodes (to record wastage) and a reference marker is placed near the foods to assist image analysis techniques (manual or automated).<sup>220-222</sup> Often the images of foods are supported by supplementary text or voice recordings describing the foods, or require user input to confirm details extracted from the image (within a software application), such as food type or portion size.<sup>220, 223, 224</sup> The active approach helps ensure the images obtained are relatively consistent for image-analysis, but relies on users to remember to use the camera at every eating episode.

The passive approach uses wearable cameras to automatically capture point-of-view images of daily events, including eating episodes, with virtually no user input. Thus passive image capture does not rely on users to capture images of foods; however, the images captured are not directed specifically at foods, nor do they contain a reference marker to assist analysis. A novel aspect of passive image capture, in comparison to active methods, is the ability to aid memory recall during retrospective assessment without the need for the user to manually record dietary intake during the assessment period.<sup>32, 213</sup>

Due to a variety of technologies suitable for use in image-assisted methods, and the differences between the active and passive approach, there is a diverse range of methods not previously examined or easily compared. Stumbo et al<sup>31</sup> have detailed the methods employed in selected image-assisted methods in development (yet to be validated) and Illner et al<sup>225</sup> have examined the strength and weaknesses of several innovative technologies in dietary assessment. However, to date no review has examined the current evidence regarding the use of image-assisted dietary assessment methods. The aim of this review was to examine all studies that have evaluated or validated an image-assisted method of dietary assessment compared to a reference method for assessing dietary EI. Due to the diversity of image-assisted methods identified, we grouped and categorized methods that employ similar methodologies for comparison.

## **5.5. Methods**

### **5.5.1 Eligibility criteria**

All studies that evaluated or validated an image-assisted method of dietary assessment compared to a reference method for assessing dietary EI were included. Technical reports associated with the studies and methods of image-assisted dietary assessment included were only used to support the description of the method and supporting systems used.

### **5.5.2 Exclusion criteria**

Studies that did not report EI or compare EI to a reference method were excluded. Methods of image-assisted dietary assessment under development that have not been evaluated among users described in technical reports were excluded. Studies that used pre-captured images or image databanks to assist portion size estimation in traditional methods of dietary assessment were also excluded.

### 5.5.3 Information sources and search strategy

Five electronic databases were searched: MEDLINE; PubMed; Web of Science; CINAHL Plus; and ProQuest. The searches were conducted in November 2013. A search strategy was developed using a combination of Medical Subject Headings and keywords. The search string was modified where appropriate for use in the other databases. Search limiters included English language, human participants, and studies reported between 1998 and the search date to ensure all technologies evaluated in image-based methods were identified. (See **Figure 11** for example search strategy for MEDLINE database). A manual search of included articles reference sections, and associated websites, supplemented the search of electronic databases. Corresponding authors of identified image-assisted methods in development (not evaluated or validated among users) were contacted to identify any additional studies. The search results from all databases and the manual search were imported into a reference software package EndNote (version 16, released August 6, 2012, Thomson Reuters, Philadelphia, Pennsylvania). After the removal of duplicates, the title and abstracts were screened by one reviewer [LG]. The full-text studies that appeared relevant were then obtained and screened. Manuscripts potentially eligible for inclusion were discussed and their inclusion or exclusion were agreed upon by two authors [LG and CN].



**Example Search Strategy**

**Source: MEDLINE<sup>a</sup>**

1. exp<sup>b</sup> Technology/<sup>c</sup>
2. exp Cellular Phone/
3. smartphone<sup>d</sup>.mp.<sup>e</sup>
4. mobile phone\$.mp.
5. mobile telephone\$.mp.
6. personal digital assistant.mp.
7. PDA.mp.
8. exp Computers, Handheld/
9. tablet computer.mp.
10. device.mp.
11. life-logging.mp.
12. exp Video Recording/
13. video.mp.
14. image\$.mp.
15. digital camera.mp.
16. wearable camera.mp.
17. sensecam.mp.
18. wearable sensor.mp.
19. camera.mp.
20. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11  
or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19
21. exp Nutrition Assessment/
22. exp Dietetics/mt [Methods]
23. dietary assessment.mp.
24. exp Diet/is, mt [Instrumentation, Methods]
25. exp Diet Surveys/
26. exp Nutrition Surveys/
27. 21 or 22 or 23 or 24 or 25 or 26
28. 20 and 27
29. limit 28 to (english language and humans  
and yr="1998 -Current")

**Figure 11 MEDLINE search strategy for the systematic review examining the evidence for image-assisted methods of dietary assessment.**

### 5.5.4 Data extraction

Data extraction was conducted by one reviewer [LG] using a custom data extraction form to extract general study details as follows: participant characteristics (sex, age, BMI); inclusion/exclusion criteria; study setting; method of image-assisted dietary assessment; study design and duration; reference method used; mean EI/energy expenditure; statistical analysis; feedback regarding method/technology, and study limitations. When further information was sought, corresponding authors were contacted via email. One follow-up email was sent if no response was received to the first. Because of the substantial heterogeneity between image-assisted methods of dietary assessment used, study designs, durations, and populations only a narrative review was performed in this systematic review.

### 5.5.5 Quality assessment

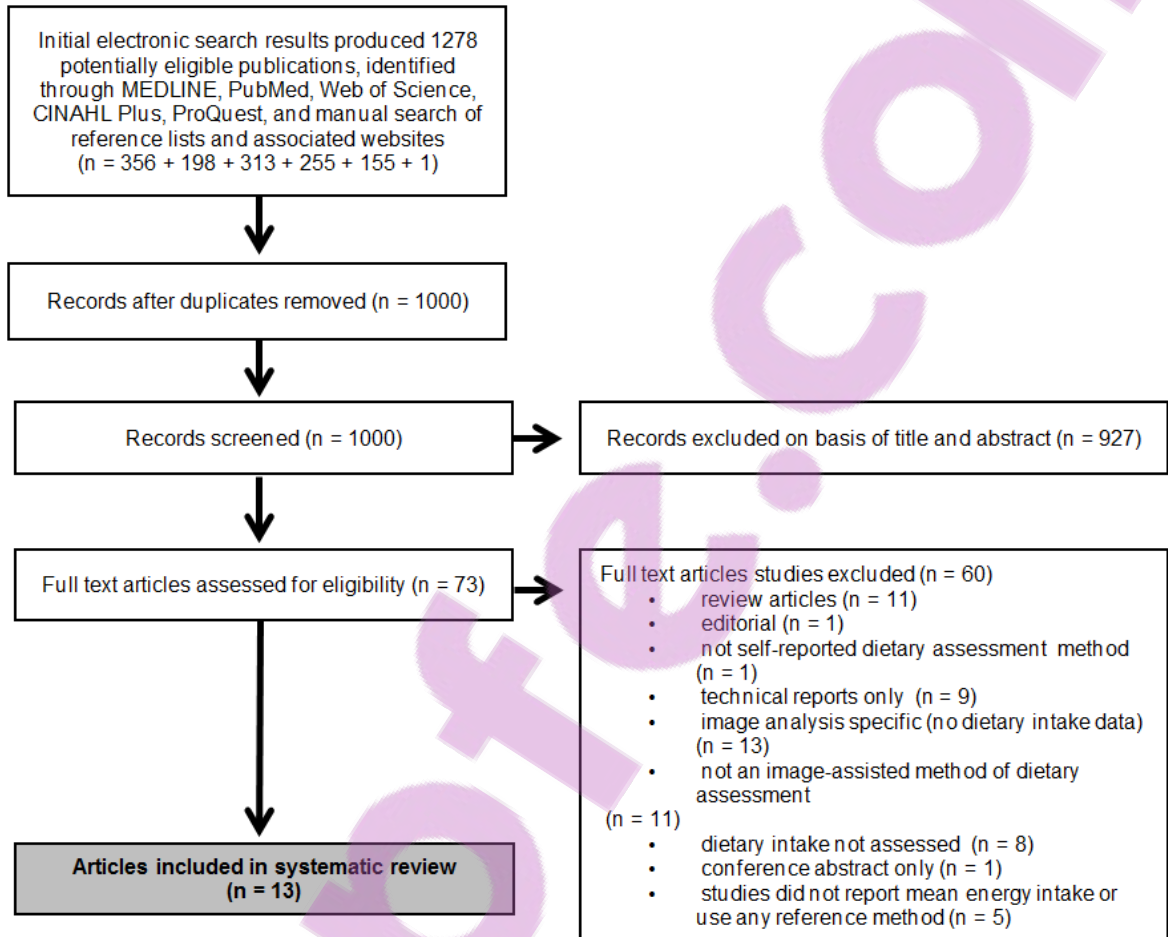
The majority of studies published in this field to date have been pilot or feasibility studies. Therefore a formal assessment of study quality was not undertaken as the assessment would not provide meaningful outcomes. However, the study designs were examined to assess risk of bias regarding the review and analysis of captured images to obtain EI data. (There is potential for bias if the image analysis is conducted without independent image analysts/researchers blinded from the reference method).

## 5.6. Results

### 5.6.1 Search results

Please refer to **Figure 12** for a flow diagram depicting the search and inclusion of the studies. Of the 1278 potentially eligible articles initially identified, 13 met the inclusion criteria. Ten studies used active image capture<sup>209-211, 222-224, 226-229</sup> with handheld devices and three used passive image capture with wearable cameras.<sup>212, 213, 230</sup> Eight studies evaluated five different image-based food records captured using handheld digital cameras, personal digital assistants (PDAs) and smartphones.<sup>209, 211, 222-224, 226-228</sup> Two studies evaluated the use of images to assist traditional written food records; one used a single-use/disposable camera,<sup>210</sup> and the other used a wearable camera.<sup>230</sup> Three studies evaluated the use of images to assist self-report during 24-hour dietary recalls. Two of the studies used wearable cameras<sup>212, 213</sup> and one study used a

handheld digital camera.<sup>229</sup> Three other image-assisted methods under development were identified by the search strategy but had not been evaluated among users assessing dietary energy intake.<sup>214, 231, 232</sup>



**Figure 12** Flowchart and inclusion process for the systematic review examining the evidence for image-assisted methods of dietary assessment.

### 5.6.2 Characteristics of included studies

The 13 included studies are presented in Table 7. The sample sizes of the studies were small. Six studies had fewer than 20 participants<sup>210, 212, 213, 224, 227, 228</sup> six studies had between 20 and 50 participants,<sup>209, 222, 223, 226, 229, 230</sup> and one study had 75 participants.<sup>211</sup> Seven studies recruited healthy adults,<sup>211-213, 222, 227-229</sup> two recruited university students,<sup>223, 226</sup> two recruited adults with overweight and obesity,<sup>209, 210</sup> one study recruited adults with type 2 diabetes,<sup>224</sup> and one study recruited a combination of athletes and physically active university students.<sup>230</sup> The mean age was available for 11 studies,<sup>209, 211-213, 222, 224, 226-230</sup> with the mean age ranging from 18 to 65 years. No study had participants below 18 years or above 70 years of age. Sex was identified in all studies. Three studies recruited female participants only.<sup>223, 226, 229</sup> Five studies used criterion reference methods to evaluate EI data.<sup>209, 212, 222, 228, 229</sup> Two of the studies used doubly labelled water (DLW) to assess total energy expenditure (TEE),<sup>209, 212</sup> and three used weighed meals.<sup>222, 228, 229</sup> Eight studies used traditional methods of dietary assessment as reference methods.<sup>210, 211, 213, 223, 224, 226, 227, 230</sup> Four studies used weighed food records,<sup>211, 223, 226, 227</sup> three used estimated food records,<sup>210, 224, 230</sup> and one study used the 24-hour dietary recall.<sup>213</sup>

### 5.6.3 Image-based food records

For the purpose of this review an image-based food record is any method where images of foods captured during eating episodes provide the primary record of dietary intake to determine energy and nutrient content. The first attempt to validate an image-based food record used camera-enabled PDAs in the Wellnavi method.<sup>223, 226</sup> The Wellnavi method required users to capture images of foods, at a 45 degree angle, before and after eating episodes. Foods were placed on a table, and the PDAs stylus was placed beside foods as a visual reference for portion size estimation. After the images were captured, users were required to describe the foods and provide ingredients with written text on the screen (using the stylus), especially when the foods were considered difficult to judge using images alone. The images and description of the foods were transmitted wirelessly to a server for manual image analysis by dietitians. To aid analysis, a brief questionnaire was used to obtain additional information on dietary behaviors such as added sugar to beverages, and typical condiment use.

Two pilot studies were conducted among female nutrition students (N=20, and N=28) who simultaneously recorded dietary intake using the Wellnavi method and weighed food record.<sup>223,</sup>

<sup>226</sup> In the first study, diet was recorded for one-day, <sup>223</sup> and in the latter participants recorded diet for one-day in June and November. <sup>226</sup> Both studies found no significant differences in EI or macronutrients between the two methods. <sup>223, 226</sup> A larger validation study was then conducted by Kikunaga et al <sup>211</sup> among adults of the general Japanese population (N=75) who simultaneously recorded their diet for 7 days using the Wellnavi method and weighed food record. Compared to the food record the Wellnavi method underestimated mean EI by 13.1% (1977±405 kcal vs. 1718±361 kcal, P<0.001) and significantly under-estimated all macronutrients. The authors noted that a high proportion of images did not contain any text describing the foods, which made accurate image analysis challenging for complex and traditional Japanese dishes.<sup>16</sup> Participant feedback in the pilot study indicated it was difficult to write text on the small screens (using the stylus), <sup>23</sup> which was likely a factor that contributed to the low compliance and subsequent under-estimation of EI. <sup>211</sup> Moreover, limitations of the PDA technology including the bulk of the device, poor battery life and image quality were apparent.

Lassen et al <sup>227</sup> conducted a study using a stand-alone handheld digital camera to evaluate the potential of the “Digital Method” image-based food record. While seated, users were required to capture images of foods on a table, at a 45 degree angle, before and after eating episodes. Users were required to separate different meal components on the plate to assist analysis and a ruler was placed beside foods as a reference for portion size estimation. A notebook was provided to record the recipes and ingredients in grams or common household measures. <sup>227</sup> Manual image analysis was conducted by two image analysts trained using a reference database of commonly consumed foods developed from a feasibility study. <sup>227</sup>

A sample of healthy adults (N=19) simultaneously recorded their dinners for five nights (excluding beverages) using the Digital Method and weighed food records. Compared to the food record the Digital Method underestimated mean EI by 11.3% (dinner only; 526±178 kcal vs. 471±167 kcal, P<0.001). <sup>227</sup> Participant feedback revealed difficulty remembering to record intake, particularly when eating out, or for rapidly consumed items not eaten from a plate. Moreover, some participants noted it was awkward to separate foods on the plate before capturing an image. <sup>227</sup>

Rollo et al <sup>224</sup> conducted a pilot study to test Nutricam an image-based food record application on a mobile phone. Similar to other methods before and after images were captured of foods on tables, at a 45 degree angle, before and after eating episodes. Additional images were captured if necessary to ensure the images were clear for analysis. A reference card was placed next to

foods for portion size estimation, and provided prompts for a brief voice recording ( $\leq 30$  seconds) to describe the food name, type, brand/product name and preparation/cooking method of each food item. The images and associated voice recordings were assessed independently by a dietitian.<sup>224</sup>

Adults with type 2 diabetes (N=10) simultaneously recorded their dietary intake using Nutricam and estimated food record for three days. Compared to the food record Nutricam underestimated mean EI by 9.3% ( $1660 \pm 439$  kcal vs.  $1505 \pm 469$  kcal,  $P < 0.05$ ). Only 71% of Nutricam entries included an image of adequate quality for analysis, and only 66% of the entries included a voice recording, which explained the underestimation. The authors also noted it was difficult to analyze complex dishes. Participant feedback revealed memory failure as the most common reason why they did not capture an image of the foods consumed.<sup>224</sup>

The Remote Food Photography Method (RFPM), and the mobile phone Food Record (mpFR) are more sophisticated methods that incorporate automated image analysis techniques into comprehensive dietary assessment systems.<sup>233, 234, 20, 41</sup> The RFPM was adapted from a validated method to assess EI using images in cafeteria settings (not self-captured).<sup>233, 234</sup> Like other methods, users are required to capture images of foods on a table at 45 degrees, before and after eating episodes.<sup>222</sup> A reference card with a printed pattern is placed next to foods to correct for color and assist in the estimation of the food's area.<sup>235</sup> The images captured are transmitted wirelessly to a server in near real-time for analysis using a custom program. Features from the images are extracted for each food identified for food classification,<sup>235</sup> and the program compares the foods with a searchable image archive of foods and portion sizes matched to the Food and Nutrient Database for Dietary Studies.<sup>222, 236</sup> The food area is converted to grams based on the association between food area and weight for each respective food.<sup>235</sup> Dietitians review the data and make changes as required and can contact users immediately if the images/data are of poor quality.<sup>235</sup> Users are also instructed to record dietary intake using pen and paper or leave a voice message describing the foods if they forget to capture images. To remind participants to record dietary intake, the RFPM incorporates the use of ecological momentary assessment (EMA); automated prompts at meal times requiring a user response.<sup>209, 222</sup>

The validity and reliability of the RFPM was initially assessed using weighed meals and a manual procedure of image analysis.<sup>222</sup> A sample of healthy adults (N=50) recorded their diet for three days using the RFPM. The dine-in group (n=25) recorded their lunch and dinners in the

laboratory, while the take-out group (n=25) recorded their lunch in the laboratory and dinner in simulated free-living conditions (pre-weighed foods provided in coolers).<sup>222</sup> Compared to the weighed meals the RFBM under-estimated the mean EI by 4.7% (dine-in group), and 5.5% (take-out group) in laboratory conditions, and by 6.6% in simulated free-living conditions (takeout-group).<sup>222</sup> An assessment of reliability between three dietitians analyzing the images demonstrated good agreement for EI ICC=0.88 (95% CI 0.81 – 0.91) and food type selection 0.99 ICC (95% 0.99, 0.99).<sup>222</sup>

The RFBM was refined before a further development study among overweight and obese participants (N=40) evaluated different EMA approaches; standard EMA (n=24) and customized EMA (n=16).<sup>209</sup> Participants recorded their diet for one week during a two-week DLW protocol to assess total energy expenditure (EE), and were provided standard EMA (set meal times) or customized EMA (individualized meal times). Using standard EMA the mean EI:EE was underestimated by 36.3% compared to only 12.4% in the customized EMA group.<sup>209</sup> After further refinement the RFBM was validated in a sample of overweight and obese participants in both laboratory (N=49, two weighed buffet meals) and free-living conditions (N=42, RFBM recorded diet for one week of a two-week DLW protocol).<sup>209</sup> Compared to weighed meals, mean EI estimated by the RFBM was very similar ( $587 \pm 209$  kcal vs.  $583 \pm 190$  kcal,  $P=0.67$ ), and compared to DLW in free living conditions the mean EI:EE was underestimated by 6.4% ( $2360 \pm 626$  kcal vs.  $2208 \pm 665$  kcal,  $P=0.16$ ). Participant feedback indicated the majority were satisfied with the method and indicated the method was easy to use compared to written records.

The mpFR uses a similar procedure to the RFBM with users required to capture images of foods on a table, at a 45 degree angle, before and after eating episodes. The images captured are transmitted wirelessly to a server for analysis using a custom program. A checked fiducial marker (reference marker) is placed next to foods to assist the automated system to estimate food volume.<sup>220</sup> The foods are segmented into individual food items using a series of techniques<sup>237-240</sup> before classification and volume estimation using calculations based on the food's shape.<sup>240</sup>

Using a different approach to the RFBM, images of foods are labelled and the results are sent back to the user to confirm or modify the foods and portion size determined by the automated system (rather than by researchers). After user adjustments and confirmation the foods are indexed with the Food and Nutrient Database for Dietary Studies<sup>236</sup> before results are sent to

researchers/dietitians. A backup electronic food record is built into the smartphone application when users forget to capture images.

At the time of writing, only a pilot study (within a PhD thesis) designed to inform a larger validation of the mpFR has been reported which assessed energy intake among users.<sup>228</sup> The pilot used manual image analysis with trained image analysts (not the automated system described above).<sup>228</sup> A sample of adults from the campus community (N=12) were provided with a range of foods (portions known and excess to their energy requirements) on three non-consecutive days to eat in both laboratory and free-living conditions, and instructed to record all eating episodes with the mpFR. Compared to the presumed EI (determined from returned uneaten foods) the mean EI was under-estimated by 6.4%. (Note image analysts had knowledge of the foods and portions provided). Participant feedback was not reported, but other research evaluating usability of the mpFR indicated users find the method easy to use and is preferred over a traditional food record.<sup>241, 242</sup>

#### **5.6.4 Image-assisted food records**

For the purpose of this review an image-assisted food record is any method where images captured during eating episodes are used to enhance or supplement a traditional text-based food record (written or electronic). Gregory et al<sup>210</sup> conducted a feasibility study among adults with obesity (N=9) to explore the use of a handheld disposable/single-use film camera to enhance an estimated food record over three non-consecutive days. Participants were required to capture a picture at arm's length from the table, and placed a 15cm ruler as a reference for plate size. Foods were then recorded into a booklet provided. After the testing period the food record and photographs were reviewed independently by two dietitians. Compared to the food record alone, reviewing the photographs increased the mean EI by 8% for dietitian #1 and by 5.2% for dietitian #2 but this was not statistically significant (P=0.87). No data pertaining to how the image review specifically changed EI was provided, but identification of misreporting errors was noted by the authors.

O'Loughlin et al<sup>230</sup> conducted a study to assess if images can enhance the food record using the wearable camera (SenseCam). The SenseCam is a wearable camera worn around the neck on a lanyard with a wide-angled lens,<sup>243, 244</sup> and images are captured passively at approximately 20 second intervals (~2000 to 3000 images per day). Internal flash memory is sufficient for one week



and battery capacity is adequate for a typical 12-16 hour day. Once turned on, the SenseCam operates continuously until the camera is switched off (a privacy button can be activated to cease image capture temporarily).

For one day, trainee jockeys (n=17), Gaelic footballers (n=15), and physically active university students (n=15) wore the SenseCam and recorded their diets using an estimated food record. After the testing period the food record was reviewed by the participant and dietitian for ambiguous information before viewing the SenseCam images. Compared to the food record alone, viewing the SenseCam images significantly increased mean EI by 12%, 23% and 11% for the trainee jockeys, Gaelic footballers, and physically active university students, respectively ( $P \leq 0.001$ ,  $P \leq 0.001$ , and  $P \leq 0.01$ ).<sup>230</sup> In all three groups only one participant's food record remained unchanged after image review. No data pertaining to exactly how the image review altered the EI was provided, but unreported foods and misreporting errors were noted by the authors. The study design had a risk for interviewer bias as changes to dietary intake were made by the same dietitian. Technical problems with SenseCam devices and user error resulted in incomplete data for 13 participants (28%), and were not included in the analysis. The authors also noted poor image quality in low light environments and devices were frequently not worn correctly affecting image quality.

### **5.6.5 Image-assisted 24-hour recalls**

For the purpose of this review an image-assisted 24-hour dietary recall is any method where images captured during eating episodes are used to self-report during the 24-hour dietary recall method. Arab et al<sup>212</sup> first tested the feasibility of a web-based, self-administered, image-assisted 24-hour dietary recall (Image-DietDay) in a sample of healthy adults (N=14). For 6-10 days of a 15-day DLW protocol participants wore a customized mobile phone around the neck (using a lanyard) that captured images every 10 seconds during eating episodes. The images were transmitted wirelessly to a server for processing (blurry and dark images removed), and a selection of images (<100) were presented in an image-viewer to assist participants during three Image-Diet Day 24-hour recalls. Compared to DLW, Image-DietDay overestimated the mean EI:EE intake by 7%,  $2711 \pm 1225$  kcal vs.  $2519 \pm 609$  kcal, respectively. The study design did not permit any analysis regarding how the images assisted the recall but participant feedback indicated that most found the images helpful. However, in some cases wearing the phones may

have altered usual eating behaviors. The authors<sup>212</sup> also noted the battery life was not always sufficient to last an entire day and the phone's narrow field of view was not ideal for dietary assessment.<sup>212</sup> Other testing of the system also reported an imaging frequency of 10 seconds captured few images of rapidly consumed foods (e.g. fruit), and no images of socially undesirable foods, such as candy, or chips.<sup>245</sup>

Gemming et al<sup>213</sup> tested the feasibility of a SenseCam-assisted interviewer-administered 24-hour dietary recall in a sample of healthy adults (N=10). Participants wore the SenseCam for two days, while conducting their usual daily activities. Day one familiarized participants with the SenseCam and the images from day two were used to assist participants' self-report after the final pass of the 24-hour dietary recall. To reduce the potential for interviewer bias the researcher did not suggest changes or scrutinize self-reported intakes, but queried unreported food items present in the images. Compared with 24-hour dietary recall alone the images increased mean EI by 12.5% (2738±502 kcal vs. 3080±712 kcal, p=0.02).<sup>213</sup> The increase was primarily due to 41 unreported food items across the sample. The unreported foods were from a range of food groups, and included both snack foods and more substantial food items. Eight changes to portions size and 12 misreporting errors were also identified by participants but together these changes had little impact on EI.<sup>213</sup> Participant feedback indicated the images were helpful and enabled participants to provide more accurate information, but some indicated they felt uncomfortable in public situations, such as riding the bus or purchasing foods. Limitations regarding SenseCam were also apparent. The imaging frequency was too slow to capture rapidly consumed foods, images were poor quality in low-light environments, and posture and body shape affected lens angle resulting in some non-useful images.<sup>213</sup>

Lazarte et al<sup>229</sup> examined the use of handheld digital cameras to enhance self-report in the Food Photography interviewer-administered 24-hour Multiple Pass Recall method (FP 24-hR). The FP 24-hR was validated among a group of healthy Bolivian women (N=43) for a single 24-hour period. Participants were provided a photo kit that contained a camera and mat with a 1.5cm grid and captured two images at 50cm distance from the table (at 90 and 45 degree angles) before and after eating episodes.<sup>229</sup> Researchers visited the participant's home during the testing period and weighed all meals. The following day a different trained interviewer assessed the participant's diet, and on the last pass of the 24-hour dietary recall the interviewer used the images (FP 24-hR) to confirm or modify the portion sizes and enquire about any foods that were partially obscured.

<sup>229</sup> Compared to weighed meals the FP 24-hR under-estimated mean EI by only 4% (1456 kcal SEM 63 kcal vs. 1399 kcal SEM 62 kcal,  $p < 0.05$ ), and Bland-Altman plots revealed good agreement between methods with no systematic bias. <sup>229</sup> No specific analysis pertaining to how the images changed the initial recall was reported. <sup>229</sup>

**Table 6 Studies that have evaluated or validated an image-assisted method of dietary assessment compared to a reference method assessing dietary energy intake.**

Author	Method	Method of image capture	Participants / (N) Mean Age (years±SD) <sup>a</sup> BMI (kg/m <sup>2</sup> ±SD)	Reference method(s)	Difference compared to reference <sup>b</sup> (%)	P-Value <sup>c</sup>	Feedback of method/technology	Study limitations
<b>Image-based food records</b>								
Lassen et al, 2010 <sup>227</sup>	<b>Digital Photography Method</b>	<b>Active</b> Nikon Coolpix SS210 digital camera	Healthy adults / N=23 <sup>d</sup> Age: 37±16 BMI: 24±3	5-day weighed FR <sup>e</sup> (dinner only)	-11.3	<0.001	<ul style="list-style-type: none"> <li>• Easy to complete</li> <li>• High compliance (94%)</li> <li>• Difficulties when away from home or food prepared by others</li> <li>• Participants reported awkward to separate items</li> <li>• Did not appear to influence eating habits to any great extent</li> <li>• Sometimes larger servings were chosen or sauces not consumed to avoid taking extra images.</li> </ul>	No criterion measure, sample size, no beverages in analysis, food items separated on plate, only dinner
Kikunaga et al, 2007 <sup>211</sup>	<b>Wellnavi method</b>	<b>Active</b> PDA <sup>f</sup> with camera + phone card	Healthy adults / N=75 Age: 49±10 BMI: 24±4	7-day weighed FR	-13.1	<0.001	<ul style="list-style-type: none"> <li>• Most participants did not capture images at 45° angle which made image analysis difficult</li> <li>• Low compliance using stylus made image analysis difficult without supporting text</li> <li>• Traditional Japanese foods hard to visually identify</li> </ul>	No criterion measure, normal body size
Martin et al, 2009 <sup>222</sup>	<b>Remote Food Photography Method (RFPM)</b>	<b>Active</b> Motorola i860 mobile phone	Healthy adults / N=50 Age: 32 (SEM 2) <sup>g</sup> BMI: 27 (SEM 1)	3-day weighed meals Dine-in group (n=25) (lunch & dinner in			<ul style="list-style-type: none"> <li>• Most participants satisfied with the RFPM and ease of use</li> <li>• Almost all participants rated that they prefer the RFPM over a written FR</li> <li>•</li> </ul>	Food items separated on multiple plates, limited number of foods provided,

Author	Method	Method of image capture	Participants / (N) Mean Age (years±SD) <sup>a</sup> BMI (kg/m <sup>2</sup> ±SD)	Reference method(s)	Difference compared to reference <sup>b</sup> (%)	P-Value <sup>c</sup>	Feedback of method/technology	Study limitations
				laboratory)	-4.7	0.046	<ul style="list-style-type: none"> <li>Some participants forgot to take images of food</li> <li>Some EMA<sup>h</sup> messages were sent at the wrong time.</li> <li>Suggestion to maintain a written FR in case of technology failure</li> </ul>	only dinner consumed in free-living conditions, only 3-days of assessment
			Take-out group (n=25) (lunch in laboratory)	-5.5	0.076			
			Take-out group (dinner in simulated free-living conditions)	-6.6	0.017			
			<b>Study 1</b> Overweight & obese adults / N=40 Age: 43±14 BMI: 24±48	<b>Study 1</b> 1-week RFPM vs. 2-week DLW <sup>i</sup> Standard EMA group (n=22) <sup>j</sup>	-36.3 -12.4	<.0001 0.22		<b>Study 1</b> No participants +65 years, small sample size in customized group, mainly females
Martin et al, 2012 <sup>209</sup>	Remote Food Photography	Active	<b>Study 2</b> Overweight & obese adults / N=50 Age: 41±13 BMI:31±5	Customized EMA group (n=13) <sup>j</sup> <b>Study 2</b> 2 weighed buffet meals in laboratory (N=49) <sup>j</sup> 1-week RFPM vs. 2-week DLW (N=42) <sup>j</sup>	-0.7 -6.4	0.67 0.16	<ul style="list-style-type: none"> <li>82% of participants rated their satisfaction with the method as 5 or higher on a 6 point Likert scale</li> <li>93% and 89% rated the ease of use as 5 or higher 93% and 96% rated the usefulness of the run-in period and training as 5 or higher on a 6 point Likert scale</li> </ul>	<b>Study 2</b> No participants +65 years, mainly females, only 1-week of assessment compared to DLW

Author	Method	Method of image capture	Participants / (N) Mean Age (years±SD) <sup>a</sup> BMI (kg/m <sup>2</sup> ±SD)	Reference method(s)	Difference compared to reference <sup>b</sup> (%)	P-Value <sup>c</sup>	Feedback of method/technology	Study limitations
Wang et al, 2002 <sup>223</sup>	Wellnavi method	Active PDA with camera + phone card	Female nutrition students / N=20 Age: NR <sup>k</sup> BMI: NR	1-day weighed FR	6	>0.05	<ul style="list-style-type: none"> <li>• Certain foods hard to visualize separately for analysis</li> <li>• Difficulty using the PDA stylus on small screen</li> <li>• Battery charging was time consuming</li> <li>• PDA was considered heavy</li> <li>• Few (10%) indicated the method was satisfactory, 40% somewhat satisfactory, 25% somewhat unsatisfactory, and 25% participants unsure</li> </ul>	No criterion measure, sample size, female nutrition students, 1-day of assessment
Wang et al, 2006 <sup>226</sup>	Wellnavi method	Active PDA with camera + phone card	Female nutrition students / N=28 Age: 20±5 BMI: 21±3	2 x 1-day weighed FR June & November	-3.8 (June) 2.3 (November)	>0.05 >0.05	<ul style="list-style-type: none"> <li>• The majority considered the Wellnavi least burdensome compared to FR</li> <li>• About half indicated they could continue using Wellnavi for one month</li> <li>• Nearly one third indicated being self-conscious about their meals seen by strangers</li> </ul>	No criterion measure, sample size, female nutrition students, 2 x 1-day of assessment only
Rollo et al, 2011 <sup>224</sup>	Nutricam	Active Sony Ericson K800i mobile phone	Adults with type 2 diabetes / N=10 Age: 65±34 BMI: 34±7	Estimated 3-day FR	-9.3	0.03	<ul style="list-style-type: none"> <li>• Software was easy to use and study participants preferred Nutricam over the FR</li> <li>• All subjects were confident they could use Nutricam to record their dietary intake for one month</li> <li>• Some poor quality images restricted image analysis</li> <li>• Participants commonly reported failure to use Nutricam at eating episodes</li> <li>• 20s voice recording limit was too short</li> </ul>	No criterion measure sample size, no criterion measure, short duration, adults with type 2 diabetes only, only 3-days of assessment

Author	Method	Method of image capture	Participants / (N) Mean Age (years±SD) <sup>a</sup> BMI (kg/m <sup>2</sup> ±SD)	Reference method(s)	Difference compared to reference <sup>b</sup> (%)	P-Value <sup>c</sup>	Feedback of method/technology	Study limitations
Schap et al, 2012 <sup>228</sup>	Mobile phone Food Record (mpFR)	Active iPhone 3GS	Adults from campus community / N=12 Age: 23 <sup>l</sup> (median) BMI: 24±4	3 non-consecutive days of weighed meals (portions of known quantities provided)	-6.4	0.243	<ul style="list-style-type: none"> <li>Some foods were not photographed by participants</li> </ul>	Sample size, short duration, no criterion measure for total energy intake, foods items known by analysts, only 3-days of assessment
<b>Image-assisted food records</b>								
Gregory et al, 2006 <sup>210</sup>	Food Diary with photographs	Active Single-use camera	Adults with obesity / N=9 Age: NR BMI: >30	Estimated 3-day FR (non-consecutive) Dietitian 1 Dietitian 2	8 5.2	0.71 0.87	<ul style="list-style-type: none"> <li>Images revealed misreporting errors</li> </ul>	No criterion measure, sample size, little detail on the changes to energy intake due to the addition of photographs

Author	Method	Method of image capture	Participants / (N) Mean Age (years±SD) <sup>a</sup> BMI (kg/m <sup>2</sup> ±SD)	Reference method(s)	Difference compared to reference <sup>b</sup> (%)	P-Value <sup>c</sup>	Feedback of method/technology	Study limitations
O'loughlin et al, 2013 <sup>230</sup>	SenseCam-assisted FR	Passive SenseCam wearable camera	Healthy young adults / N=47	Estimated 1-day FR alone				
			Trainee jockeys / n=17 Age: 18±2 BMI: NR	Trainee jockeys (n=11) <sup>j</sup>	12	≤0.001	<ul style="list-style-type: none"> <li>User and camera error resulted in 28% (n=13) of participant data excluded from analysis</li> <li>Camera not worn properly by all participants</li> <li>Poor image quality in low-light conditions</li> </ul>	No criterion measure, mainly physically active participants, no details on changes made due to images
			Gaelic footballers / n=15 Age: 22±1 BMI: NR	Gaelic footballers (n=10) <sup>j</sup>	22.7	≤0.001		
Active university students / n=15 Age: 23±1 BMI: NR	Active university students (n=13) <sup>j</sup>	11.2	≤0.01					
<b>Image-assisted 24-hour dietary recalls</b>								
Arab et al, 2011 <sup>212</sup>	Image-DietDay 24-hour dietary recall	Semi-Passive Nokia N80 Mobile Phone	Healthy adults / N=14 Age: 35±12 BMI: 27±7	3 x Image-DietDay 24-hour dietary recall vs. 2-week DLW	7.6	NR	<ul style="list-style-type: none"> <li>No technical failures occurred</li> <li>Battery not always sufficient</li> <li>Device cumbersome to wear for the majority of participants</li> <li>57% found the images helpful, and 79% were comfortable using the ImageViewer</li> <li>Sometimes eating behavior was affected (eating out less often and eating more rapidly)</li> </ul>	Sample size, predominantly females, motivated adults already participating in nutrition research



Author	Method	Method of image capture	Participants / (N) Mean Age (years $\pm$ SD) <sup>a</sup> BMI (kg/m <sup>2</sup> $\pm$ SD)	Reference method(s)	Difference compared to reference <sup>b</sup> (%)	P-Value <sup>c</sup>	Feedback of method/technology	Study limitations
Gemming et al, 2013 <sup>213</sup>	<b>SenseCam-assisted 24-hour dietary recall</b>	<b>Passive</b> SenseCam wearable camera	Healthy adults / N=10 Age:33 $\pm$ 11 BMI:26 $\pm$ 11	1 x 24-hour dietary recall alone	12.5	0.02	<ul style="list-style-type: none"> <li>Wearing SenseCam was a low burden</li> <li>Images helped participants remember unreported foods</li> <li>Posture and body shape affect lens direction</li> <li>Poor image quality in low-light environments</li> <li>Imaging frequency too low to capture all foods consumed</li> <li>Device fault resulted in loss of images for 2 participants</li> </ul>	No criterion measure, sample size, mainly males, only 1 x 24-hour dietary recall
Lazarte et al, 2012 <sup>229</sup>	<b>Food Photography 24h recall (FP 24-hR)</b>	<b>Active</b> Samsung Digimax S760 digital camera	Adult women / N=43 Age: 35 $\pm$ 9 BMI: 25 $\pm$ 4	1-day weighed meals (kept by research assistant)	-3.9	<0.05	<ul style="list-style-type: none"> <li>Some foods obscured in images</li> <li>Memory lapses could not always identify unknown food</li> </ul>	Only 1-day of assessment, females only

<sup>a</sup>SD = Standard deviation; <sup>b</sup>Difference in mean energy intake compared to reference method (%); <sup>c</sup>Exact P-value if reported; <sup>d</sup>Energy intake data for 19 participants; <sup>e</sup>FR = Food Record; <sup>f</sup>PDA = Personal Digital Assistant; <sup>g</sup>SEM = Standard error of the mean; <sup>h</sup>EMA = Ecological Momentary Assessment; <sup>i</sup>Doubly labelled water; <sup>j</sup>Fewer participants due to dropouts and/or excluded data; <sup>k</sup>NR = not reported; <sup>l</sup>Standard deviation not reported.

## 5.7. Discussion

We conducted the first systematic review to examine studies which have evaluated or validated methods of image-assisted dietary assessment. Research to date has primarily explored the potential of image-assisted methods in pilot and feasibility studies, and few methods have been formally validated using criterion measures and adequately sized samples.<sup>209, 222, 229</sup> However, several studies have demonstrated how images can enhance self-reported dietary intake by revealing unreported foods and misreporting errors.<sup>210, 213, 230</sup> The additional dietary information obtained from the images appears to increase reported EI<sup>210, 213, 230</sup> and likely reduces random errors.<sup>96</sup> Furthermore when used as the primary record of dietary intake, images can be analyzed to obtain valid and reliable estimates of EI with reduced measurement error (for EI) compared to traditional methods.<sup>26, 131, 152-154, 209, 216-219, 222</sup> However, due to the complexity and diversity of foods, EI is likely to be under-estimated if the methods procedure is not followed correctly by the user, the images are of poor quality, or if the user forgets to capture images prior to the eating episode.<sup>209, 211, 224, 227</sup>

Trade-offs during image analysis are also made as certain dietary components including hidden ingredients and cooking method, which affect energy and nutrient composition cannot be determined with image analysis alone. Consequently, it appears essential that images of foods must be supported by additional dietary information to achieve optimal accuracy.<sup>211, 222, 224</sup> However, the coding errors associated with image analysis are likely to be random,<sup>96</sup> which are less problematic compared to the systematic bias observed when food type and portion size are self-reported.<sup>27, 28, 119, 246, 247</sup> Thus there are both strengths and limitations of using images to assess dietary intake, but these cannot be entirely understood until further high quality studies have been conducted. Moreover, as image-assisted methods and systems continue to develop, the strengths and limitations will also evolve.

The search strategy identified three other image-assisted methods in development (yet to be evaluated among users)<sup>31, 214, 231, 232</sup> that have innovative features that may enhance image-assisted methods further. Two of these methods, The Food Intake Visual Recognizer (FIVR),<sup>231</sup> and The Diet Data Recorder System (DDRS)<sup>232</sup> are image-based food records (on smartphones) that also incorporate the use of automated image analysis systems.<sup>231, 232, 248</sup> However, FIVR aims to incorporate voice recognition software to clarify details of dietary intake, and DDRS

removes the need for a reference marker by using a laser within a smartphone case to project a visual reference to assist analysis.<sup>232</sup>

Techniques to analyze images without a reference marker have also been described for the bespoke wearable camera eButton (worn on the chest) specifically designed for the passive assessment of dietary intake and physical activity.<sup>214, 221, 249</sup> The eButton and other future wearable devices may address some technical limitations, such as insufficient battery life, poor quality images, and insufficient imaging frequencies<sup>212, 213, 230</sup> but will need to capture useable images in all environments and during non-daylight hours to effectively record dietary intake.<sup>212, 213, 230</sup> Considering the diversity and complexity of dietary intake in free living environments, accurate assessment of dietary intake using passive methods alone will be very challenging.

Privacy concerns also need to be addressed. Though wearable cameras capture images of third parties in a similar manner to smartphones or security cameras, their acceptance and etiquette for use in society is yet to be established. The limited release of smart-wearable eyewear by Google “Glass” has received substantial media attention regarding the devices innovative applications, but also concerns regarding privacy at a government level.<sup>250</sup> It appears wearable devices need to be paused or switched off in certain buildings or locations, and images could be captured accidentally when the user or others expect privacy, especially problematic if the research involves children and the images are transmitted automatically in real-time. In order to address privacy concerns related to the use of wearable cameras in health research, Kelly et al<sup>251</sup> have developed an ethical framework that provides guidelines for best practice. Other potential safeguards could also alleviate privacy concerns, such as automated face-blurring, and sensors (accelerometers) to trigger image capture or store images (in memory) only when eating is detected.<sup>252, 253</sup> However, it is clear that further research is required to better understand these ethical issues and potential solutions.

Other questions regarding image-assisted dietary assessment remain. No study has validated an image-assisted method among the elderly (>70 years), children and adolescents, and the feasibility of image-assisted methods in large studies (N>100) has not been demonstrated. Older adults may fail to remember the method more often and are potentially less accustomed to using smartphones and other technologies, while usability studies among children and adolescents indicate they prefer methods using technologies over traditional methods.<sup>241, 254, 255</sup> With respect to

large samples, participants will need to own or be provided with a suitable device (to reduce the potential for respondent bias),<sup>96</sup> which increases study costs.

Limitations of the review need to be considered. The majority of studies reviewed were pilot and feasibility studies, thus future research may not reflect the results of these preliminary studies. Due to the heterogeneity of the technologies used, methods employed to assess dietary intake and different study designs, only a narrative review could be conducted. Furthermore limiting the search strategy to scientific journal articles may have excluded the most recent technologies or unpublished information as some commercial methods may not undergo scientific testing.

Study heterogeneity also made evaluating study quality challenging. The European Micronutrient Recommendations Aligned (EURRECA) Network of Excellence scoring system is a useful tool to objectively assess the quality of dietary intake validation studies,<sup>256</sup> but is not particularly suited to rating the quality of studies evaluating image-based methods. The EURRECA system allocates points for the data gathered by a face-to-face interview, but image-based methods can be assessed remotely by independent analysts/researchers.<sup>256</sup> Development of a scoring system that differentiates between traditional self-report data and data obtained independently from image analysis (manual or automated) would be useful.

## **5.8. Conclusions**

Current evidence regarding the validity of image-assisted methods of dietary assessment is limited, but studies to date have demonstrated images can enhance self-report data, and provide the primary record of dietary intake to obtain valid estimates of EI (when incorporated into a comprehensive system). Additional validation studies using criterion measures are needed. The validity among children, adolescents, and the elderly, as well as the feasibility of using image-assisted methods in large samples, warrants examination. Wearable cameras are a recent development in dietary assessment but further research is required to better understand the potential applications and pitfalls of using wearable technologies.

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# CHAPTER 6. FEASIBILITY OF A SENSECAM-ASSISTED 24h RECALL TO REDUCE UNDER-REPORTING OF ENERGY INTAKE

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## 6.1. Introduction to publication

A feasibility study was required to explore if wearable camera images can be incorporated into and enhance self-report in the 24-hour dietary recall method, and establish if the devices and methods used would be suitable for a larger validation study. This chapter (Chapter 6) is a reformatted version of the manuscript entitled “Feasibility of a SenseCam-assisted 24-h recall to reduce under-reporting of energy intake” published in the European Journal of Clinical Nutrition, 2013, Volume 68, Issue 10, Pages 1095-1099. DOI 10.1038/ejcn.2013.156. The latest impact factor available was 2.95 (2013). The chapter presents the results from the feasibility study, which explored the potential of wearable cameras to enhance self-report in 24-hour dietary recalls. This study was undertaken during a three-month research exchange in 2012, at the British Heart Foundation Health Promotion Research Group, University of Oxford, where the candidate was familiarised with the wearable camera, SenseCam and software used for the analysis (under supervision by Dr Aiden Doherty who developed the software and has expertise in the field). The study was undertaken to address Objective Three, which was to explore the feasibility of using wearable cameras to assist an interviewer-administered 24-hour dietary recall.

## 6.2. Author contribution

Luke Gemming was involved in developing the research question, ethics applications, study design, recruitment, data collection and data analysis. He also interpreted the findings and wrote the paper for publication.

# FEASIBILITY OF A SENSECAM-ASSISTED 24H RECALL TO REDUCE UNDER-REPORTING OF ENERGY INTAKE

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### 6.3. Abstract

**BACKGROUND/OBJECTIVES:** The SenseCam is a camera worn on a lanyard around the neck that automatically captures point-of-view images in response to movement, heat, and light (every 20 to 30s). This device may enhance the accuracy of self-reported dietary intake by assisting participants' recall of food and beverage consumption. It was the objective of this study to evaluate if the wearable camera, SenseCam, can enhance the 24-hour dietary recall by providing visual prompts to improve recall of food and beverage consumption.

**SUBJECT/METHODS:** Thirteen volunteer adults in Oxford, United Kingdom were recruited. Participants wore the SenseCam for two days while continuing their usual daily activities. On day 3, participants' diets were assessed using an interviewer-administered 24-hour recall. SenseCam images were then shown to the participants and any additional dietary information that participants provided after viewing the images was recorded. Energy and macronutrient intakes were compared between the 24-hour recall and 24-hour recall+SenseCam.

**RESULTS:** Data from 10 participants were included in the final analysis (8 males and 2 females), mean age  $33 \pm 11$  yrs, mean BMI  $25.9 \pm 5.1$  kg/m<sup>2</sup>. Viewing the SenseCam images increased self-reported EI by approximately  $1432 \pm 1564$  KJ or 12.5% compared with the 24-hour recall alone ( $p=0.02$ ). The increase was predominantly due to reporting of 41 additional foods (241 vs. 282 total foods) across a range of food groups. Eight changes in portion size were made which resulted in a negligible change to EI.

**CONCLUSIONS:** Wearable cameras are promising method to enhance the accuracy of self-reported dietary assessment methods.

## 6.4. Introduction

The 24-hour dietary recall is widely used in dietary assessment due to its low participant burden, ease of administration, and suitability for a wide range of populations including participants with low literacy.<sup>2</sup> However, as a retrospective method it relies on self-report without verification, thus lapses in participant's memory, errors in portion size estimation, or intentional misreporting remain unidentified, but contribute to measurement error.<sup>8, 257, 258</sup>

Analyses of data from national nutrition surveys in many countries including Australia, New Zealand, and the United States of America which used the 24-hour recall have demonstrated substantial under-reporting of energy intake (EI), particularly in females, overweight, and obese participants.<sup>70, 71, 73</sup> Considerable under-reporting has also been revealed in doubly labelled water validation studies using the 24-hour recall administered in-person or via the telephone.<sup>258-261</sup> Under-reporting leads to attenuation and misclassification error, thus impeding the ability to identify associations between diet and disease. Consequently the need for technological innovation is well recognised,<sup>15, 16</sup> as technology has the potential to provide objective dietary intake data, reduced participant burden, standardised and automated methods of assessment, and new methods, previously not feasible, to assess dietary intake.

The development of structured interviewer-administered and self-administered computer based 24-hour recall systems can reduce interviewer bias and measurement error, but such systems still rely on self-report without the ability to verify dietary recall.<sup>20, 26, 262</sup> The recent development of wearable cameras with a point-of-view lens may provide a complementary objective measure to assist self-report, as these devices can record food consumption objectively and passively; which was previously only possible using a trained observer. Such devices are common place in adventure sports, but have recently been integrated directly into smart glasses (e.g. Google Glass) for everyday use, to complement and enhance smart phone features. Thus the rapid development and use of wearable cameras in society may provide new opportunities to obtain objective dietary intake data.<sup>263</sup>

Arab et al.<sup>21</sup> first demonstrated the feasibility of wearable cameras for dietary assessment in using a customised mobile phone worn around the neck that captured images automatically every 10s. The images were sent to an internet server automatically and assisted participants self-report dietary intake using a web-based 24-hour recall (Image-DietDay) which revealed promising



results<sup>212</sup>; however, the cameras narrow field of view and insufficient battery life were noted limitations.

The SenseCam is a wearable camera worn around the neck and captures wide angle point-of-view images passively, every twenty to thirty seconds, in response to movement (tri-axial accelerometer), heat (infrared heat sensor), and light (light intensity sensor).<sup>243</sup> SenseCam and other similar devices can capture images automatically over entire days, weeks, or years, and are used to create digital life-logs. Life-logging is the digital capture and storage of personal data with the aim to record complete and searchable personal digital archives to assist people with everyday tasks, and/or remember past events.<sup>264-266</sup> Thus wearable cameras, such as SenseCam, are used to assist people with memory impairment, as the captured images provide a powerful cue for memory recall,<sup>33, 267</sup> but have also been used in health research,<sup>244</sup> to enhance self-reported measures of physically active travel,<sup>268, 269</sup> sedentary behaviour,<sup>270</sup> physical activities,<sup>271</sup> and as a supplement to food records.<sup>272</sup>

Wearable cameras may also enhance the 24-hour dietary recall by providing visual prompts to improve recall of food and beverage consumption. Therefore we conducted a feasibility study to evaluate the potential of the SenseCam to assist an interviewer-administered 24-hour dietary recall. The study was designed to assess the degree to which the images assisted and changed the participants' self-reported dietary intake. Specific objectives' were to determine the effect viewing the images had on self-reported energy and nutrient intakes.

## 6.5. Methods

A convenience sample of thirteen healthy adults between the age of 18 and 65 years were recruited through an advertisement posted on notice boards in Oxfordshire, United Kingdom. Participants were excluded if they followed strict dietary regimes (e.g. vegan) to ensure a wide range of foods were captured, or were unable to complete usual activities of daily living. Participants were provided a brief training session, and information sheet, explaining how to use and wear the SenseCam. The SenseCam is very simple to operate and only requires the participant to turn the device on for continuous operation. A privacy button can be activated to temporarily stop image capture when required (SenseCam automatically starts capturing images again after 7 minutes).



Participants were instructed to wear the SenseCam for two full days whilst continuing their usual daily activities. The two-day period allowed participants to become familiar with using the SenseCam and participants were informed their diet would be assessed using a standard method for nutrition research. On day three, participants had their diet assessed over the previous 24-hours (day 2) by a trained dietitian (LG) using an interviewer administered multiple pass 24-hour dietary recall (MP24), based on the United States Department of Agriculture multiple pass method.<sup>26</sup> A portion size guide and standard household measures were used to assist participants' self-reported dietary intake.<sup>273</sup>

After the MP24, participants were given the opportunity to privately screen the captured images using a freely available SenseCam browser<sup>274</sup> and instructed to delete any photos they wished. This procedure followed ethical guidelines for SenseCam research to ensure the privacy of the participants was maintained (some images may contain private and/or sensitive content). The remaining SenseCam images were viewed by participants and dietitian together to identify all eating episodes and to confirm or modify details reported in the initial 24-hour recall (MP24+SenseCam). Dietary details recorded in the MP24 were re-stated, but the information was not scrutinised and no changes were suggested by the dietitian to reduce the possibility of interviewer-bias. However, the dietitian did query unreported foods visible in the images and participants confirmed or modified these foods accordingly.

Unreported foods, changes to portion size, and other misreporting errors (e.g. exchanging or removing foods) were grouped by the following food categories: breads and cereals; beverages (including milk; excluding water due to no energy content); fruit and vegetables; meats and dairy (e.g. cheese); biscuits, sweets, and snacks; condiments (spreads, sauces, dips and dressings). After completion of the MP24+SC (SenseCam) participants completed a brief feedback survey to explore the user experience of wearing the device. The survey used seven point Likert scales, or categorical scales with open text response sections. The study was approved by the Central University Research Ethics Committee University of Oxford (Ref: SSD/CUREC1A/12-008), and the University of Auckland Human Participants Ethics Committee (Ref:7942).

### **6.5.1 Analysis**

Foods and beverages were analysed using nutrient analysis software WISP (Tinuviel Software, V 3.0, Warrington, United Kingdom). Data analysis was performed using SPSS Statistics (V 20.0,

IBM, Armonk, New York, USA). A paired t-test was used to compare the differences in self-reported energy and nutrient intakes between the MP24 and MP24+SC. Participant characteristics were described with summary statistics. Statistical significance was set at  $\alpha \leq 0.05$ .

## 6.6. Results

### 6.6.1 Participants

Thirteen participants were recruited but ten participants (8 males and 2 females), aged  $33 \pm 11$  years with a mean BMI  $25.9 \pm 5.1 \text{ kg/m}^2$  were included in the analysis (Table 7). Two participants were excluded due to a technical fault and loss of images, and one was excluded for protocol non-adherence (SenseCam infrequently worn). The participants were predominantly healthy and physically active (excluding one participant with obesity), all had completed a bachelor's degree or higher, and all were currently employed in professional positions. The excluded participants (1 Male, 2 Females) were slightly older  $39 \pm 13$  years but had a similar BMI and education.

**Table 7 Characteristics for the ten participants included in the analysis**

<b>Participant characteristics (n=10)</b>	
<b>Male (n)</b>	8
<b>Female (n)</b>	2
<b>Mean <math>\pm</math> SD</b>	
<b>Age (yrs)</b>	$33 \pm 11.3$
<b>Height (m)</b>	$1.78 \pm 0.1$
<b>Weight (kg)</b>	$82.3 \pm 21.8$
<b>BMI (<math>\text{kg/m}^2</math>)</b>	$25.9 \pm 5.51$

### 6.6.2 Dietary recall

Energy and macronutrient intakes are presented in **Table 8**. The MP24+SC resulted in a significantly greater reported mean EI than the MP24 alone ( $12888 \pm 2977 \text{ KJ}$  vs.  $11455 \pm 2099 \text{ KJ}$ ,  $p=0.02$ ) with a mean difference of 12.5%. Significantly higher reported intakes of protein, total fat, saturated fat, and mono-unsaturated fat were also evident with the MP24+SC compared to the MP24.

**Table 8 Energy and macronutrient intakes from one interviewer-administered multiple pass 24-hour dietary recall (MP24), and the MP24 with the assistance of SenseCam images (MP24+SC).**

Nutrient	MP24	MP24+SC	Mean Difference
	(n=10)	(n=10)	
Energy (KJ)	11 455 ± 2099.1	12 887.6 ± 2977.3	1431.8 ± 1563.7*
Protein (g)	106.7 ± 45.9	110.2 ± 64.0	17.1 ± 22.2*
Carb (g)	317.28 ± 63.7	355.2 ± 67.3	38.0 ± 56.7
Fat (g)	121.82 ± 32.7	135.9 ± 42.4	14.1 ± 16.9*
SAFA (g)	35.6 ± 13.27	40.8 ± 16.6	5.2 ± 6.4*
MUFA (g)	37.5 ± 15.8	43.1 ± 16.7	5.6 ± 6.1*
PUFA (g)	21.0 ± 13.1	25.6 ± 12.3	4.7 ± 8.0
Fibre (g)	20.3 ± 8.1	22.7 ± 9.4*	2.4 ± 2.8*

Means and standard deviations, difference = MP24+SC – MP24, \*P<0.05

SAFA: saturated fat, MUFA: monounsaturated fat, PUFA: polyunsaturated fat.

Information on unreported foods, changes to portion size and misreported foods detected by SenseCam are presented in Table 9. A total of 41 unreported foods in the MP24 were revealed by viewing the SenseCam images (MP24+SC), 241 vs. 282 total foods respectively (additional 17% foods items). The additional foods were from all food categories and had energy contents from 0KJ to 1820KJ. The beverage category had greatest number of unreported items (n=9) but provided less energy than other groups excluding fruits and vegetables. Unreported breads and cereals, meats and dairy, and biscuits sweets, and snacks accounted for the greatest additional energy. The condiments category had the fewest unreported foods (n=4) but on average these additions each provided substantial additional energy (773 ± 737KJ).

There were only eight changes to portion size, (five increases in portion size, three reductions in portion size) that provided little effect on EI overall (-259KJ to 189KJ). Misreporting errors i.e. foods incorrectly reported in the initial MP24 and modified after image review (e.g. salmon exchanged for chicken) had a greater effect on EI (-787KJ to 165KJ) compared to changes to portion sizes and the majority of misreporting errors were in the fruits and vegetables category (n=8).

### 6.6.3 Feedback survey

Results from the participant feedback survey are presented in **Table 10**. The survey revealed participants found the images helped them remember foods they had forgotten about (median score 7) and were able to provide more accurate information (median score 7) but had less impact on helping them to remember extra details of how foods were prepared or purchased (median score 4). Participants indicated wearing the SenseCam and using it to assess their diet was a low burden but three sometimes felt uncomfortable in public situations, such as riding the bus or purchasing items (open text feedback). Wearing the SenseCam never (50%), seldom (10%), or sometimes (40%) affected dietary behaviours. Qualitative feedback revealed five participants were conscious of the device during food consumption and some considered making healthier food choices and may have eaten fewer snacks, but the degree of behaviour change was not clear. Participants indicated that about one week would be the maximum time they would wear a SenseCam.

**Table 9 Energy provided from unreported foods, change to portion size or misreported foods revealed from one SenseCam-assisted interviewer administered MP24+SC.**

n=10		Alterations	Breads & Cereals	Beverages (excl. water)	Fruit and Vegetables	Biscuits, Snacks, Sweets	Meats and Proteins	Spreads, Sauces, Dressings
<b>Unreported Foods</b>	(n)		7	9	7	8	6	4
	<b>Energy (KJ)</b>							
	Mean ± SD		585.6±255.0	277.2±192.9	323.2±171.1	510.7±294.2	688.7±535.2	773.2±736.8
	Total		4099.5	2494.5	2262.3	4086.1	4132.1	3092.8
<b>Δ Portion Size</b>	(n)		1	3	1	1	1	1
	<b>Energy (KJ)</b>							
	Mean ± SD		-	-55.2±34.8	-	-	-	-
	Total		112.1	-165.6	5.64	-68.5	-258.6	189.9
<b>Misreported Foods</b>	(n)		0	2	8	0	1	1
	<b>Energy (KJ)</b>							
	Mean ± SD		-	-73.9±149.9	-11.5±433.6	-	-	-
	Total		-	147.7	-80.3	-	1087.2	1651.6

**Table 10 Participant evaluation of the SenseCam-assisted 24-hour recall (MP24+SC).**

<b>Median values, n=10</b>	<b>Strongly disagree = 1 to strongly agree = 7*</b>					
The images helped me to remember some foods I had forgotten about	7					
The images helped me to remember extra details of how my foods were cooked, prepared or purchased	4					
The images helped me to remember the portion size of the foods I ate	5					
The images helped me to verify the portion size of foods I ate using the portion size guides	6					
The images allowed me to provide more accurate information about the foods I ate	7					
	<b>very low burden =1 to very high burden = 7*</b>					
Was the camera a burden to wear?	2.5					
Was reviewing the images on the computer a burden?	2					
Was the overall method to assess your diet a burden?	2					
	<b>Never</b>	<b>Seldom</b>	<b>Sometimes</b>	<b>Usually</b>	<b>Always</b>	
Wearing the camera affected my eating behaviour (n)	5	1	4	0	0	
I felt uncomfortable wearing the camera (n)	3	4	3	0	0	
	<b>1 day</b>	<b>2-3 days</b>	<b>Week</b>	<b>Fortnight</b>	<b>Month</b>	<b>&gt; Month</b>
What is the maximum period you would wear the camera for?	0	4	5	0	1	0

## 6.7. Discussion

This study demonstrated that a wearable camera can be used to enhance the 24-hour dietary recall by revealing unreported foods and misreporting errors. Overall reviewing the images revealed 17% additional food items and increased reported EI by 12.5%.

As a novel study no direct comparison was possible, however, the 24-hour recall method typically provides EI data that is under-reported by approximately 8-24% compared to doubly labelled water.<sup>8</sup> Thus the increase in self-reported EI, revealed from viewing passively captured images, indicates that wearable cameras may help to reduce levels of under-reporting. Though, additional and more rigorous testing of wearable cameras is necessary.

O'Loughlin et al<sup>272</sup> conducted a similar study (n=34) in Ireland that used SenseCam to enhance a 1-day food kept record by trainee Jockeys, Gaelic football players, and university students which revealed a 10-18% increase in EI after image review. No data regarding what accounted for the increase was reported but unreported foods and changes to portion size were indicated by the investigators. Arab et al.<sup>212</sup> also reported promising results using images captured automatically on mobile phones to assist a self-reported 24 recall (Image-DietDay) but the study did not classify how the images assisted recall.

Other image-assisted methods to assess dietary intake have are also in development. Sun et al<sup>205</sup> has described a customised wearable camera system for objective dietary assessment. Similar to the SenseCam the device is worn at chest height but aims to use automated images analysis to objectively assess intake, however, at the time of writing no dietary intake data has been presented. Other research investigating image-assisted electronic food records on smartphones (or cameras) is encouraging.<sup>224, 242, 275</sup> However, this approach is fundamentally different as participants are still required to initiate data collection, thus a similar burden to traditional self-report methods is placed on the participant to actively record food consumption. Though, it is likely future developments of technology will allow these two image-assisted approaches to complement each other in an effort to objectively assess dietary intake.

The use of images captured from a wearable camera to assist dietary recall in this study revealed a diverse range of unreported foods throughout the day (only one food item revealed at supper). Some foods, including tea, black coffee, mandarins, and peas provided little energy but other foods including avocado on toast, potato crisps, cheese, and lemon drizzle cake provided



considerable additional energy. The wide variety of foods and the fact that both healthy and unhealthy foods were under-reported indicated under-reporting was likely random. The degree of under-reporting revealed may reflect the physically active sample, as increased levels of physical and varied lifestyle have been shown to reduce the accuracy of self-reported intake.<sup>157, 272</sup> Conversely, this finding may simply reflect widespread under-reporting that plagues traditional dietary assessment methods.<sup>8</sup>

The misreported foods, as identified by participants (i.e. removed or corrected following image review), further exposed and reduced random error associated with existing dietary assessment methods. The errors were predominately single food items (e.g. orange corrected to banana) but some involved multiple foods within the same eating episode (small salmon fillet and salad corrected to chicken breast, jacket potato, with salad and caesar dressing). Fewer changes to portion size were probably attributed to poor image quality (foods in low-light, food partially obscured, or undesirable angles) and the decision not to question the participant's self-report. This reduced the potential for interviewer bias and any change to portion size may lead to a correlated error (as the true portion size remained unknown).<sup>119, 276, 277</sup>

Participant feedback indicated viewing the images assisted with portion size estimation but also revealed wearing the camera may have affected dietary behaviours; thus may not be a true representation of usual intake. Similar participant feedback was reported by Arab et al. (24) with mobile phones worn around the neck to capture dietary intake. Nearly all participants found the images helpful during the Image-DietDay 24-hour recall, but some were self-conscious in public which may have affected normal behaviour.

In the present study the magnitude of behaviour change was not clear but social desirability and other psychosocial factors including social approval and fear of negative evaluation affect dietary behaviours<sup>154, 246, 247, 278, 279</sup> and self-reported dietary intake.<sup>206, 260, 280</sup> Wearable cameras may exacerbate behaviour change as devices are visible to others and objectively record food consumption in real-time. Moreover the ability to omit foods during subsequent self-reported dietary intake is minimized as all food are recorded (unless the device was switched off) therefore may further affect behaviours, especially in groups prone to misreporting including women, overweight and obese.<sup>152, 197, 217</sup>

It was observed that often participants' memory was prompted to recall additional foods before the specific image revealing the unreported food was displayed. The mechanism that acts to enhance

memory recall is unknown, but it's suggested images are possibly captured at the same moment memory encoding is taking place <sup>266</sup>, and functional magnetic resonance imaging (fMRI) has revealed regions of the brain where memories are processed and stored are activated when viewing SenseCam images, but not activated reviewing a written diary of the same events. <sup>32</sup> Thus viewing the images provides both a powerful cue for memory recall and an objective record of the day's events if memory isn't prompted. In combination this provides participants a better opportunity to correctly self-report dietary intake and reduce under-reporting.

The strength and novel feature of this study was the direct comparison between traditional self-report and self-report with the assistance of SenseCam. Often studies identify under-reporting but can only suggest why or how under-reporting has occurred. The SenseCam and other wearable cameras allow under-reporting to be explored in detail providing insight into the cause of under-reporting, previously not feasible in a free living situation.

However, the SenseCam has some limitations. The imaging frequency of 20-30sec was not always sufficient to capture all foods consumed, posture and body shape can affect lens angle resulting in non-useful images (more commonly in women), and poor image quality in low-light environments were limitations of the SenseCam device with respect to assessing dietary intakes. Further, the device malfunctioned for two participants that resulted in a loss of images and one participant was non-compliant (camera worn infrequently). Similar reliability and compliance issues were noted by O'Loughlin et al when the SenseCam was to enhance written food records. <sup>272</sup> These issues would need to be resolved before wide-scale use of wearable cameras in dietary assessment.

This study also had limitations. A sole dietitian (LG) conducted the dietary recalls without a gold-standard reference method thus interviewer error cannot be ruled out, and the sample size was small and primarily consisted of well-educated active adult men. Therefore the findings of this pilot may not apply to women or other groups, and should be repeated in an adequately sized sample to confirm these findings.

## **6.8. Conclusion**

In summary the use of wearable cameras appears to be a promising method to enhance self-reported dietary assessment. Viewing the images revealed a number of unreported foods, and

other misreporting errors, which increased self-reported EI. Overall this provided a clear indication to how wearable cameras may reduce levels under-reporting. Further research using gold-standard methods, such as doubly labelled water, is required to validate the use of wearable cameras in dietary assessment, and the degree to which wearable cameras affect dietary intake and behaviours should be explored.

### **Acknowledgements**

We would like to thank the participants and the British Heart Foundation Heart Promotion Research Group, University of Oxford for their expertise, guidance, and technical support for SenseCam research.

### **Conflict of Interest**

There were no conflicts of interest.



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# **CHAPTER 7. WEARABLE CAMERAS CAN REDUCE DIETARY UNDER-REPORTING: DOUBLY LABELLED WATER VALIDATION OF A CAMERA-ASSISTED 24-HR RECALL**

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## **7.1. Introduction to publication**

The feasibility study indicated wearable cameras may enhance self-report in the 24-hour dietary recall by revealing unreported foods and misreporting errors. Therefore, if similar findings could be demonstrated using a criterion reference method this would provide strong evidence supporting their use in future methods of dietary assessment and nutrition research. This chapter (Chapter Seven) is a reformatted version of the manuscript entitled “Wearable cameras can reduce dietary under-reporting: Doubly labelled water validation of a camera-assisted 24-HR recall” was published in the British Journal of Nutrition, 2015 volume 113, pages 284-291 DOI: 10.1017/s0007114514003602. The latest impact factor available was of 3.302 (2012). A few minor revisions were made to this reformatted manuscript at the request of the thesis examiners. The chapter presents the results from a validation study that examined the magnitude to which wearable cameras enhance self-report in 24-hour dietary recalls. The study was undertaken to address Objective Four, which was to validate a wearable camera image-assisted 24-hour dietary recall using the criterion measure doubly labelled water.

## **7.2. Author contribution**

Luke Gemming was involved in developing the research question, ethics application, study design, recruitment, study management, data collection and analysis. He also interpreted the findings, and wrote the paper for publication.

# **WEARABLE CAMERAS CAN REDUCE DIETARY UNDER-REPORTING: DOUBLY LABELLED WATER VALIDATION OF A CAMERA-ASSISTED 24-HR RECALL**

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### 7.3. Abstract

Preliminary research suggests that wearable cameras may reduce under-reporting of energy intake (EI) in self-reported dietary assessment. The aim of the present study was to test the validity of a wearable camera-assisted 24h dietary recall against doubly labelled water. Total energy expenditure (TEE) was assessed over a 15-day DLW protocol among 40 adults (*n* 20 males; age 35, SD 17 yrs; BMI 27, SD 8; and 20 females; age 28, SD 7yrs; BMI 22, SD 2). EI was assessed using three multiple-pass 24h dietary recalls between days 2-4, 8-10, and 13-15 (MP24). On the days prior to each nutrition assessment, participants wore an automated wearable camera (SenseCam) in free-living conditions. The wearable camera images were viewed by participants following completion of the dietary recall, and their changes to self-reported intakes were recorded (MP24+SenseCam). TEE and EIs assessed by MP24 and MP24+SC were compared. Among men, MP24 and MP24+SC underestimated TEE by 17% and 9%, respectively ( $P<0.001$  and  $P=0.02$ ). Among women, MP24 and MP24+SC underestimated TEE by 13% and 7%, respectively ( $P<0.001$  and  $P=0.004$ ). The assistance of the wearable camera (MP24+SC) reduced the magnitude of under-reporting by 8% for men and 6% women compared to the MP24 alone ( $P<0.001$ , and  $P<0.001$ ). The increase in EI was predominantly from 265 unreported foods revealed by participants during the image review. Wearable cameras enhance the accuracy of self-report by providing passive and objective information regarding dietary intake. High definition image sensors and increased imaging frequency may improve the accuracy further

## 7.4. Introduction

Traditional methods of dietary assessment are subjective and rely on self-report. Therefore the accuracy of dietary data is influenced by memory recall, burden of administration,<sup>2</sup> psychosocial factors,<sup>28, 278, 281</sup> and other behavioural characteristics<sup>134, 156-158</sup> with gender,<sup>73, 150, 151</sup> age,<sup>70, 73, 145, 146</sup> body size,<sup>73, 146, 152-155</sup> and ethnicity<sup>73, 150, 151, 213</sup> all shown to affect reporting.

To address these constraints there is interest in image-assisted dietary assessment.<sup>205, 209, 214, 231, 282</sup> Handheld devices were first used to capture images of foods manually but development of automated wearable cameras has allowed first-person point-of-view image capture to be explored.<sup>212, 213, 230, 245</sup> Wearable cameras provide a new opportunity to improve the accuracy of dietary assessment as the images/video provide a passive and objective record of an individual's eating episodes.<sup>205</sup>

Initial estimates suggest wearable camera-assisted methods may have a relatively small measurement error for energy intake (EI) (7%),<sup>212</sup> and increase self-reported EI of traditional methods by 10-18% .<sup>213, 230</sup> The increased EI results from detection of unreported foods, changes to reported portion size, and other misreporting errors identified within the images.<sup>213</sup> However, previous studies relied on the participant to manually capture images,<sup>212</sup> had small sample sizes,<sup>212, 213</sup> and none have compared wearable-camera assisted dietary assessment against a criterion measure, such as doubly labelled water.<sup>213, 230</sup>

In the present study we used doubly labelled water (DLW) to validate a wearable camera-assisted 24h recall. Analyses compared reported EI from 24h dietary recalls alone and dietary recalls plus the wearable camera (SenseCam) compared with total energy expenditure (TEE), estimated using DLW. A secondary objective was to examine the mechanism by which camera images enhance dietary recalls by quantifying alterations in self-report after viewing the images.

## 7.5. Subjects and methods

Forty volunteers, aged 18-64yrs, (20 male, 20 female) from the greater Auckland city metropolitan area, New Zealand were recruited by advertisements on community notice boards located at 15 supermarkets and three university campuses, and a campaign through a participant recruitment service website ([www.researchstudies.co.nz](http://www.researchstudies.co.nz)). The recruitment service sent email announcements to people who had previously indicated interest in human research, and used paid advertisement



campaigns on Facebook. Potential participants who indicated interest were phoned, assessed for eligibility, and provided with written and verbal information regarding study procedures. Written informed consent was obtained before commencement of study.

Participants were informed the purpose of the research was to evaluate the use of Passive Image Capture to Record Everyday Events (PICTURE study) using wearable cameras. There was no specific reference to a validation study but participants were informed the images would be used to help assess their dietary intake and other health behaviours, such as the time spent watching television or travelling to work (not reported here).

All eligible participants were in self-reported good health, were not actively pursuing weight loss, and did not plan to conduct additional physical activity (above normal) or travel during the study period. Pregnant and lactating females or people with a recent acute illness, blood tests or intravenous fluids two weeks prior to the study scheduled study period were excluded. Recruitment efforts were targeted to all adults 18 to 65 years of age, but the participants contacted ensured an equal number of male and female participants were selected. The University of Auckland Human Participants Ethics Committee approved the research (ref 8701). An \$80 NZD gift card was given to participants at the conclusion of the testing period to compensate them for their time.

### **7.5.1 Study design**

The study was a cross-sectional repeated measures design. Each participant took part in the study for a 15-day period in free living conditions, wore a wearable camera on four days, and data were collected at four appointments; a baseline assessment and three follow-up dietary assessments. Data collection was between March and September 2013.

Participants were contacted 1-3 days prior to their scheduled baseline assessment to reaffirm the study procedures and schedule the nutrition assessments. Participants fasted overnight ( $\geq 10$ h) and were instructed to refrain from any strenuous activity the day before the baseline assessment. Anthropometric characteristics, weight in light clothing with shoes and jewellery removed ( $\pm 0.05$ kg, BWB-620, Wedderburn, Australia), height ( $\pm 0.1$ cm, Secca, London, United Kingdom), and percentage body fat ( $\pm 5$  ohm, Imp DF50, ImpediMed, Pinkenba, Australia) were assessed.

Resting energy expenditure (REE) was measured before participants were given a weight-specific dose of DLW to determine TEE during the study period. Participants then wore a wearable camera (SenseCam) for four days; one familiarisation day, and each day prior to three interviewer-administered multiple pass 24-hour dietary recalls (MP24) conducted between days 2-4 (nutrition assessment 1), days 8-10 (nutrition assessment 2), and days 13-15 (nutrition assessment 3). Therefore, there was a minimum of three days and a potential maximum of eight days between nutrition assessments.

Five timed urine samples were collected for the determination of TEE at baseline, 5hr post dose, and days 3, 9 and 15. Participants were instructed to collect at least 50 mL of the second void of the day, to place and seal the sample in a specimen pot and record the time-of-void on a form provided. The samples were collected from participants at the earliest opportunity, either at the next nutrition assessment or from their home (if diet was assessed before collection). To assess any weight change during the testing period, body mass was reassessed on day 15 using the same scales. During the study period participants were told to follow their usual daily routines. A basic instruction leaflet for the SenseCam and a timeline of scheduled study assessments were provided at the conclusion of the baseline assessment. Standardised text messages were used to remind participants of the study protocol (e.g. Day 3: please remember to collect urine sample #3 (not the first void of the day) PICTURE STUDY). Messages were sent at times to align with the participant's reported usual daily schedule.

### **7.5.2 Use of wearable camera**

The SenseCam is a wearable camera worn around the neck on a lanyard with a wide-angled lens. <sup>243, 244</sup> Sensors detect movement (accelerometer), heat (infrared), and light to approximately trigger image capture approximately every 20s (~2000-3000 images per day). Internal flash memory is sufficient for one week and battery capacity is adequate for a typical 12-16h day. Once turned on, the SenseCam operates continuously until the camera is switched off; or a privacy button can be activated to cease image capture temporarily (7min). Participants were provided instructions and demonstrated they could operate and wear the device correctly at the baseline assessment. On the recording days participants were instructed to wear the device from when they woke (after bathing and dressing) until bedtime but could remove the camera anytime they felt uncomfortable or in locations where photography was inappropriate (e.g. gymnasium or public

restroom). An information sheet was provided to help participants determine when the camera should be switched off or not worn. The images were encrypted to ensure participants could not view the images before the nutrition assessment or if lost could not be viewed by third parties. After the completion of each MP24 participants were provided with a chance to screen the images privately and instructed to delete any image they did not wish to disclose before a joint image review with the researcher.<sup>251</sup>

### 7.5.3 Energy intake assessment

**MP24:** The dietary recalls were conducted by a trained dietitian (LG) using a pen and paper based multiple pass method with a forgotten foods list to probe for unreported foods, adopted from the United States Department of Agriculture<sup>26</sup> followed by an image review, see **Figure 13**. The assessments were conducted at the University of Auckland or participants' homes, or workplaces. Standard household measures, example crockery and glassware, and a portion size guide were used to assist participants to estimate portion sizes. The portion size guide used<sup>273</sup> was developed for the Australian population where the food supply is similar to New Zealand (no New Zealand specific portion size guide has been developed).

**MP24+SC:** After the final pass of MP24 the researcher (LG) used Doherty's wearable camera browser<sup>244</sup> to review the SenseCam images with the participant (after the images were screened privately by the participant). The participants were instructed to confirm, modify, add, or remove food items present in the images (MP24+SC). To assist the process the researcher simply restated the foods and portions self-reported in the MP24, but did not suggest changes or scrutinise self-reported intakes and queried about any unreported food items present in the images. All changes made by the participants were detailed to determine the frequency and impact on EI. All unreported foods, misreporting errors, and alterations to portion size grouped by the following food categories: breads and cereals; beverages (excluding water due to no energy content); fruit and vegetables; meats & fish dairy products; snack foods (biscuits, sweets, and other snack foods); condiments (spreads, sauces, dips and dressings); alcohol; and other. The changes to self-report were both individual foods and composite foods (some foods cannot be separated into individual components).

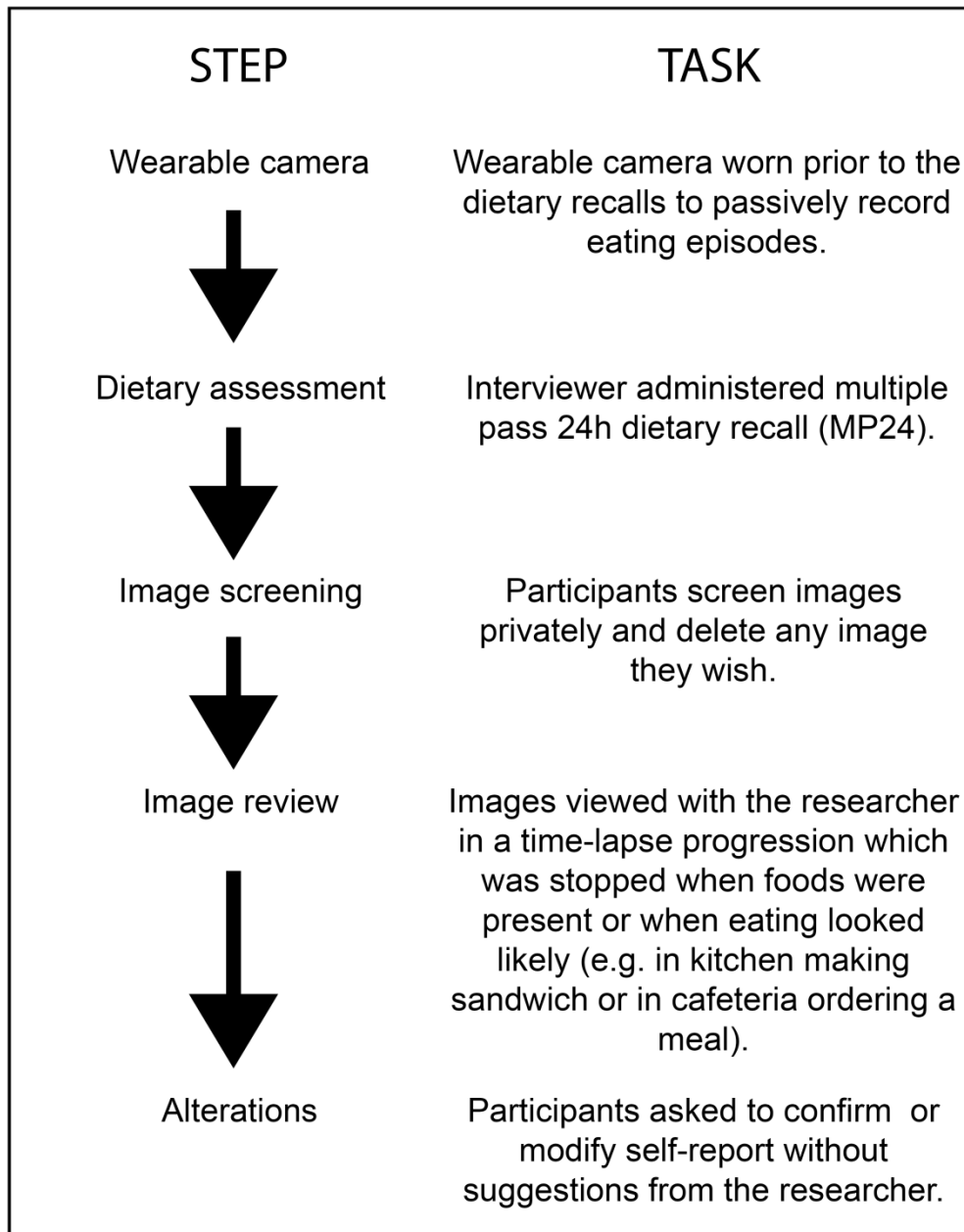


Figure 13 Procedure to estimate energy intake with the wearable camera

#### 7.5.4 Measurement of total energy expenditure

Daily TEE was measured using the DLW method. At the baseline assessment participants ingested a pre-mixed dose of  $\sim 0.1\text{g}$  99.9%  $^2\text{H}_2\text{O}/\text{kg}$  total body water (TBW) and  $2\text{g}$  10%  $\text{H}_2^{18}\text{O}/\text{kg}$  TBW. To ensure the full dose was consumed the dose bottle was rinsed three times with tap water followed by an additional mouth rinse. To ascertain background isotope levels a baseline urine sample was collected before dosing. Participants collected timed urine samples (5h post-dose, and on days 3, 9 and 15) were frozen (in duplicate in glass bottles) until study completion and analysed using an elemental analyser (Thermo, USA) coupled with a DeltaV isotope ratio mass spectrometer (Thermo, USA). Daily TEE was calculated by the multipoint method by linear regression from the difference between elimination constants of  $^{18}\text{O}$  and  $^2\text{H}$  with individual respiratory quotient determined using the mean from the three MP24+SC dietary recalls<sup>133</sup>.

#### 7.5.5 Resting energy expenditure

A standardised protocol was used to assess REE between 07:00 and 10:00. The TEE divided by REE was used to calculate the participants' activity factor during the study period. Participants were instructed to fast overnight ( $\geq 10\text{h}$ ) and refrain from any strenuous activity the day before the assessment. Before commencement participants were positioned (near supine) on a folding bed for  $\geq 10\text{min}$  asked to relax but remain awake. Testing was conducted in an environmental chamber maintained at  $22^\circ\text{C}$  with lights turned off during all assessments (participants remained awake throughout). REE was measured by indirect calorimetry using mouth piece and nose clip analysed breath by breath with a Moxus Modular system (S-3A/I Oxygen Analyser, CD-3A Carbon Dioxide Analyser, and KTC3 Turbine Volumetric System, AEI technologies, Pittsburgh, USA). A 30min measurement protocol was followed with data from the first 10min and final 2min omitted, along with periods of movement by the participant. Before each assessment the metabolic cart was calibrated with standard gas mixtures and a volumetric syringe. The activity factor was calculated by dividing TEE by REE.

### 7.5.6 Statistical analysis

All participants' data were included in the final analysis as device non-compliance and technical issues best reflect free-living conditions. Dietary intake was analysed using the nutrient analysis software FoodWorks 7 Professional edition (Xyris Software, Australia). Data analysis was performed using the software package for statistical analysis SPSS Statistics (V 20.0, IBM, USA). Paired t-tests were used to compare differences in self-reported EI between the MP24 and MP24+SC and EIs versus TEE. Limits of agreement between the EIs of the MP24 and MP24+SC and TEE were assessed according to the recommendations of Bland and Altman<sup>283</sup>. Alterations in self-report (MP24+SC) and participant characteristics were described with summary statistics. Statistical significance was set at  $\alpha \leq 0.05$ .

## 7.6. Results

All participants completed the study procedures. General characteristics of the study population are presented in **Table 11**. The participants were predominantly New Zealand Europeans and the majority had tertiary education, but differences in age, body size and education between the male and female samples were apparent. Men were predominately overweight or obese (65%) and approximately eight years older than women who were generally of normal body weight (75%). Moreover a greater proportion of women had attended university or completed graduate degrees (80% versus 65%). Mean body weight did not differ significantly between day 0 and day 15 for men or women (difference = -0.4kg SD 0.2 kg,  $P=0.296$  and 1.1 kg SD 0.7 kg,  $P=0.400$ , respectively).

**Table 11 Demographic characteristics of the study sample.**

	Male		Female	
	Mean	SD	Mean	SD
<b>Age (years)</b>	34.8	12.6	27.1	7.5
<b>Weight (kg)</b>	86.4	14.7	61.3	9.7
<b>Height (m)</b>	178.0	6.1	165.3	6.9
<b>BMI (kg/m<sup>2</sup>)</b>	27.2	3.9	22.3	2.3
	<i>n</i>	%	<i>n</i>	%
<b>Body Size</b>				
Normal	7	35	17	85
Overweight	9	45	3	15
Obese	4	20	0	0
<b>Ethnicity</b>				
NZ European	14	70	15	75
Maori	2	10	1	5
Asian	4	20	4	20
<b>Education</b>				
High school or less	7	35	4	20
University diploma or undergraduate degree	10	50	11	55
Postgraduate degree	3	15	5	25

TEE measures and EI data for all 40 participants were used. Three participants did not wear the camera for one of three recording days (two participants indicated they were in bed for most of the day, and one participant was noncompliant for one of the three recording days) and six device malfunctions occurred which resulted in failure to capture images. Additionally on two occasions participants forgot to bring the camera to the assessment. However, the MP24 was still conducted as usual and thus the MP24 and MP24+SC simply had the same values for these 11 instances (9% of all dietary recalls). Regarding the image screening the proportion of participants that chose not to screen the images privately increased at each successive nutrition assessment (n=13, n=18, and n=25 respectively). When images were screened the median time was 5.5 min (range = 1.0 to 17.1 min, IQR = 5.2 min).

For both male and females the 24h dietary recalls were distributed across all days of the week, but the proportion was lower on weekend days, shown in **Table 12**. Mean TEE measured by DLW and reported EIs assessed from the three 24h recalls (MP24 and MP24+SC) are presented in **Table 13**. For men the reported EIs were 17% (MP24) and 9% (MP24+SC) below the measured TEE. For women the mean reported EIs were 13% (MP24) and 7% (MP24+SC) below TEE. For men raw correlations between TEE and EI in the MP24 and MP24+SC were 0.68 and 0.61, respectively. In women correlations were 0.82 and 0.81, respectively. An assessment of agreement revealed EI does not influence the magnitude of measurement error (see online

supplementary material, **Figure 16** and **Figure 17**). The reduced magnitude of under-reporting of EI is presented in **Table 14**. The assistance of the wearable camera (MP24+SC) significantly reduced under-reporting for both men and women compared to the MP24 alone in all three dietary recalls, and there was no significant difference observed between TEE and EI of the MP24+SC in nutrition assessment two.

**Table 12 Distribution by day of the week for the dietary recalls collected for the total sample<sup>\*</sup>.**

	Male	Female
	%	%
Monday	18	12
Tuesday	15	13
Wednesday	18	22
Thursday	12	22
Friday	15	12
Saturday	10	8
Sunday	12	12

<sup>\*</sup> Each participant (n=40) had three multiple pass dietary recalls obtained over a two week period.

The increased EI associated with MP24+SC is presented in **Figure 15**. There was no relationship evident between the increase in EI and TEE, but viewing the images sometimes resulted in a decreased EI. Alterations in participants self-report are summarised in **Table 14**. The increase in reported EI was predominantly due to the addition of 265 unreported foods. Portion size was increased in most instances (49/51) but overall this had less impact on reported EI than misreported foods that were removed or exchanged during the image review.

One male and three females were excluded for REE data as the participants did not achieve a rested state during the REE procedures. The REE and activity factor for men and women were  $7807 \pm 2125$  kJ, activity factor  $1.9 \pm 0.5$ , and  $6548 \pm 2033$  kJ activity factor  $1.8 \pm 0.6$  respectively.



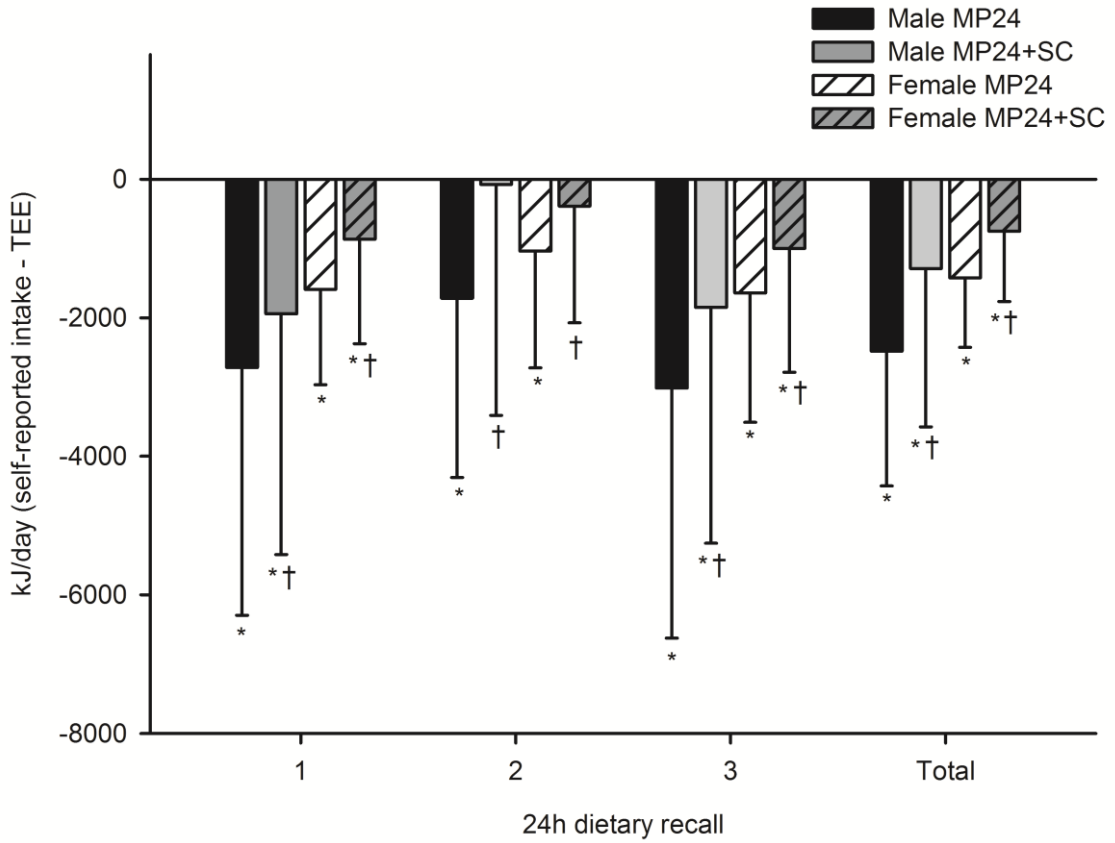
**Table 13 Daily energy intake (EI) measured in three Multiple Pass 24h dietary recalls (MP24 and MP24+SenseCam) and total energy expenditure (TEE) measured with the doubly labelled water technique.**

	Male (n=20)						Female (n=20)					
	EI (kJ/day)		TEE (kJ/day)		TEE - EI	P	EI (kJ/day)		TEE (kJ/day)		TEE - EI	P
	mean	SD	mean	SD	%		Mean	SD	TEE	SD	%	
<b>Total</b>												
<b>MP24</b>	12 004	2122	14 485	2632	-17	<0.001	9420	1694	10 841	1639	-13	<0.001
<b>MP24+SC</b>	13 196*	2529			-9	0.02	10091*	1672			-7	0.004
<b>Recall 1</b>												
<b>MP24</b>	11 770	3564	14 485	2632	-19	0.003	9253	1501	10 841	1639	-15	<0.001
<b>MP24+SC</b>	12 543*	3941			-13	0.02	9975*	1674			-8	0.02
<b>Recall 2</b>												
<b>MP24</b>	12 769	3183	14 485	2632	-12	0.008	9805	2699	10 841	1639	-10	0.013
<b>MP24+SC</b>	14 411*	3417			-1	0.923	10455*	2621			-4	0.319
<b>Recall 3</b>												
<b>MP24</b>	11 472	3447	14 485	2632	-21	0.001	9202	2068	10 841	1639	-15	<0.001
<b>MP24+SC</b>	12 634*	3331			-13	0.025	9843*	1983			-9	0.218

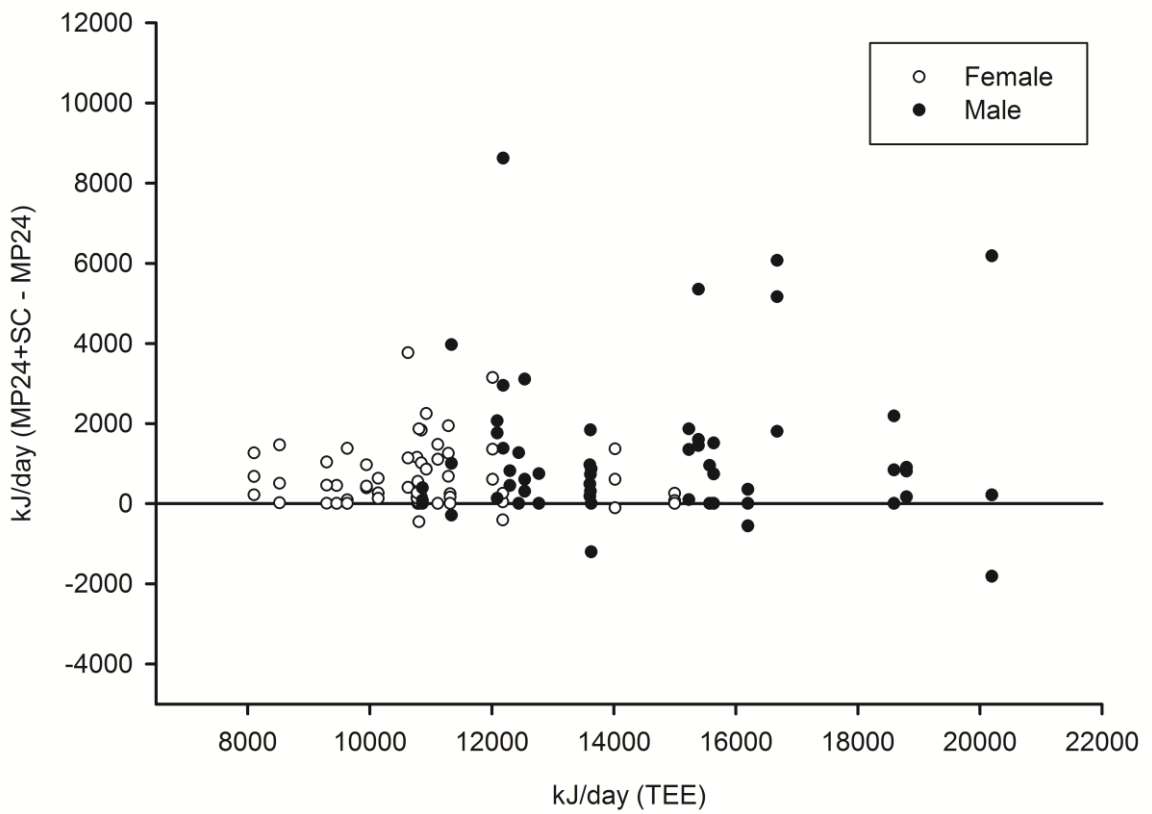
SC = SenseCam, \* MP24+SC significantly different to MP24 P≤0.05

**Table 14 Alterations in energy intake for all participants viewing wearable camera images after completion of the multiple pass dietary recalls (MP24+SenseCam).**

	Unreported foods				▲ Portion Size				Misreported foods			
	<i>n</i>	Energy (kJ)		Total	<i>n</i>	Energy (kJ)		Total	<i>n</i>	Energy (kJ)		Total
		Mean	SD			Mean	SD			Mean	SD	
<b>Breads/ cereals</b>	23	462	162	10 634	16	462	306	7386	3	-607	191	-1821
<b>Beverages</b>	40	308	182	12 334	6	26	80	155	13	-135	149	-1754
<b>Fruit/ vegetables</b>	47	153	98	7187	10	43	56	434	8	-130	107	-1037
<b>Meat /fish/eggs</b>	11	590	140	6494	3	88	22	264	2	-402	211	-804
<b>Dairy</b>	18	616	181	11 090	2	333	78	667	3	-113	56	-340
<b>Snack foods</b>	64	571	425	36 547	3	1140	411	3419	3	-1112	331	-3335
<b>Condiments</b>	50	307	270	15 343	7	181	35	1266	1	-184	-	-184
<b>Alcohol</b>	7	712	130	4983	1	128	-	128	0	-	-	-
<b>Other</b>	5	1191	203	5957	3	-30	105	-91	3	-2526	793	-7577
<b>Total</b>	265	417	222	110 570	51	267	166	13 628	36	-468	311	-16 852

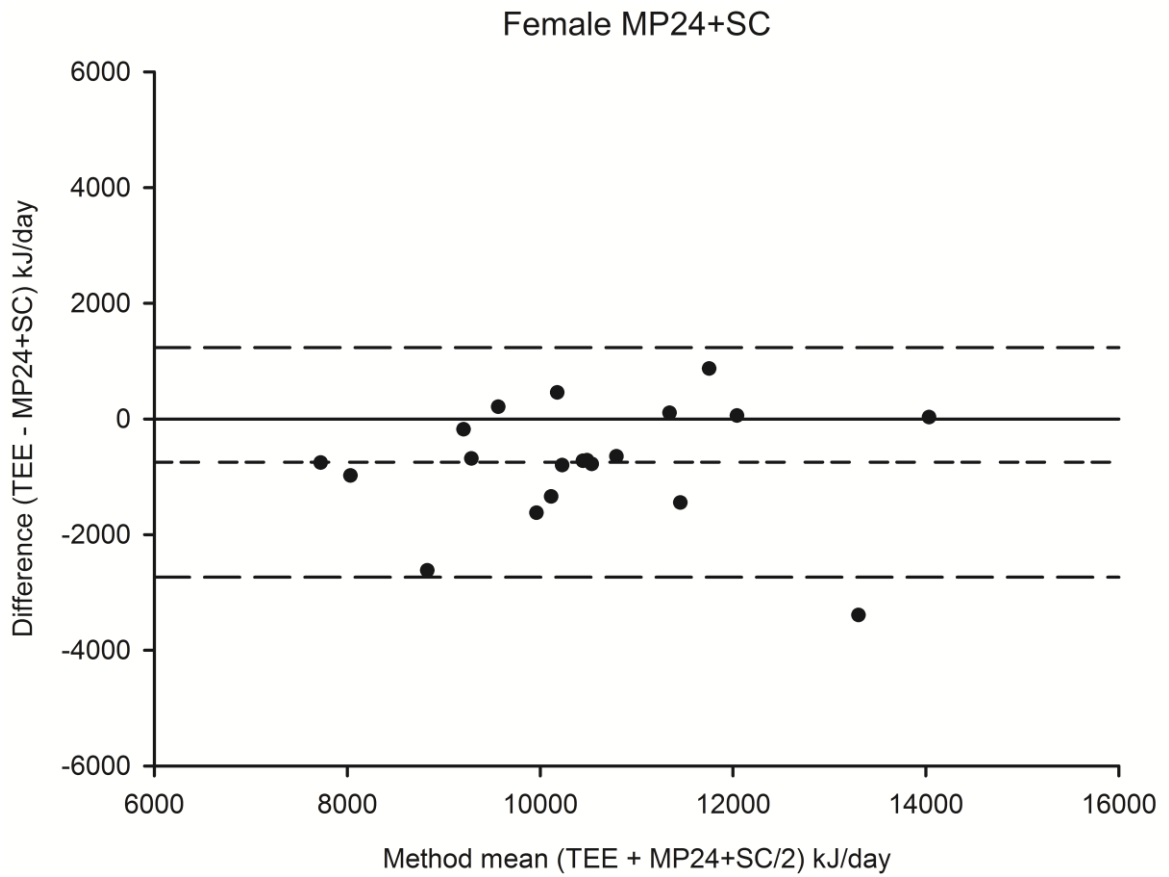


**Figure 14** Under-reported energy intake in the 24h dietary recall alone (MP24) and with the assistance of the wearable camera (MP24+SC) compared to total energy expenditure (TEE) for men and women. \*Significantly different to TEE  $P \leq 0.05$ . †Significantly different to MP24,  $P \leq 0.05$ .



**Figure 15** Change to self-reported energy intake in the 24h dietary recalls (MP24) after viewing the wearable camera images (MP24+SenseCam), compared to total energy expenditure (TEE) for men and women (n=120), three 24h dietary recalls for each participant).





**Figure 17 Agreement between mean self-reported energy intake (MP24+SenseCam) and TEE for women (n=20).**

## 7.7. Discussion

The present study validated a wearable camera-assisted dietary recall against DLW and examined the impact of wearable cameras on dietary underreporting. Overall the addition of wearable cameras significantly reduced the magnitude of dietary energy under-reporting by 9% in men and 6% in women compared to dietary recall alone. The findings confirm preliminary research which suggested wearable cameras may reduce measurement error by revealing unreported foods and misreporting errors.<sup>213, 272</sup>

The degree of under-reporting dietary EI observed in the MP24 alone (male 17%, female 13%) was similar to that reported in other 24h recall DLW validation studies, which have reported EI values approximately 8-24% below TEE.<sup>8</sup> When compared with the largest DLW study (n=524) to date, which validated the Automated Multiple Pass Method (AMPM), the level of dietary EI underreporting bias was comparable for males (14% among overweight men and 20% among obese men compared to 17% in the present study) but higher for females (6% among women with normal body weight compared to 13% in the present study).<sup>26</sup> The lower value observed in the AMPM validation was likely attributable to the structured AMPM software (not pen and paper), and robust trial conditions used to replicate the procedures of the NHANES survey<sup>26</sup> in conjunction with a motivated sample, which received substantial financial incentives.

There have been few DLW validations of image-assisted dietary assessment methods. A custom wearable camera “eButton” designed to objectively assess dietary intake and physical activity has been demonstrated, but is yet to be validated.<sup>205, 214</sup> Other image-assisted methods in development differ as they require participants to actively capture images using smart phones or other handheld devices. Nonetheless validation of the Remote Photography Food Method (a manually triggered image-based dietary record) against DLW among free-living adults (predominantly overweight and obese) revealed reduced measurement error compared to traditional methods (mean EI 6% below TEE compared to 12-49% among overweight and obese populations reported elsewhere).<sup>26, 152-154, 209, 216, 218, 219</sup> Similar image-based dietary records in development are yet to be validated with human participants.<sup>231, 282</sup>

Several factors may explain why under-reporting was not completely eliminated with the assistance of the wearable camera. The wearable cameras imaging frequency was insufficient (2~3 images per minute) to capture all foods consumed, and image quality was relatively poor,

especially in low light environments. Moreover the position of the camera on the body allows the lens angle to be affected by posture, and foods in bowls or on high tables can be obscured easily. Intentional under-reporting may also go undetected if participants delete images of foods during the private screening. However, the short duration participants took to screen the images and the proportion of participants that chose not to screen their images in second and third nutrition assessment, suggested this was not a frequent issue. Reactivity could also be a factor. Previous studies have indicated using wearable cameras are a low burden but may impact on participants' usual dietary behaviours; however, the degree of behaviour change was unclear.<sup>212, 213</sup> Additional dietary recalls for non-camera days would have provided a within-person comparison to assess reactivity.

Other study limitations include the relatively small heterogeneous sample that was not representative of the general population; therefore the study may have produced different results. Moreover, due to differences in body size male and female data were treated separately. However, participants of all body sizes were deliberately recruited as the earlier feasibility study revealed camera-assisted recalls were helpful for all types of people<sup>213</sup>. Additionally, the prevalence of under-reporting increased substantially in New Zealand's most recent adult nutrition survey among people with normal body weight, as well as overweight and obese<sup>97</sup>. Furthermore, a sole dietitian conducted the nutrition assessments and image review process, thus interviewer bias cannot be ruled out (the interview procedures were not audited). Additionally, the dietary intake data may not be representative of usual intake, due to the short duration of the study, limited number of dietary recalls conducted, and the lower proportion of weekend days versus weekdays.<sup>95</sup>

A unique feature of the study was the detailed comparison between traditional self-report alone versus self-report assisted by the wearable camera. This study design allowed determinants of under-reporting to be identified, and confirmed unreported snack foods, condiments and beverages are a primary source of under-reported EI in a free-living setting. An interesting finding in both the feasibility<sup>213</sup> and current study was the frequency that fruit and vegetables were unreported (47/265 foods). Often these were during snacks, such as bananas, apples, carrots, and raisins, and further highlights the difficulty participants have remembering snacking episodes during retrospective dietary assessments. The alterations by participants to portion size may have produced correlated errors (as the true portion size remained unknown),<sup>119, 276, 277</sup> but in most



instances the portion size was clearly incorrect (e.g. two vs. one slice of toast). The decision not to question or scrutinise the participants self-report during the image-review reduced the potential for interviewer bias<sup>96</sup> but trained image analysts or use of automated image-analysis techniques could enhance the method further.<sup>209, 240</sup>

The strength of automated wearable cameras over handheld devices is their ability to capture images passively, which means they are potentially less intrusive during daily activities and may reduce participant burden. Wearable technologies can also collect physical activity data passively (using inbuilt accelerometers and GPS), a key lifestyle consideration often overlooked when collecting dietary intake data.<sup>144, 185</sup> Thus wearable technologies have potential greater than simply revealing under-reported foods and misreporting errors, which needs to be explored.

## **7.8. Conclusions**

The wearable camera significantly reduced the magnitude of under-reporting in the 24h dietary recall by 9% in men and 6% in women, as the images revealed unreported foods and misreporting errors not captured by the traditional method alone. Wearable cameras with faster imaging frequencies, high definition image sensors, and the use automated image analysis techniques may enhance the method further. Additional research is needed in larger representative samples of the population. Future studies should explore the use of wearable cameras in different settings using a variety of image-assisted methods.

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The authors responsibilities were as follows: LG, CN, ER, RM, AD, and NG: study design; LG and CNM: data collection and study management; LG, ER, RM, and NG: energy expenditure analyses; LG, CN, ER, RM, AD, NG, and JU: data interpretation; LG: statistical data analysis; and LG wrote the manuscript; CN, ER, RM, AD, NG, and JU edited the manuscript. None of the authors had a personal or financial conflict of interest.

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# CHAPTER 8. THE USE OF A WEARABLE CAMERA TO CAPTURE AND CATEGORISE THE ENVIRONMENTAL AND SOCIAL CONTEXT OF SELF-IDENTIFIED EATING EPISODES

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## 8.1. Introduction to publication

Wearable cameras provide a unique opportunity, which was previously not feasible, to passively collect objective data on behaviours in free-living settings. Consequently, these new data may provide additional useful information regarding the populations' dietary intake and dietary behaviours compared to the data currently collected. This chapter (Chapter Eight) is a reformatted version of the manuscript entitled "The use of a wearable camera to capture and categorise the environmental and social context of self-identified eating episodes" submitted to the journal "Appetite" on the 10<sup>th</sup> September 2014. The journal specialises in behavioural nutrition and the cultural, sensory, and physiological influences on choices and intakes of foods. The manuscript has been through peer-review, revised and resubmitted, and is currently awaiting final editorial decision. The most recent impact factor available was 2.520 (2013). The chapter presents results from a manual image analysis conducted on the dataset obtained in the PICTURE study reported in Chapter Seven. The study was undertaken to address Objective Five, which was to assess the utility of wearable cameras to objectively record and reliably assess environmental and social contexts of eating episodes.

## 8.2. Author contribution

Luke Gemming was involved in developing the research question, ethics application, study design, data collection and analysis. He also interpreted the findings, and wrote the paper for publication.

# THE USE OF A WEARABLE CAMERA TO CAPTURE AND CATEGORISE THE ENVIROMENTAL AND SOCIAL CONTEXT OF SELF-IDENTIFIED EATING EPISODES

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### 8.3. Abstract

**Background:** Research investigating the influence of the environmental and social factors on eating behaviours in free-living settings is limited. This study investigates the utility of using wearable camera images to assess the context of eating episodes.

**Methods:** Adult participants (N=40) wore a SenseCam wearable camera for 4 days (including 1 familiarisation day) over a 15-day period in free-living conditions, and had their diet assessed using three image-assisted multiple-pass 24-hour dietary recalls. The images of participants eating episodes were analysed and annotated according to their environmental and social contexts; including eating location, external environment (indoor/outdoor), physical position, social interaction, and viewing media screens.

**Results:** Data for 107 days were used, with a total of 742 eating episodes considered for annotation. Twenty nine percent (214/742) of the episodes could not be categorised due to absent images (12%, n=85), dark/blurry images (8%, n=58), camera not worn (7%, n=54) and for mixed reasons (2%, n=17). Most eating episodes were at home (59%) and indoors (91%). Meals at food retailers were 24.8 minutes longer (95% CI: 13.4 to 36.2) and were higher in energy (mean difference = 1196kJ 95% CI: 242, 2149) than at home. Most episodes were seated at tables (27%) or sofas (26%), but eating standing (19%) or at desks (18%) were common. Social interaction was evident for 45% of episodes and media screens were viewed during 55% of episodes. Meals at home watching television were 3.1 minutes longer (95% CI: -0.6 to 6.7) and higher in energy intake than when no screen was viewed (543kJ 95% CI: -32 to 1120).

**Conclusion:** The environmental and social context that surrounds eating and dietary behaviours can be assessed using wearable camera images.

**Keywords:** SenseCam, nutrition assessment, context, eating behaviours

## 8.4. Introduction

Poor quality diets, excess energy intakes, and unhealthy energy dense foods are associated with increased morbidity and mortality from diet-related non-communicable diseases.<sup>4, 5, 54</sup> Understanding the determinants of eating behaviours, including the environmental and social context in which they occur, is important to inform nutrition policies and interventions to positively change these behaviours.<sup>40-44</sup> Investigations on human eating and dietary behaviours have examined a range of sensory and internal physiological mechanisms relating to food intake, primarily within laboratory settings.<sup>41, 42, 284-286</sup> However, research exploring the influence of environmental and social factors on intake in free-living settings is needed,<sup>35-39, 44, 286</sup> as lab-based research is not indicative of real-world eating behaviours.<sup>287-289</sup>

Environmental and social factors that are associated with or affect food intake include eating location (eating at home, versus out-of-home), physical position (seated eating at dining tables versus sofa or work desk), social-interaction (eating alone or in a social situation), presence of media screens (eating viewing television and other media screens), and other ambient factors (lighting, temperature, sounds and colours).<sup>41, 286, 290</sup> For example viewing media screens is associated with increased energy intake (EI) in laboratory settings,<sup>291</sup> but this may not reflect free-living conditions. However, if true, in which real-world contexts is the associated increase in EI present? Accurate measurement of the eating episodes and contexts surrounding food consumption in free-living settings are therefore important.<sup>286, 292</sup>

The difficulty with undertaking research in free-living settings is the absence of an unobtrusive measure to record valid data on contexts and dietary intake.<sup>36, 286, 293-295</sup> Lab-based research, though stringent in design, is not always indicative of real-world eating behaviours.<sup>42, 285-289</sup> Direct observations in free-living settings are possible, but researchers can inadvertently become part of the context they are observing,<sup>38</sup> and direct observations are not practical for large-scale research.

Wearable cameras may provide an unobtrusive approach to passively record contexts, as they capture images of events automatically from a first-person perspective.<sup>243, 244</sup> In a recent doubly labelled water validation study we demonstrated that wearable camera images can enhance self-report in dietary assessment by revealing unreported foods and misreporting errors not captured by traditional methods alone.<sup>296</sup> Therefore, we investigate the utility of wearable cameras to

objectively record and reliably assess environmental and social contexts of eating episodes, and compare the contexts EI and density using data obtained from wearable camera-assisted 24-hour dietary recalls in the validation study.<sup>296</sup>

## 8.5. Methods

The images and dietary EI data used in this study were taken from a 15-day study using doubly labelled water to validate the wearable camera image-assisted 24h dietary recall, conducted between March and September 2013<sup>296</sup>. The study recruited forty healthy adult participants (20 males; age 35, SD 17 yrs; BMI 27, SD 4; and 20 females; age 28, SD 7yrs; BMI 22, SD 2) from Auckland, New Zealand using an advertisement on a research studies website and flyers placed on community and university notice boards. This study was not designed or powered to detect differences between specific contexts during eating episodes, but rather to evaluate and demonstrate the potential of wearable cameras to passively record and assess contexts objectively. For this reason we limited our analysis to five contexts similar to those currently assessed in national dietary surveys,<sup>24, 85</sup> and only compared the episodes duration, EI and density of the different contexts. **Figure 18** presents a flow diagram of the study procedures and the dimensions coded for each eating episode. Ethical approval for the study was granted by the University of Auckland Human Participants Ethics Committee on the 30th November 2012 (Ref 8170). All participants provided written informed consent and were given information on appropriate use of a wearable camera in a free-living setting. Participants were compensated with an \$80 (NZD) gift card for their time.

### 8.5.1 Data collection

SenseCam is a wearable camera worn around the neck on a lanyard with a wide angle lens that automatically captures first person point-of-view images approximately every 20 seconds.<sup>243</sup> The exact imaging frequency differs as images are captured in response to sensors that detect changes in movement, heat and light.<sup>243</sup> The battery life is approximately 16 hours and thus sufficient to capture a participant's typical day without turning the device off. This allows both planned and spontaneous eating episodes to be captured passively.

Participants wore the SenseCam four allocated days from wake until sleep over the two week period in a free-living setting (completing their usual daily activities). Participants were familiarised with the device for 1-day before wearing the camera each day prior to three interviewer-administered multiple pass 24-hour dietary recalls (MP24). The three nutrition assessments for each participant were conducted between days 2-4 (nutrition assessment 1), days 8-10 (nutrition assessment 2), and days 13-15 (nutrition assessment 3). During the dietary assessment, the SenseCam images were downloaded from the device into freely available wearable camera software.<sup>274</sup> Participants screened the images privately, and were instructed to delete any that they did not want to be viewed by the researchers.<sup>251</sup> The remaining images were used by participants to enhance their self-reported dietary intake (MP24+SenseCam). The captured images are used in the present study to classify the context of the self-identified eating episodes.

### **8.5.2 Data processing**

The eating episodes were first defined and labelled in the software. The images were viewed chronologically by the researchers and the eating episodes were numbered and categorised into six possible meal types using the self-reported 24h-hour recall data: (1) breakfast, (2) morning snacks, (3) lunch, (4) afternoon snacks, (5) dinner, and (6) evening snacks/supper. These categories are in-line with those used in the National Health and Nutrition Examination Surveys to describe eating occasions (excluding brunch).<sup>24</sup> The starts of episodes were defined using the first image of food present, not including food preparation or cooking. The ends of episodes were defined using the image following the last image where food was present, rather than using the last image where food was present, as wearable cameras are insensitive to sub-15 second changes. For episodes where foods were only partially consumed, the image following the last to depict eating (indicated by movement of the food or participant in relation to the food) was used. Once the episodes were defined in the browser a new screen appeared showing all the images for the given episode. To confirm the duration of the episodes were defined correctly, the researcher viewed images before and after episodes to ensure no additional foods were consumed; the eating episodes were verified by comparing the time stamps and foods visible within the images to those self-reported by participants during the three SenseCam-assisted 24h recalls.

### 8.5.3 Annotation protocol

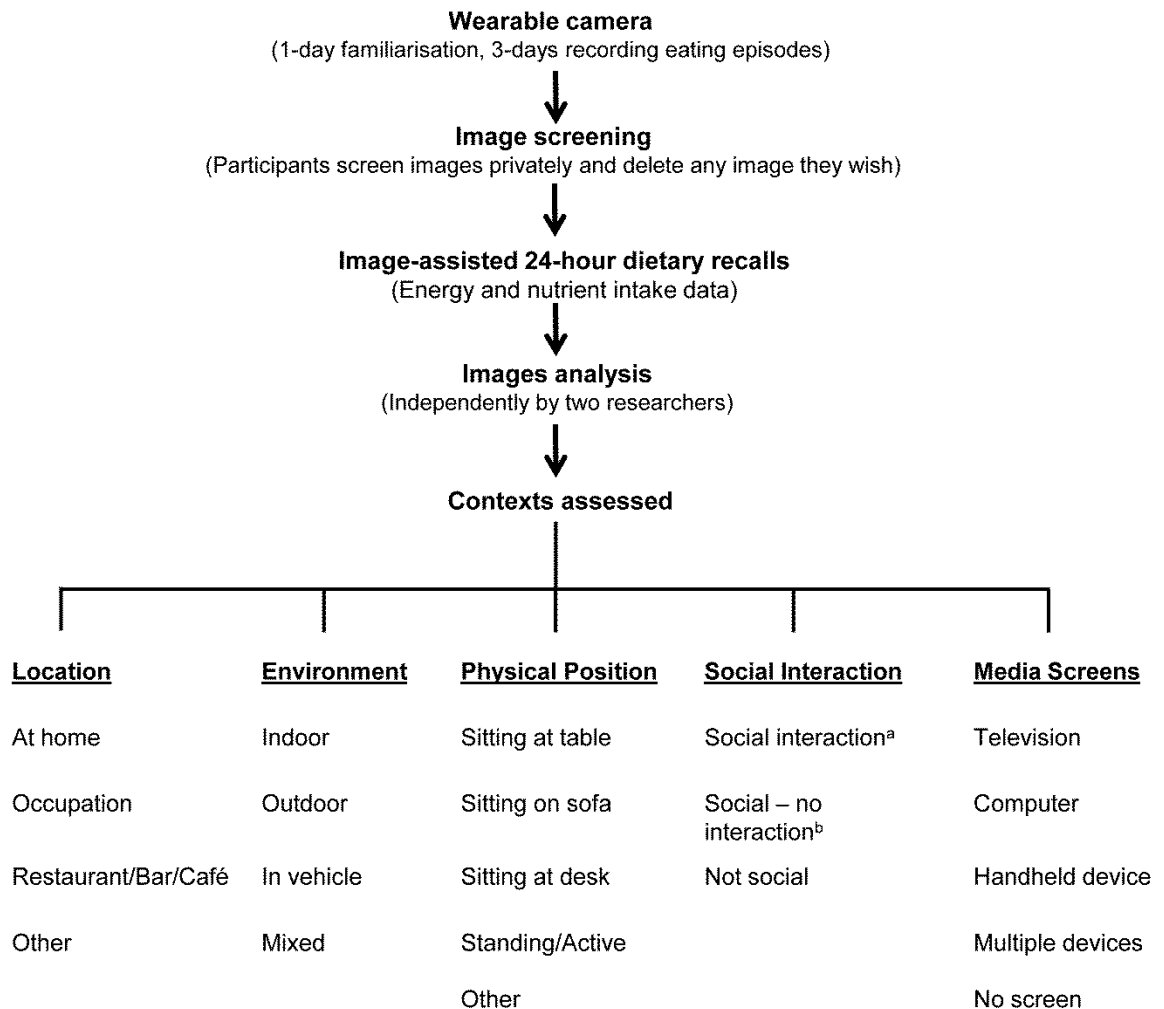
**Figure 18** shows the eating episodes were annotated on five dimensions (location, external environment, physical position, social interaction, and media screens) and included similar contexts as those self-reported in the National Diet and Nutrition Surveys of the United Kingdom, and those explored by other work using wearable cameras and personal digital assistants.<sup>85, 297, 298</sup> A final dimension was an optional comment field for episodes which could not be confidently annotated, which included (1) foods absent in images, (2) dark/blurry images, (3) camera not worn, and (4) for mixed reasons. In a similar manner to defining the episodes duration, the images before and after the defined eating episode provided visual clues to annotate on the context dimensions. Visual clues included approaching the outside of a food retailer or work location, viewing a menu with others while seated at a table, or walking to the sofa with the television turned on. Social interaction was primarily indicated by an active conversation with third parties. Other indicators of social interaction included body language/movements and eye contact of third parties. To determine the consistency among raters for classifying the five dimensions (location, external environment, physical position, social interaction, and media screens) a random sample of  $\geq 25\%$  of the eating episodes was independently annotated by two researchers (LG, ES) and an inter-rater reliability analysis using a kappa statistic was performed.

### 8.5.4 Data analysis

The data from the eating episodes were stored in the SenseCam software's Microsoft SQL database. The data were extracted for further analysis to SPSS (IBM Corporation, Version 20, USA). The variables recorded for each episode included participant ID, eating episode, meal type, annotatable, reason why episode was not-annotatable, start time, end time, duration, number of images, EI, and energy density. The contextual dimensions coded were location, external environment, physical position, social interaction, and media screens. Summary statistics were generated for each meal type to investigate how many eating episodes could be classified. Summary statistics were then generated for the context dimensions of all eating episodes, main meals (breakfast, lunch and dinner) and during snacking episodes (morning snacks, afternoon snacks, evening snacks). Mean differences and 95% confidence intervals were used to compare



different contexts for duration EI and density. Unpaired t-tests assessed any differences in EI and density between episodes that could be assessed with those that could not be assessed.



**Figure 18** Flowchart of study procedures to capture and categorise the environmental and social contexts of eating episodes using wearable camera images. Contexts were assessed using five dimensions with dimension-specific sub categories. <sup>a</sup>Participant actively engaged in social interaction during the eating episode. <sup>b</sup>Participant in a social situation e.g. café but not engaged in social interaction.

## 8.6. Results

The mean (SD) wear time of the wearable cameras was 13h 0min ( $\pm$  2h 23min) per day. Due to non-compliance wearing the camera (n=3), and technical failures that resulted in incorrect time stamps (n=4) and loss of images (n=6), data from 107/120 days were used in this analysis. **Table 15** provides details of the 742 self-reported eating episodes over the 107 days with associated images. The total time to define the eating episodes within the software, input the data for all variables, and annotate the episodes was 64h, an average of approximately 36 ( $\pm$  14.2) min per day of dietary intake. The average time for the manual annotation of context attributes associated with any given episode was 1min 21s ( $\pm$  44s). A random subset of 144 episodes (27%) was annotated independently by two researchers. The inter-rater reliability was 0.96 for location, 0.81 for indoor/outdoor, 0.84 for sitting/standing position, 0.68 for social interaction status, and 0.79 for the presence of media screens.

**Table 15 Eating episodes identified by 40 participants during three wearable camera image-assisted 24h dietary recalls.**

Meal	Number episodes	Mean energy intake (kJ $\pm$ SD)	Mean energy density (kJ/g $\pm$ SD)
Breakfast	115	2013 $\pm$ 1496	4.9 $\pm$ 3.5
Morning snack/s	123	752 $\pm$ 943	4.8 $\pm$ 5.7
Lunch	87	2681 $\pm$ 1654	6.1 $\pm$ 3.3
Afternoon snack/s	201	988 $\pm$ 1156	7.4 $\pm$ 7.2
Dinner	103	3506 $\pm$ 1832	5.6 $\pm$ 2.6
Evening Snack/s	113	1071 $\pm$ 1095	7.3 $\pm$ 7.1
All eating episodes	742	1668 $\pm$ 1665	6.2 $\pm$ 5.7

### *Effectiveness of wearable cameras to capture eating episodes for analysis*

From the 742 self-reported eating episodes, 29% (214 episodes) could not have their context categorised due to absent images (12%, n=85), dark/blurred images (8%, n=58), camera not worn (7%, n=54) and for mixed reasons (2%, n=17). Of the 71% of episodes (n = 528) that could be annotated, 35,299 images were captured, with one image being captured every 13.0s  $\pm$  3.2s.

**Table 16** compares the EI and density of eating episodes that could not have their context annotated (n = 528) with those that could not be annotated (n = 214). There were no significant differences observed in EI or density for specific meals that were coded compared to those not coded. The majority of episodes that could not be annotated were snacks (169/214), which had a similar energy content overall (mean difference = 44kJ 95% CI: -167 to 262, P=0.664) but were less energy dense (-1.8kJ/g 95% CI: -3.2 to -0.4, P=0.010).

**Table 16 A comparison of eating episodes that could be annotated for context using SenseCam images (n=528) compared to those that could not (n=214).**

	Energy intake (kJ ± SD)		Mean Difference kJ (95% CI)	P-Value	Energy density (kJ/g ± SD)		Mean Difference kJ/g (95% CI)	P-Value
	Not – Annotatable	Annotatable			Not – Annotatable	Annotatable		
<b>Breakfast</b>	1528 ± 1618 (n = 24)	2141 ± 1445 (n = 91)	613 (-125 to 1352)	0.101	4.4 ± 4.2 (n = 24)	5.0 ± 3.4 (n = 91)	0.6 (-1.2 to 2.5)	0.535
<b>Morning snack/s</b>	755 ± 1184 (n = 33)	751 ± 845 (n = 90)	-4 (-456 to 448)	0.986	4.7 ± 6.4 (n = 33)	4.9 ± 5.5 (n = 90)	0.2 (-2.3 to 2.7)	0.859
<b>Lunch</b>	2638 ± 2694 (n = 6)	2684 ± 1577 (n=81)	46 (-2774 to 2867)	0.968	7.8 ± 5.6 (n = 6)	6.0 ± 3.1 (n = 81)	-1.8 (-7.6 to 4.1)	0.467
<b>Afternoon snack/s</b>	857 ± 1064 (n = 70)	1057 ± 1200 (n = 131)	200 (-125 to 525)	0.227	9.5 ± 8.0 (n = 70)	6.3 ± 6.5 (n = 131)	-3.2 (-5.4 to -1.0)	0.05
<b>Dinner</b>	4341 ± 2079 (n = 15)	3363 ± 1760 (n = 88)	-987 (-2174 to 219)	0.103	5.2 ± 2.6 (n = 15)	5.6 ± 2.6 (n = 88)	0.7 (-1.1 to 1.9)	0.550
<b>Evening snack/s</b>	1053 ± 1219 (n = 66)	1097 ± 905 (n = 47)	43 (-352 to 439)	0.829	7.5 ± 7.4 (n = 66)	7.0 ± 6.7 (n = 47)	-0.5 (-3.1 to 2.2)	0.717
<b>Total</b>	1271 ± 1614 (n = 214)	1829 ± 1646 (n = 528)	558 (299 to 816)	<0.001	7.2 ± 7.1 (n = 214)	5.7 ± 4.9 (n = 528)	-1.5 (-4.3 to -2.5)	0.006

### ***Duration, energy intake and density of eating episodes by contexts***

**Table 17** shows the 528 eating episodes classified for context and their associated duration, EI, and density. On average the duration of eating episodes was 14.7 (±16.8) minutes. Snacking episodes were 3.9 minutes shorter on average (95% CI: -6.8 to -1.0) than meals, and contained approximately two thirds less energy (-1762kJ, 95% CI: -2002 to -1523) and were less energy dense (-0.4kJ/g 95% CI: -1.3 to -0.5).

### ***Location and Environment***

With respect to location, meals at home were 5.3 minutes longer (95% CI: 8.2 to 9.8) than meals in occupational settings (82% were lunch), but had a similar energy content and density. Snacks

at home were 4.4 minutes shorter (95% CI: -9.2 to -0.3) than snacks in occupational settings, but were higher in energy (367kJ 95% CI: 131 to 602) and more energy dense (2.5kJ/g, 95% CI: 0.8 to 4.2). Few episodes (6%) were in food retailers (restaurants/cafés/bars/fast food), but meals were 24.8 minutes longer (95% CI: 13.4 to 36.2) than meals at home, were higher in energy (1196kJ 95% CI: 242 to 2149), but had a similar energy density. Regarding other environmental factors, eating episodes indoors were 8.2 minutes longer (95% CI -2.4 to -18.9) than episodes outdoors, but had a similar EI and density. There were few (3%) episodes in vehicles or mixed environments (e.g. walking in park, drinking a coffee before catching a bus, and continuing to drink the coffee).

### ***Physical Position***

Regarding physical positions, meals consumed while seated at tables were 7.3 minutes longer (95% CI: 2.7 to 11.8) than meals in other positions, had a higher EI (938kJ 95% CI: 512 to 1365), but were less energy dense (0.9kJ 95% CI: -1.57 to -0.19). When compared directly to meals consumed while seated on sofas, meals at tables were 7.0 minutes longer (95% CI: 2.6 to 11.5), had more energy (462kJ, 95% CI:-29.8 to 955), and a similar energy density. The majority of eating episodes while standing/active were snacks (73%), which were 9.8 minutes shorter (95% CI: -12.8 to -6.8) than when seated, with a similar EI, but were more energy dense (2.9kJ/g 95% CI: 1.7 to 4.8).

### ***Social Interaction***

With respect to social context, meals with social interaction were 11.4 minutes longer (95% CI: 7.4 to 15.5) than meals with no social interaction, had more energy (684kJ 95% CI: 279 to 1088), but a similar energy density. Snacks with social interaction were 4.2 minutes longer (95%, CI: 0.0 to 8.6) than snacks with no social interaction, but with a similar EI and density. Few episodes (11%) were in social situations with no interaction.

### ***Media Screens***

Regarding screens, both meals and snacks consumed while viewing any type of screen were 4.3 and 2.7 minutes shorter (95% CI: 0.1 to 8.4 and -6.8 to 1.38, respectively) than when no screen was viewed, with EIs similar for both types of meals. Snacks consumed while viewing screens also had a greater energy density (1.8kJ/g 95% CI: 2.9 to 3.4) compared to when no screen was

viewed. Viewing media screens during eating episodes only within the home were also examined (see **Table 18**). Meals watching television at home were 3.1 minutes longer (95% CI: -0.6 to 6.7) than meals not viewing screens and were higher in energy (543kJ 95% CI: -32 to 1120). Snacks viewing television were a similar duration compared to snacks when no television was viewed, but were higher in EI (514kJ 95% CI: 47 to 1077). Computers were the most common screen viewed during snacks at home (31%) but were similar in duration, EI and density to when no screen was viewed.

**Table 17 Meal and snack eating episodes (N=528) from 40 participants by location, environmental context, positional context and social context.**

Context	Meals	Snacks	All eating episodes
<b>LOCATION</b>			
<b>At home</b>	<b>n=165 (63%)</b>	<b>n=147 (55%)</b>	<b>n=312 (59%)</b>
Energy intake (kJ± SD)	2665 ± 1562	992 ± 1002	1877 ± 1567
Energy density (kJ/g ± SD)	5.5 ± 3.0	6.5 ± 6.5	6.0 ± 5.0
duration (min ± SD)	11.3 ± 9.7	10.5 ± 14.5	11.7 ± 12.2
<b>Occupation</b>	<b>n=51 (20%)</b>	<b>n=68 (25%)</b>	<b>n=119 (23%)</b>
Energy intake (kJ± SD)	2550 ± 1333	625 ± 711	1450 ± 1398
Energy density (kJ/g ± SD)	5.4 ± 2.8	4.0 ± 5.5	4.6 ± 4.6
duration (min ± SD)	18.0 ± 15.1	15.0 ± 17.2	16.2 ± 16.3
<b>Restaurant/Bar/Café</b>	<b>n=21 (8.1%)</b>	<b>n=13 (4.9%)</b>	<b>n=34 (6%)</b>
Energy intake (kJ± SD)	3861 ± 2038	1714 ± 2164	3040 ± 2311
Energy density (kJ/g ± SD)	4.7 ± 1.9	3.8 ± 2.6	4.4 ± 2.2
duration (min ± SD)	37.5 ± 24.8	31.4 ± 28.1	35.2 ± 25.9
<b>Other</b>	<b>n=23 (8.8%)</b>	<b>n=40 (14.9%)</b>	<b>n=63 (12%)</b>
Energy intake (kJ± SD)	2492 ± 2346	1175 ± 1028	1656 ± 1739
Energy density (kJ/g ± SD)	6.7 ± 4.5	8.0 ± 6.5	7.5 ± 5.8
duration (min ± SD)	23.6 ± 32.0	11.1 ± 13.4	15.7 ± 22.7
<b>ENVIRONMENT</b>			
<b>Indoor</b>	<b>n=243 (93%)</b>	<b>n=236 (88%)</b>	<b>n=479 (91%)</b>
Energy intake (kJ± SD)	2760 ± 1683	904 ± 1001	1846 ± 1670
Energy density (kJ/g ± SD)	5.3 ± 2.8	5.9 ± 6.2	5.6 ± 4.8
duration (min ± SD)	16.2 ± 15.1	23.2 ± 30.6	14.1 ± 15.0
<b>Outdoor</b>	<b>n=12 (4.6%)</b>	<b>n=18 (6.7%)</b>	<b>n=30 (5.7%)</b>
Energy intake (kJ± SD)	2094 ± 1524	1231 ± 1040	1576 ± 1303
Energy density (kJ/g ± SD)	8.4 ± 5.5	6.3 ± 5.9	7.2 ± 5.8
duration (min ± SD)	20.9 ± 25.7	11.9 ± 14.7	22.3 ± 28.3
<b>In Vehicle</b>	<b>n=3 (0.6%)</b>	<b>n=10 (3.7%)</b>	<b>n=13 (2.5%)</b>

Context	Meals	Snacks	All eating episodes
Energy intake (kJ± SD)	1674 ± 893	1511 ± 1508	1549 ± 1358
Energy density (kJ/g ± SD)	6.6 ± 3.1	7.8 ± 7.9	7.5 ± 7.0
duration (min ± SD)	7.7 ± 5.7	10.0 ± 10.1	10.2 ± 6.0
<b>Mixed</b>	<b>n=2 (0.8%)</b>	<b>n=4 (1.5%)</b>	<b>n=6 (1.4%)</b>
Energy intake (kJ± SD)	3655 ± 826	1754 ± 2027	2388 ± 1888
Energy density (kJ/g ± SD)	7.8 ± 0.9	3.1 ± 1.8	4.6 ± 2.8
duration (min ± SD)	68.6 ± 79.2	26.0 ± 28.2	40.2 ± 47.0

### PHYSICAL POSITION

<b>Sitting at table</b>	<b>n=100 (38%)</b>	<b>n=41 (15%)</b>	<b>n=141 (27%)</b>
Energy intake (kJ± SD)	3301 ± 1826	1146 ± 1521	2762 ± 1932
Energy density (kJ/g ± SD)	5.0 ± 2.2	4.8 ± 5.2	4.9 ± 3.3
duration (min ± SD)	21.2 ± 20.2	24.7 ± 30.2	22.2 ± 23.5
<b>Sitting on sofa</b>	<b>n=81 (31%)</b>	<b>n=57 (21%)</b>	<b>n=138 (26%)</b>
Energy intake (kJ± SD)	2839 ± 1529	1089 ± 965	2116 ± 1578
Energy density (kJ/g ± SD)	5.6 ± 2.6	5.4 ± 5.5	5.5 ± 4.0
duration (min ± SD)	14.2 ± 9.3	11.2 ± 12.6	12.9 ± 10.8
<b>Sitting at desk</b>	<b>n=24 (9.0%)</b>	<b>n=67 (23%)</b>	<b>n=95 (18%)</b>
Energy intake (kJ± SD)	2296 ± 1251	756 ± 751	1244 ± 1289
Energy density (kJ/g ± SD)	9 (24)	4.4 ± 6.1	4.7 ± 5.2
duration (min ± SD)	5.3 ± 2.9	5.0 ± 5.7	15.5 ± 12.7
<b>Standing/Active</b>	<b>n=28 (11%)</b>	<b>n=74 (28%)</b>	<b>n=102 (19%)</b>
Energy intake (kJ± SD)	1296 ± 1093	829 ± 795	957 ± 905
Energy density (kJ/g ± SD)	7.8 ± 5.4	8.1 ± 7.1	8.0 ± 6.7
duration (min ± SD)	10.6 ± 23.0	5.7 ± 7.0	7.2 ± 13.5
<b>Other</b>	<b>n=18 (6.9%)</b>	<b>n=67 (25%)</b>	<b>n=52 (10%)</b>
Energy intake (kJ± SD)	2004 ± 1001	958 ± 1058	1320 ± 1145
Energy density (kJ/g ± SD)	5.1 ± 2.9	6.2 ± 5.8	5.8 ± 5.0
duration (min ± SD)	13.6 ± 11.7	12.0 ± 12.9	12.6 ± 12.4

SOCIAL	Meals	Snacks	All eating episodes
<b>Social Interaction</b>	<b>n=124 (48%)</b>	<b>n=115 (43%)</b>	<b>n=239 (45%)</b>
Energy intake (kJ± SD)	3081 ± 107	1066 ± 1210	2112 ± 1846
Energy density (kJ/g ± SD)	5.2 ± 2.7	5.6 ± 5.9	5.4 ± 4.5
duration (min ± SD)	22.7 ± 21.1	15.2 ± 20.8	19.1 ± 21.3
<b>Social – no interaction</b>	<b>n=27 (10%)</b>	<b>n=33 (12%)</b>	<b>n=60 (11%)</b>
Energy intake (kJ± SD)	2969 ± 1740	851 ± 819	1804 ± 1681

<b>Context</b>	<b>Meals</b>	<b>Snacks</b>	<b>All eating episodes</b>
Energy density (kJ/g ± SD)	5.5 ± 1.9	8.1 ± 7.5	6.9 ± 5.8
duration (min ± SD)	22.7 ± 11.2	8.2 ± 9.3	9.6 ± 8.3
<b>Not Social</b>	<b>n=109 (42%)</b>	<b>n=120 (45%) (120)</b>	<b>n=229 (43%)</b>
Energy intake (kJ± SD)	2256 ± 1366	892 ± 934	1541 ± 1344
Energy density (kJ/g ± SD)	5.9 ± 3.6	5.6 ± 6.1	5.7 ± 5.1
duration (min ± SD)	11.4 ± 9.5	11.7 ± 12.7	11.2 ± 6.6
<hr/>			
<b>MEDIA</b>			
<b>Any Screen</b>	<b>n=131 (50%)</b>	<b>n=157 (59%)</b>	<b>n=288 (55%)</b>
Energy intake (kJ± SD)	2693 ± 1439	905 ± 913	1718 ± 1479
Energy density (kJ/g ± SD)	5.4 ± 2.6	5.2 ± 6.0	5.3 ± 4.8
duration (min ± SD)	14.6 ± 11.4	13.9 ± 15.5	14.2 ± 13.8
<b>Television</b>	<b>n=57 (22%)</b>	<b>n=31 (12%)</b>	<b>n=88 (17%)</b>
Energy intake (kJ± SD)	2977 ± 1575	1341 ± 1060	2400 ± 1613
Energy density (kJ/g ± SD)	5.4 ± 2.4	7.6 ± 6.9	6.2 ± 4.6
duration (min ± SD)	14.7 ± 9.8	11.0 ± 21.6	13.4 ± 13.0
<b>Computer</b>	<b>n=48 (18%)</b>	<b>n=92 (32%)</b>	<b>n=140 (27%)</b>
Energy intake (kJ± SD)	2382 ± 1288	764 ± 872	1318 ± 1285
Energy density (kJ/g ± SD)	5.2 ± 2.9	4.8 ± 6.1	5.0 ± 5.2
duration (min ± SD)	14.3 ± 10.8	13.9 ± 12.4	14.0 ± 11.8
<b>Handheld Device</b>	<b>n=13 (5.0%)</b>	<b>n=16 (6.0%)</b>	<b>n=29 (5.5%)</b>
Energy intake (kJ± SD)	2325 ± 1580	916 ± 907	1547 ± 1421
Energy density (kJ/g ± SD)	4.7 ± 2.2	5.5 ± 5.6	5.1 ± 4.4
duration (min ± SD)	12.6 ± 14.1	10.5 ± 8.2	11.5 ± 11.1
<b>Multiple Devices</b>	<b>n=13 (5.0%)</b>	<b>n=18 (6.7%)</b>	<b>n=31 (6%)</b>
Energy intake (kJ± SD)	2966 ± 934	869 ± 645	1748 ± 1300
Energy density (kJ/g ± SD)	6.3 ± 2.8	2.4 ± 1.4	4.1 ± 2.8
duration (min ± SD)	17.4 ± 16.7	21.6 ± 20.3	19.9 ± 18.7
<b>No screen</b>	<b>n=129 (50%)</b>	<b>n=111 (41%)</b>	<b>n=240 (45%)</b>
Energy intake (kJ± SD)	2771 ± 1900	1041 ± 1218	1962 ± 1821
Energy density (kJ/g ± SD)	5.7 ± 3.4	7.0 ± 6.4	6.3 ± 5.1
duration (min ± SD)	18.7 ± 21.0	11.2 ± 17.8	15.1 ± 20.4
<hr/>			
<b>TOTAL (n)</b>	<b>n=260</b>	<b>n=268</b>	<b>n=528</b>
Energy intake (kJ± SD)	2742 ± 1671	962 ± 1050	1829 ± 1646
Energy density (kJ/g ± SD)	5.5 ± 3.0	5.9 ± 6.2	5.7 ± 4.9
duration (min ± SD)	16.7 ± 17.0	12.8 ± 16.5	14.7 ± 16.8

**Table 18 Duration, energy intake and density of meals and snacks at home (N=312) viewing media screens from 40 participants.**

<b>Context</b>	<b>Meals</b>	<b>Snacks</b>	<b>All meals</b>
<b>MEDIA AT HOME</b>			
<b>ANY SCREEN</b>	<b>n=93 (56%)</b>	<b>n=91 (62%)</b>	<b>n=184 (59%)</b>
Energy intake (kJ± SD)	2751 ± 1685	1055 ± 992	1913 ± 1510
Energy density (kJ/g ± SD)	5.3 ± 2.6	5.8 ± 6.1	5.6 ± 4.7
duration (min ± SD)	13.3 ± 9.4	11.9 ± 12.5	12.6 ± 11.0
<b>Television</b>	<b>n=53 (32%)</b>	<b>n=22 (15%)</b>	<b>n=75 (24%)</b>
Energy intake (kJ± SD)	3095 ± 1584	1405 ± 1132	2600 ± 1627
Energy density (kJ/g ± SD)	5.6 ± 2.4	8.6 ± 7.3	6.5 ± 4.6
duration (min ± SD)	14.9 ± 10.1	6.9 ± 6.0	12.6 ± 9.8
<b>Computer</b>	<b>n=21 (13%)</b>	<b>n=45 (31%)</b>	<b>n=66 (21%)</b>
Energy intake (kJ± SD)	2136 ± 1337	925 ± 956	1311 ± 1222
Energy density (kJ/g ± SD)	4.8 ± 3.0	5.5 ± 6.1	5.2 ± 5.3
duration (min ± SD)	11.6 ± 7.4	12.2 ± 9.7	12.0 ± 9.0
<b>OTHER SCREENS</b>	<b>n= 19 (12%)</b>	<b>n=24 (16%)</b>	<b>n=43 (14%)</b>
Energy intake (kJ± SD)	2484 ± 1072	977 ± 870	1643 ± 1217
Energy density (kJ/g ± SD)	5.3 ± 2.7	4.0 ± 3.7	4.6 ± 3.3
duration (min ± SD)	10.7 ± 8.7	15.7 ± 19.0	13.5 ± 15.4
<b>NO Screen</b>	<b>n=72 (44%)</b>	<b>n=56 (39%)</b>	<b>n=128 (41%)</b>
Energy intake (kJ± SD)	2551 ± 1685	890 ± 1019	1825 ± 1649
Energy density (kJ/g ± SD)	5.7 ± 3.4	7.5 ± 7.0	6.5 ± 5.3
duration (min ± SD)	11.8 ± 10.1	8.5 ± 17.2	10.5 ± 13.8
<b>TOTAL</b>	<b>n=165</b>	<b>n=147</b>	<b>n=312</b>
<b>Energy intake (kJ± SD)</b>	<b>2665 ± 1562</b>	<b>992 ± 1001</b>	<b>1877 ± 1567</b>
<b>Energy density (kJ/g ± SD)</b>	<b>5.5 ± 3.0</b>	<b>6.5 ± 6.5</b>	<b>6.0 ± 5.0</b>
<b>duration (min ± SD)</b>	<b>12.7 ± 9.7</b>	<b>10.5 ± 14.5</b>	<b>11.7 ± 12.2</b>



## 8.8. Discussion

In this study we sought to investigate whether wearable camera images could enhance the data obtained in dietary assessment, by objectively assessing the context surrounding eating episodes. Where data available for analysis, we found 71% of the eating episodes reported in the image-assisted 24-hour dietary recalls could be identified and annotated for context using the wearable camera images. Of those identified, it was possible to objectively determine the location, external environment, physical position, and whether the participant was engaged in social interaction or viewed media screens during the episode.

When combined with data obtained using an image-assisted 24h dietary recall<sup>296</sup> EI values associated with different contexts could be evaluated. For example, 8% of main meals were consumed out-of-home at food retailers, and were over twice as long and approximately 1196 kJ higher in energy (95% CI: 242 to 2149) than meals at home. The annotation was possible not only for the episode itself, but also using the images proceeding and succeeding the episode. An advantage of this was that it enabled the researchers to determine if the participant was in a social situation, where there appeared to be no direct social interaction e.g. eating alone at a work cafeteria. The images also allow greater specificity, such as the differences observed in duration and EI and density for eating episodes between different positional contexts (seated at tables versus sofas and standing/active).

Other studies exploring the use of technologies to assess eating contexts have recently been reported, but these studies have not recorded dietary intake.<sup>297-299</sup> Chen et al<sup>297</sup> explored eating patterns of forty university students wearing SenseCam for 1-5 days and used a similar procedure of manual annotation. In agreement with our data, they found that eating episodes with social interaction were significantly longer compared to eating alone (11.2 minutes versus 7.4), and episodes watching television were longer compared to episodes without television, but the difference was not statistically significant (8.8 minutes versus 7.8 minutes). These data support lab-based research that has indicated meal duration,<sup>300</sup> social interaction,<sup>87, 301</sup> and viewing screens are associated with increased EI.<sup>291</sup>

This study was not designed or powered to detect differences between specific contexts during eating episodes. For this reason we limited our analysis to five contexts similar to those currently assessed in national dietary surveys,<sup>24, 85</sup> and only compared the episode duration and EI data;

however, many other contexts relevant to behavioural nutrition and human eating research could also be assessed, such as food advertising, purchasing habits, meal frequency, plate size, social modelling, ambient lighting and total screen time.<sup>41, 42, 302</sup>

Wearable cameras, unlike direct observation, also offer the opportunity for secondary analysis, thus maximising the utility of data obtained. Additionally, raters can be trained before reanalysing the dataset, as we have shown the procedure to annotate the episodes for a category of interest can be easily tested for inter-reliability. This is in contrast to direct observation techniques where inter-rater reliability has only been established in a few studies.<sup>301, 303, 304</sup> However, noncompliance wearing the camera and technical failures resulted in 11% of data loss which must be considered. Where data available twenty-eight percent (214 episodes) of eating episodes captured could not be classified. The most common reason (85/214) was due to no associated images, mainly during snacking episodes. Some snack foods are easily consumed between the automated image capture (e.g. biscuits and nuts), thus faster imaging frequencies should allow a greater proportion of short eating episodes to be annotated. Dark and blurry images were also difficult to classify. Often breakfast and evening meals are consumed in low-light environments, especially when eating out at a restaurant or bar. Cameras better enabled to capture images in low light environments could reduce the magnitude of this limitation.<sup>213, 296, 305</sup>

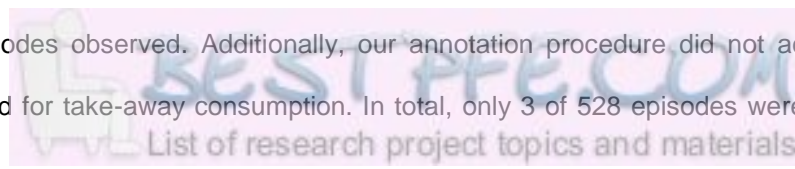
Wear time was also an issue, with 7% of episodes occurring when the camera was not worn. These episodes were mainly at night when participants took the camera off, but remained awake for prolonged periods (self-reported eating episodes after the camera was switched off). Better instructions for participants to keep the camera on during all wake hours, and less obtrusive devices may increase wear time in future research.<sup>213, 230, 296</sup> Our data also reveals that future research investigating specific contexts will need to take into account the proportion of contexts that occur in free-living settings. For example, only 25% of the total snacking episodes were in occupational settings, thus if snacking habits at work were of research interest, the relatively low proportion of these events would need to be considered in study designs and power calculations.

This work relied on manual input and annotation of the data, but future work could develop automated computer vision techniques to process the data.<sup>306, 307</sup> The manual process took a substantial amount of time to input the dietary intake data, and the subsequent annotation took on average an additional 1 minute 21 seconds ( $\pm 44$  s) for every eating episode. However, this work focused on the feasibility of using wearable cameras to record context attributes surrounding

eating episodes but could provide a gold standard reference for automated machine learning systems to detect behaviours and features within images. Automated image-analysis has potential to increase research efficiencies and allow image-based research on a larger scale. There are already considerable efforts being undertaken to passively assess dietary intake using wearing cameras, which aims to remove the need for the initial dietary assessment (used in this study) entirely, though extensive work is still required.<sup>214, 221, 306</sup> encouragingly, Jia et al<sup>306</sup> have demonstrated that a semi-automated system can estimate portion size with less bias and variability than human raters. However, only limited foods were assessed (n=100), and limitations exist in free-living settings that automated systems will need to address, such as poor lighting, dishes/meals that may obscure some foods on the plate, and current limitations of nutrient databases, as density data are not yet available for all foods.<sup>306</sup>

Our procedure to manually annotate eating episodes demonstrated strong inter-rater reliability. For example, using the guidelines of Landis and Koch, the inter-rater reliability could be considered almost perfect for location (0.96), for indoor/outdoor/in vehicle (0.81), and sitting/standing position (0.84), while social interaction status (0.68), and the presence of media screens (0.79) were classified with substantial agreement.<sup>308</sup> Social interaction was challenging to annotate as interaction may only be captured in a few images scattered throughout the episode. Likewise, media screens were challenging to annotate due to their frequent but sometimes very brief use (i.e. not captured). Thus, cameras with faster imaging frequencies at higher resolution may allow easier classification of these contexts. Furthermore, future studies could incorporate the manual annotations procedures into the initial dietary assessments to reduce annotation time. In this study the manual annotation was conducted retrospectively, as the dataset was obtained from a completed study and therefore was more arduous than would be the case if completed during the dietary assessments.

Due to the exploratory nature and primary aims of this study all eating episodes from participants were treated as discrete data. Thus, one participant could contribute disproportionately for contexts with only a few episodes assessed. Furthermore the analysis grouped some distinctly different contexts together, such as fast food retailers, restaurants, bars and cafes. These different eating locations warrant their own subgroups, but were grouped together due to the small number of episodes observed. Additionally, our annotation procedure did not account for fast foods purchased for take-away consumption. In total, only 3 of 528 episodes were consumed at



fast food retailers, as participants usually consumed take-away meals in other locations. To address this, the annotation procedure would need to include where the food was purchased prior to the episode or the food type (if purchased by someone else). Additionally, we only explored the EI and energy density of meals and snacks, whereas examining the food groups and macronutrient content of the episodes would have provided an additional level of information. However, in future research such information could easily be examined for these types of datasets.

Our findings should be used to develop guidelines and protocols for visual research on nutrition behaviours and eating in free-living conditions to allow future studies to be uniformly compared. An ethical framework for visual research using wearable cameras has already been developed,<sup>251</sup> together these would help to ensure future research is of a high quality with ethical considerations appropriately addressed.

## **8.9. Conclusion**

In summary, this is the first study to assess the context of eating episodes using wearable camera images to enhance energy and nutrient data obtained during image-assisted dietary assessment. We show that the technique is feasible and provides a new approach to collect objective data on nutrition behaviours in a free-living setting that is currently lacking.<sup>42, 285, 286</sup> At this stage wearable cameras should not be viewed as a replacement device for traditional methods of dietary assessment, but instead as a complementary tool to both enhance traditional self-report and provide contextual data surrounding eating behaviours in free-living settings. Our findings should be used to develop guidelines and protocols for visual research on nutrition behaviours and eating in free-living conditions to allow future studies to be uniformly compared. Objective assessments will provide more detailed and valid information on the contexts of eating episodes in free-living settings.

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## CHAPTER 9. THESIS DISCUSSION

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This thesis investigated the use of wearable cameras to (1) reduce the reporting bias associated with traditional self-reported dietary assessment, and (2) passively record and assess the context of dietary behaviours. Due to the recognised limitations of self-reported dietary intake, multiple efforts are underway to enhance dietary assessment through technology.<sup>15, 31, 215, 309</sup> However, there has been little research that has evaluated image-assisted methods of dietary assessment, or explored the potential of wearable cameras to enhance self-reported intake. In order to achieve the main aim of the thesis, a statistical analysis of the ANS08/9 datasets was first undertaken to determine the prevalence of low energy reporters (LERs), and highlight the need for technological innovation in dietary assessment. A systematic review was conducted to establish what is already known in the field of image-assisted dietary assessment, and what is still required. A feasibility study and a validation study were conducted to trial the use of wearable cameras in dietary assessment, and aimed to identify mechanisms and the magnitude to which wearable camera images could reduce measurement bias in 24-hour dietary recalls. It was hypothesised that images captured by wearable cameras would reduce the self-report bias for dietary energy intake (EI) compared to self-report alone by providing additional information to augment memory recall, and enhance self-report. To achieve the secondary aim of the thesis a manual image analysis of the dataset obtained in the validation study was undertaken to evaluate if the images captured using wearable cameras could be used to objectively and reliably assess the environmental and social context of eating episodes.

### ***Primary findings***

The primary findings of this thesis were: (1) 21% of men and 25% of women were classified as LERs in the ANS08/9, and a systematic bias was observed with LERs more prevalent among women, people aged >65 years, and Maori and Pacific people, (2) previous research up to 2013 suggests image-assisted methods of dietary assessment can provide objective information to independently verify and assess self-reported dietary intake, but the limited existing evidence highlighted the need for further research, (3) wearable cameras can reveal unreported or misreported errors in the 24h-hour dietary recall not captured by traditional methods alone, which

increases self-reported dietary EI, (4) wearable cameras reduce the magnitude of under-reporting bias for dietary EI in 24-hour dietary recalls by 9% in men and 6% in women compared to dietary recalls alone, and (5) wearable camera images can be analysed to objectively and reliably assess environmental and social contexts of dietary behaviours, therefore providing a novel method to passively record objective data on dietary behaviours in free-living settings.

### ***Analysis of the ANS 08/9***

Although the limitations of self-reported dietary intake were well established,<sup>2, 8, 9, 84</sup> It had been over a decade since EI data obtained using the 24-hour dietary recall method had been evaluated using a national dataset.<sup>73</sup> Moreover, substantial changes to physical characteristics of the NZ population were evident (Chapter Two), which are known to affect self-report.<sup>73, 146, 152-155</sup> Additionally, there was a reported paradox of decreased EI in parallel with increased body weight, therefore we undertook analysis of the ANS 08/9 data using the Goldberg cut-offs,<sup>144, 184, 185</sup> and estimated the prevalence of LERs by gender, body size (normal, overweight, obese), age, and ethnicity (Chapter Four).

After exclusions were made, a total of 3919 participants (NZ European n = 2286, Maori n = 976, and Pacific people n = 657), were included in the ANS 08/9 analysis. The main finding was that overall 21% of men and 25% of women were classified as LERs, and a systematic bias was observed, with LERs more prevalent among women, people aged >65 years, and in Maori and Pacific peoples. When compared to a similar analysis undertaken on the previous 1997 National Nutrition Survey (NNS97) data,<sup>73</sup> the prevalence of LERs had increased substantially in nearly all subgroups over the decade, and notably amongst people of normal body size and in young adults. The findings revealed that caution must be exercised when interpreting EI data in the ANS 08/9, and indicated that under-reporting remains a key limitation of self-reported intake.

These primary findings provided justification to investigate the use of wearable cameras to enhance the 24-hour dietary recall. Other efforts trialling wearable cameras in dietary assessment had predominantly used the food record (FR) method.<sup>205, 310</sup> However, national nutrition surveys in N.Z., and in other countries, such as the U.S. and Australia use the 24-hour dietary recall.<sup>25, 86,</sup>  
<sup>93</sup> Thus, efforts to improve the existing method may be more easily accepted and implemented into current dietary surveillance programmes. Moreover, using a similar (augmented/improved)

method of dietary assessment should allow data from previous surveys to be more easily compared than if a new method is used.

The ANS 08/9 analysis also demonstrated the apparent paradox of reduced EI with increased body weights was most certainly an artefact caused by self-report bias. The increase in the prevalence of LERs among people of normal body weight, and young adults, was potentially due to an increased influence of psychosocial factors (e.g. social desirability) and other behavioural characteristics (e.g. body dissatisfaction).<sup>8, 10, 28</sup> Observed differences over time may be explained by sociocultural changes and events within NZ society between the NNS97 and ANS 08/9 surveys; there has been an increase in screen-based activities, a substantial shift in the genre and quantity of television shows and media advertising, many of which portray a slim-body image or health-related content (e.g. reality television focussed on weight loss, cosmetic surgery, makeover, modelling etc.), and widely publicised nation-wide government-led health campaigns.<sup>28, 199-203</sup> Together, with an increased public awareness of nutrition-related health and dieting practises, this may have influenced people's self-perceptions,<sup>200-203</sup> and therefore increased the likelihood of dietary under-reporting.<sup>28, 199</sup> The increased prevalence of LERs amongst people of normal body size was considered when designing the validation study.

### ***Systematic review***

The systematic review aimed to examine the evidence of image-assisted methods for assessing dietary EI. There had been five previous reviews examining the use of technologies in dietary assessment,<sup>16, 19, 29-31</sup> but no review had specifically investigated the evidence for image-assisted dietary assessment. Therefore, it was deemed necessary and timely (due to rapid advances in computer handheld and wearable technologies) to define the field of image-assisted dietary assessment, group and categorise similar image-assisted methods developed. It was also required to inform and guide the use of wearable cameras, in the feasibility (review initially undertaken in 2011), and validation study conducted for this thesis. We aimed to examine all studies that have evaluated or validated an image-assisted method of dietary assessment compared to a reference method for assessing dietary EI.

A total of 13 eligible studies were included in the review, ten studies used active image capture using handheld devices<sup>209-211, 222-224, 226-229</sup> and three used passive image capture using wearable cameras.<sup>212, 213, 230</sup> Eight studies evaluated five different image-based food records.<sup>209, 211, 222-224,</sup>

<sup>226-228</sup> Two studies evaluated the use of image-assisted written food records,<sup>210, 230</sup> and three studies evaluated the use of image-assisted 24-hour dietary recalls.<sup>212, 213, 229</sup> The main findings from the review were: (1) images captured during eating episodes can enhance self-report in both prospective and retrospective methods by revealing unreported foods and identify misreporting errors not captured by traditional methods alone, and (2) when images are used as the primary record of dietary intake they can be used to provide valid estimates of EI. However, the review also revealed how image-assisted methods that rely on independent image analysis can easily underestimate EI due to: (1) the diversity and complexity of foods that make it hard to identify certain ingredients and quantities of foods, (2) poor quality images that cannot be analysed, and (3) the need for users to capture images before all foods are consumed.

However, these limitations can be minimised. For example, EMA appears to be an effective way to remind participants to record intake (capture images), and development of comprehensive procedures for image analysis and standardised training regimes reduces the potential error and improves reliability.<sup>209, 222</sup> The review also revealed that image-assisted methods are preferred over their traditional FR's and 24-hour recalls, with participant feedback indicating that image-assisted methods are easier to use and have lower burden.

Given that image-assisted dietary assessment is an emerging field, it was not surprising that the review primarily consisted of studies with either small sample sizes,<sup>210, 212, 213, 224, 227, 228</sup> or studies that only assessed relative validity using traditional methods of dietary assessment as reference methods.<sup>15, 16, 18, 23, 24, 28, 29, 32</sup> Moreover, no studies had been conducted among children, adolescents, or in the elderly (aged >70 years). Specifically, the evidence regarding the use of wearable cameras were limited to three studies,<sup>212, 213, 230</sup> two of which only assessed relative validity for 1-day dietary intake.<sup>213, 230</sup> Thus, high-quality evidence was needed.

### ***Feasibility study***

The feasibility study was designed to assess the degree to which the images assisted and changed the participants' self-reported dietary intake. Specific objectives were to determine the effect viewing the images had on self-reported energy and nutrient intakes. The feasibility study included thirteen British adult participants (10 male, 3 female; mean age 33 ± 11 years), and assessed dietary intake for one-day (SenseCam-assisted 24-hour dietary recall). Overall, the assistance of the images increased self-reported EI by 12.5% (P=0.02). The increase in EI was



predominantly due to unreported food revealed by the images. Misreporting errors (incorrect food type reported or foods reported that were not consumed) and changes to portion size were also common, but together these resulted in only modest changes to EI.

The feasibility study also revealed limitations of the SenseCam, and this guided the design of the validation study. First it was found that the imaging frequency of the SenseCam (20-30 seconds) was insufficient to capture all foods consumed. This finding supported a similar observation made by Arab et al<sup>245</sup> using mobile phones worn around the neck with a 10-second imaging frequency. Other notable limitations were the position of the device, which allowed the lens to be affected easily by posture and body shape, and poor image quality, especially in low-light environments, which resulted in non-useful images.<sup>213</sup> Technical issues were also experienced (data loss for two participants), and reports by other researchers using SenseCam<sup>230</sup> indicated wear days should be limited to the minimum required for the validation study aims. On the other hand, participant feedback, which indicated that wearing the camera and the method used to assess dietary intake was a low burden, was encouraging. Participants also indicated approximately one week would be an acceptable time to wear the SenseCam. Thus, it was evident the SenseCam was not an optimal device for image-assisted dietary assessment, but the promising results combined with favourable participant feedback provided the rationale, evidence, and experience required to validate the image-assisted 24-hour dietary recall.

### ***Validation study***

A total of 40 adults (20 male, 20 female) were recruited for the 15-day DLW validation study (PICTURE study) reported in Chapter Seven. Males were older than females ( $35 \pm 17$  years versus  $28 \pm 7$  years, respectively) and predominantly overweight ( $BMI = 27 \pm 8 \text{ kg/m}^2$ ), while females were predominantly of normal body size ( $BMI = 22 \pm 2 \text{ kg/m}^2$ ). Given the technical issues experienced in the feasibility study, participants were only required to wear SenseCam on the familiarisation day, and each day prior to the three nutrition assessments (to provide the best possible chance the camera would operate normally and reduce data loss). Overall, use of the wearable cameras reduced the magnitude of under-reporting bias for dietary EI by 9% in men and 6% in women compared to dietary recalls alone. However, the use of DLW demonstrated images alone will not eliminate the under-estimation of dietary EI (men -9%, women -7%), unless satisfactory images are captured for all foods consumed to assist self-report (the various reasons

why images are not always captured or of satisfactory quality to assist self-report were discussed above in the findings for the feasibility study).

The alterations to self-report dietary intake data further supported results from the feasibility study, as unreported foods provided the biggest impact on EI, and other misreporting errors and changes to portion size were present but together contributed only 28% of the change to EI (unreported foods (n = 265) = 110,570 kJ vs. misreported foods (n=36) = -16852 kJ, and change to portion size (n = 51) = 13628 kJ). These results demonstrate that wearable cameras enhance the 24-hour dietary recall method, as the images reveal unreported foods and misreporting errors, and this helped to reduce under-reporting reporting bias for dietary EI.

### ***Image analysis to assess context of eating episodes***

The image dataset obtained in the validation study was used to objectively assess the context of self-reported eating episodes, and was reported in Chapter Eight. A manual procedure to review the images was used and each eating episode assessed for eating location, external environment (indoor/outdoor), physical position, social context, and viewing of media screens. This was the first study to combine dietary intake data with an objective assessment of context using wearable camera images in a free-living setting. Previous research investigating dietary behaviours has been primarily limited to laboratory studies, which are not always indicative of real-world eating behaviours,<sup>42, 285-289</sup> and self-reported context has limited potential scope and untested validity. Moreover, the recent inclusion of self-reported eating context recorded in large-scale dietary surveillance programmes<sup>85, 86, 91</sup> provided further rationale to explore and evaluate the potential of obtaining objective data through wearable camera images.

After exclusions image data were available for 107 days with a total of 742 eating episodes. The main finding was that 71% of the eating episodes could be classified for context through manual annotation, and the reliability of the assessment was considered almost perfect for location for indoor/outdoor/in vehicle and sitting/standing position, while social interaction status and the presence of media screens were classified with substantial agreement. The remaining 29% of episodes that could not be analysed suggested the need for faster imaging frequencies, and better image quality in low-light environments, as quick eating episodes were often missed (particularly snack foods), and dark/blurry images could not be analysed.

### ***Overall strengths and limitations***

Strengths and limitations of specific studies were discussed within their respective chapters. However, this thesis has its own strengths and weaknesses. Firstly, this was one of the first pieces of research that aimed to address a key limitation in the 24-hour dietary recall method by assisting memory recall through wearable camera images. Previous work developing software and systematic procedures has led to noteworthy enhancements of the 24-hour dietary recall method, but these improvements have limited ability to augment participants' memory recall, a pivotal requirement to enhance a retrospective assessment. Alternatively, this research was designed specifically to assist memory recall, and demonstrated that images could assist participants to report more accurate information, and allow researchers to verify all foods consumed reported during the interview (all foods captured by the camera).

Secondly, within the field of dietary assessment, this is the first research to thoroughly examine the mechanisms whereby wearable cameras assist self-report. Prior to this research, the specific factors that result in the underestimation of dietary EI had not been quantified. Thirdly, this was the first research to validate a wearable camera-assisted method using DLW in an adequately sized sample, and the DLW is the gold-standard methodology for validating dietary EI in free-living settings. Finally, this research examined two separate benefits of wearable cameras: the reduction of measurement errors, and the ability of wearable cameras to capture additional objective information on dietary behaviours. Together, these provide stronger justification and evidence for the use of wearable cameras in dietary assessment than when considered alone.

There are also a number of limitations that need to be considered. Firstly, both the feasibility study (Chapter Six) and PICTURE validation study (Chapter Seven) had relatively small sample sizes, and there were apparent demographic differences of the male and female samples in the validation study; However, the validation study (N = 40) is the second largest DLW study ever conducted evaluating a handheld/wearable technology-assisted method. This was partly due to the lack of financial resources available to conduct a larger study using DLW. Certain populations were therefore underrepresented, and additional studies are needed to ensure wearable cameras assist other population groups to the same degree.

Secondly, the feasibility and PICTURE study, only assessed dietary intake for one (Chapter Six) and three days (Chapter Seven) respectively. Therefore, due to both inter- and intra-individual

daily and seasonal variability in peoples' diets, the results may not reflect habitual dietary intake.<sup>95, 166</sup> Thirdly, the research did not assess whether wearing the SenseCam, despite early reports<sup>212, 230, 245</sup> and indications from the feasibility study<sup>213</sup> affected dietary behaviours. The decision not to assess such reactivity was due to a number of reasons: (1) assessing reactivity would require different study designs that did not answer the primary aims of the thesis, and (2) due to the emerging nature and continuing rapid development of wearable technologies, it was judged that reactivity would likely differ as the technologies progressed. Therefore, reactivity was outside the scope of this research, but should be a consideration for future research.

Fourthly, by designing the studies to assess the mechanisms whereby wearable cameras assist self-report (alterations to self-report), the studies did not incorporate the image reviews as part of the usual 24-hour dietary recall procedures. It would be more efficient for future studies to combine the image review directly into the 24-hour dietary recall procedures. Moreover, only participants made changes to their self-report, but to obtain optimal accuracy it would be advantageous for trained image analysts conducting the assessments to verify the food types and portion size.<sup>209, 222, 233, 234</sup> However, this approach ensured interviewer bias was minimised.

Lastly, the SenseCam wearable camera used in this thesis is not optimal for dietary assessment. Limitations of the SenseCam were evident in the findings of the feasibility study, validation study, and secondary image-analysis to assess contexts. As discussed above the SenseCams size, poor image quality, and insufficient imaging frequency to capture quality images of all foods consumed, likely limited the full potential that wearable camera images may enhance self-report in the image-assisted 24-hour dietary recall (MP24+SC). Very recent improvements in wearable camera technology during the latter stages of this thesis have addressed some of these limitations identified, and such technologies continue to develop and improve rapidly.

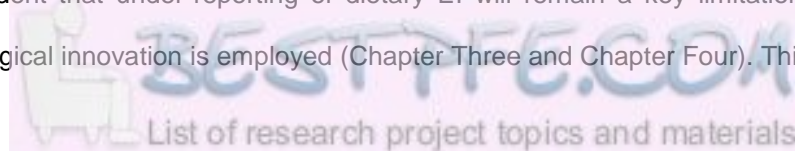
### **9.1.1 Contributions of this thesis**

The research conducted for this thesis provided the following contributions to the field of nutrition research and dietary assessment: (1) provided recent evidence highlighting reporting bias for self-reported EI in a national nutrition survey dataset, and demonstrated under-reporting of EI will remain a key limitation of self-reported dietary intake until technological innovations are employed, (2) undertook the first systematic review of image-assisted methods of dietary assessment, which revealed image-assisted methods can improve traditional dietary assessment methods, and highlighted the technical challenges that need to be addressed in future methods/research, (3) established that wearable cameras can enhance self-report in the 24-hour dietary recall by revealing unreported foods and misreporting errors, thereby increasing self-reported EI and reducing reporting bias for dietary EI, and (4) further demonstrated the potential utility of wearable cameras in nutrition research by evaluating their ability to passively record and objectively assess dietary behaviours in free-living settings.

## **9.2. Future implications**

In the period of time since this research began, wearable technologies have become a hot topic in the media as both large and start-up companies have released consumer friendly wrist-worn fitness trackers, smart watches, and wearable cameras. Some wearable technologies were commercially available prior to 2011 (e.g. heart rate monitors), but the rapid increase in their capabilities and range of products available, in conjunction with the associated media attention, has changed the landscape significantly. Consequently, it is evident wearable technologies are rapidly becoming ubiquitous in society, but understanding of how these technologies could be applied in public health research is still in its infancy.<sup>244</sup> To date, excluding the research undertaken in this thesis, there have only been three articles published in scientific journals evaluating the use of wearable cameras for dietary assessment among users.<sup>212, 230, 245</sup> Therefore, although the findings of this thesis have implications for future research, they need to be considered in light of the early stages of this emerging field. This thesis has raised several questions regarding image-assisted dietary assessment, which warrant further investigation.

Firstly, it is evident that under-reporting of dietary EI will remain a key limitation of self-report unless technological innovation is employed (Chapter Three and Chapter Four). This is of concern



as epidemiological data reveals nutrition-related diseases, such as cancers, cardiovascular diseases, obesity, and diabetes have reached epidemic proportions.<sup>6</sup> Further, trends in body size indicate NZ and other countries are in positive energy balance.<sup>58, 65, 78, 311, 312</sup> Moreover, statistical modelling indicates body size is likely to rise even further.<sup>198</sup>

The high prevalence of LERs among people with overweight and obesity, and a notable increase in LERs among people with normal body weight (Chapter Four) dictates that new methods of dietary assessment need to focus on addressing the limitations of self-report itself, rather than simply improving procedures to collect self-report data. By design, image-assisted methods of dietary assessment independently verify self-reported intake, thereby minimising a key limitation of self-report alone (Chapter Five). Wearable cameras also remove the need for participants to manually record dietary intake for the period assessed, and further reduce the chance foods will be unreported compared to handheld devices, which still rely on participants' memory as images are captured manually (Chapter Five, Chapter Six, and Chapter Seven).

Secondly, assistance of the images helps to lessen both random and systematic errors. Random errors are reduced as the images can be used to identify the correct food type, provide independent estimates of portion size, and identify other misreporting errors (Chapter Five, Chapter Six, and Chapter Seven). Although the magnitude of the underreporting identified and reduced by the wearable camera images were relatively modest (Chapters Six, and Chapters Seven), they are important, as reducing error in measurement for any branch of science is essential for the incremental improvements in our knowledge.<sup>313</sup> Moreover, reduced random error is especially beneficial for smaller studies, which cannot minimise the negative impact of random errors by increasing the number of observations and/or days diet that are assessed.<sup>84</sup>

Systematic errors are also theoretically reduced, as the images help to ensure the data collected is of similar quality for all participants, compared to traditional methods which see systematic differences in reporting bias with respect to age,<sup>70, 73, 145, 146</sup> gender,<sup>70, 145, 147-149</sup> body size,<sup>73, 146, 152-155</sup> ethnicity,<sup>73, 150, 151</sup> and lifestyle.<sup>134, 156-158</sup> Reducing systematic error is essential to enhance our understanding of nutrition-related diseases, as systematic differences between groups in the measurement errors are not usually amenable to correction, and can have serious consequences when interpreting data (erroneous findings).<sup>84, 164</sup> However, it must be noted that some participants using image-assisted methods may intentionally misreport their intake by choosing

not to capture images of foods during certain meals, and such error will go undetected in any future method.

Thirdly, the validation study demonstrated use of the wearable cameras reduced the magnitude of under-reporting bias for dietary EI by 9% in men and 6% in women compared to dietary recalls alone (Chapter Seven). This finding provides the first evidence that retrospective self-report can be improved beyond enhancements to the traditional methodological procedures. Wearable cameras should be trialled for use in large-scale dietary surveillance programmes and studies which incorporate the 24-hour dietary recall method. A reduced reporting bias for EI will better reflect the true dietary intake for populations compared to current data. This will better inform nutrition policies and public health interventions, and improve the chance of detecting significant associations in studies of diet and disease relationships. <sup>18, 34, 127, 159, 160</sup>

Fourthly, the findings from the systematic review (Chapter Five) and the two studies undertaken (Chapters Six and Chapters Seven) indicate that, to some degree, under-estimation of dietary EI is likely to occur in image-assisted methods, unless images of satisfactory quality are captured for all foods consumed. Therefore, future image-assisted methods will need to minimise this common limitation. Methods which employ active image capture using handheld devices will require reminders for participants to record diet, and these should be customised (for participants) to ensure the cues are timely with respect to eating episodes. <sup>209</sup> Methods which use passive image capture from wearable cameras will be limited by imaging frequency, image quality, and wear-time. Therefore, technological improvements of these features compared to SenseCam used in this thesis (mean imaging frequency = 13.0s ± 3.2s, image quality = poor, mean wear time = 13 h, 0 min ± 2 h, 23 min) should enhance the image-assisted methods further, while slower imaging frequencies, reduced image quality and wear time will likely see inferior results.

Lastly, wearable cameras provide additional objective information on dietary behaviours compared with traditional methods alone (Chapter Eight); the proposed inclusion of wearable cameras in dietary surveillance programmes would provide valid and reliable population-level data on dietary behaviours, and over time, trends in dietary behaviours could be assessed. Consequently, these new data may provide additional useful information regarding the populations' dietary intake and dietary behaviours compared to the data currently collected. Additionally, research investigating human eating and nutrition behaviours can use wearable cameras to conduct more research in free-living settings, and considering the numerous

contextual factors shown to influence dietary intake and food choice,<sup>41, 42</sup> a new tool to passively collect objective data in free-living settings would be useful.<sup>286, 293</sup> Furthermore, in addition to dietary intake and dietary behaviours, other health behaviours can be assessed using wearable cameras, such as exposure to food advertising,<sup>302</sup> time spent in different modes of exercise,<sup>271</sup> durations of active travel and routes,<sup>268</sup> sedentary behaviours,<sup>270, 314</sup> and the built environment.<sup>315</sup> Therefore, future research that employ wearable cameras could potentially have a wider scope, which may allow resources to be pooled, and would better utilise the data collected and time given by participants.

### **9.3. Future research recommendations**

This research established that wearable cameras can enhance self-report by reducing under-reporting of dietary EI and can be used to assess the context of eating episodes through manual annotation. However, before it would be feasible to implement wearable cameras in large-scale research, further developments and testing of the image-assisted 24-hour recall are required. Moreover, other questions relating to the potential of wearable cameras remain, which warrant examination.

#### ***Development of software for cohesive image-assisted 24-hour dietary recall***

To feasibly incorporate the image-assisted 24-hour recall into large-scale dietary studies, customised software is required to integrate the image-review and context assessment within a cohesive and efficient method.

Customised software should:

- Enable a simple or automatic (wireless) procedure to upload the images.
- Guide participants to screen the images efficiently and effectively by providing on-screen prompts and tips.
- Combine the input of dietary intake data (using an appropriate nutrient database) with the captured images to assist participants and trained researchers in image-analysis to attain optimal accuracy.



- Allow researchers to define the duration of eating episodes and assess contextual attributes for each episode easily as the interview progresses.
- Allow researchers to *easily link the* dietary intake data obtained during the nutrition assessment (foods, energy and nutrients) with the associated eating episode attributes e.g. time, duration, and contextual assessment.
- Achieve the most efficient and optimal method to complete the 24-hour recall procedures with the assistance of wearable camera images e.g. the method may only require a single pass over the 24-hour period, compared to the multiple passes currently used.

The following automated image-analysis features, if feasible to develop, would enhance the system and efficiency of the method further

- Filter all images that are dark/blurry.<sup>306, 316</sup>
- Identify and tag all potential eating episodes to guide researchers and recognise potential unreported foods.
- Develop onscreen portion size tools to assist portion size estimation.
- Enable face blurring techniques to reduce privacy concerns.
- Allow wireless upload of images with an online image viewer to enable telephone based image-assisted dietary recall, or web-based automated self-reported dietary recall, to be conducted as demonstrated by Arab et al (Image-DietDay).<sup>212</sup>

### ***Recommended studies in free-living settings***

As indicated in Chapter Seven and in the limitations above, this research was conducted with relatively small sample sizes of healthy adults, and did not assess reactivity (behaviour change) while wearing the camera. Moreover, there are many other questions regarding the potential of wearable cameras in nutrition research that have arisen and need investigation. Therefore, a series of studies is required to address these gaps in the literature.

- **Evaluation of image-assisted 24-hour dietary recalls in children, elderly (>65 years) and specific ethnic and socioeconomic population groups**
  - There is a high prevalence of LERs among adults aged  $\geq 65$  years in dietary surveys, likely due to age-related decline in memory and cognitive function. Thus, wearable cameras may be ideally suited to enhance dietary recalls in this population group, and therefore should be evaluated.
  - Wearable cameras may allow dietary recalls to be completed among younger children than usual, and enhance the information collected from all children, and therefore should be evaluated.
  - Population groups prone to under-reporting, such as Maori, Pacific people people with obesity, or people on restricted diets, may provide more accurate information if their dietary intake is monitored by the wearable camera, and therefore should be explored.
- **The feasibility and acceptability of image-assisted methods in large-scale research and monitoring**
  - A study should evaluate if image-assisted 24-hour dietary recalls are feasible and cost effective compared to traditional recalls in a sample  $N \geq 100$ .
  - A study should evaluate the acceptability and privacy concerns related to large-scale research using wearable cameras
- **Assessment of reactivity while wearing wearable cameras**
  - Reactivity (behaviour change) should be examined to ensure the dietary recalls assessed by wearable cameras are indicative of participants' usual intake. A within-person comparison between participants' wear and non-wear days could be used.
- **Unannounced image-assisted 24-hour dietary recalls**
  - Often unannounced 24-hour dietary recalls are conducted in nutrition research to reduce the potential of behaviour change during the assessment period.

Therefore, the feasibility of implementing unannounced image-assisted 24-hour dietary recalls should be evaluated. This would require participants to wear cameras for sustained periods e.g. seven days or more.

- **Wearable cameras in nutrition interventions**

- Non-compliance reduces interventions effectiveness. Currently non-compliance is assessed using biomarkers (for some nutrients) or relies on self-reported dietary intake alone. Therefore, wearable cameras may provide a useful tool to monitor and verify compliance in dietary interventions, which should be explored.

- **Wearable cameras for private practice, clinical and community settings**

- Reviewing the cameras images provides valuable insights into participants/patients/clients daily lives and the environments they live in. This information is potentially valuable for dietitians/nutritionists in private practice, and in clinical and community settings to make informed decisions and provide the best possible care.

### ***Recommended laboratory studies***

A series of laboratory studies can answer additional questions that may enhance image-assisted methods using wearable cameras further.

- **Assessing the potential of image-assisted dietary recalls for periods longer than 24-hours**

- A key limitation of the 24-hour dietary recall, not addressed in this thesis, is that only one-day of dietary intake is assessed. Experience gained working with wearable cameras and reviewing images of eating episodes suggests wearable cameras may allow valid 48-hour or potentially 72-hour recalls to be conducted, which would greatly reduce the burden and costs of nutrition research compared to conducting multiple separate 24-hour dietary recalls.

- The potential for dietary recalls longer than 24-hours could first be examined using weighed meals in the laboratory. For example, participants would consume two buffets meals (breakfast and lunch) in the laboratory over three successive days while wearing a wearable camera. On day four, an independent researcher (without knowledge of the meals) would assess participants' dietary intake for the six meals consumed over the previous 72, 48, and 24-hours using an image-assisted dietary recall.
  
- **Determining the optimal imaging frequency**
  - The optimal imaging frequency could be assessed in the laboratory to determine the ideal rate to capture images of all foods consumed, while maximising battery life and memory capacity.
  
- **Detecting eating episodes using wrist-worn accelerometers**
  - Amft et al <sup>253</sup> have demonstrated that eating can be detected using wrist worn accelerometers (to detect movement on three axis). Therefore, it might be possible to develop an algorithm to initiate image capture, or store images in the devices memory, only when or around the time (e.g.  $\pm 5$  seconds) eating is detected. This would greatly reduce the number of images captured, maximise battery life, and alleviate some privacy concerns. Moreover, the range of devices available, such as wrist-worn fitness trackers and smart watches (which contain accelerometers and allow customised software), are increasing rapidly, and thus may provide a suitable and practical device for participants to wear.

## 9.4. Conclusion

Wearable cameras reduce the magnitude of under-reporting bias for dietary EI in 24-hour dietary recalls by 9% in men and 6% in women compared to dietary recalls alone. The images reveal unreported foods and misreporting errors not captured by traditional self-report. Used in nutrition research, wearable cameras can verify and enhance self-reported dietary intake, and compared to self-report alone, allow additional information on dietary behaviours to be objectively assessed. Further benefits from using wearable cameras may be achieved using faster imaging frequencies (<10 seconds), high resolution images/video, and independent image-analysis to verify and/or assess food type and portion size reported. However, additional research and development of software is likely required to feasibly incorporate wearable cameras and the image-assisted 24-hour recall into large-scale dietary studies.



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# APPENDICES

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# APPENDIX 1

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## Systematic review data extraction form



# Image-assisted dietary assessment: a systematic review of the evidence

## Data extraction form

<b>Title:</b>		
<b>Author:</b>	<b>Year:</b>	<b>Endnote Number #</b>
<b>Extracted by:</b>		<b>Source Database:</b>

<b>1.Setting</b>						
<b>2.Objective</b>						
<b>3.Method of recruitment</b>						
<b>4.Participant Characteristics (e.g. male or female population, age range)</b>						
<b>N=</b>	<b>Male</b>	<b>Female</b>	<b>Age Range</b>	<b><math>\bar{x}</math> Age</b>	<b><math>\bar{x}</math> Body mass</b>	<b><math>\bar{x}</math> BMI</b>
<b>Health Status:</b>						
<b>Targeted at special population/setting:</b>						
<b>Population group</b>	<b>Ssocioeconomic status</b>		<b>Education Level</b>		<b>Other</b>	
<b>5. Inclusion Criteria</b>				<b>Exclusion Criteria</b>		
<b>6. Device:</b>						

<b>7. Image-assisted method:</b>	
<b>8. Study duration &amp; protocol:</b>	
<b>9. Statistical analysis</b>	
<b>10. Reference methods used</b>	
<b>11. Outcomes (mean energy intake/energy expenditure)</b>	
<b>12. Feedback regarding technology/method:</b>	
<b>13. Study limitations:</b>	
<b>Included</b>	<b>Excluded</b>
<b>Reason:</b>	

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## **APPENDIX 2**

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**Ethics approval letter for the feasibility study from the University of Auckland Human Participants Ethics Committee**

The University of Auckland  
Private Bag 92019  
Auckland, New Zealand

Level 10, 49 Symonds Street  
Telephone: 64 9 373 7599  
Extension: 87830 / 83761  
Facsimile: 64 9 373 7432

## UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE

11-Apr-2012

### MEMORANDUM TO:

Dr Cliona Ni Mhurchu  
SOPH General Admin

### Re: Application for Ethics Approval (Our Ref. 7942)

The Committee considered your application for ethics approval for your project titled **Self-reported dietary intake using passive digital photography** on 11-Apr-2012.

Ethics approval was given for a period of three years with the following comment(s).

- The Committee notes the care with which its concerns have been addressed and acknowledges the changes made to try and address them. The Committee remains concerned about the reliance on participants to respect the privacy of others, particularly in private settings, and asks that in undertaking the pilot, you take particular care in instructing participants about this. In receiving approval for the pilot, you should also not assume that approval of an application for a main study will automatically follow. The Committee reserves the right to withhold or vary its approval for a main study, if required.

- It is made clear to participants that they will have an opportunity to review all their images in private before the researcher views them, which implies that if there are any inappropriately recorded images, these can be deleted/removed. It would be pertinent to state in the PIS and CF that this is the case.
- Please consider destroying the images once the researcher has reviewed them, rather than storing them for the same 15-year duration as other data.

The expiry date for this approval is 11-Apr-2015.

If the project changes significantly you are required to resubmit a new application to the Committee for further consideration.

In order that an up-to-date record can be maintained, you are requested to notify the Committee once your project is completed.

The Chair and the members of the Committee would be happy to discuss general matters relating to ethics approvals if you wish to do so. Contact should be made through the UAHPEC secretary at [humanethics@auckland.ac.nz](mailto:humanethics@auckland.ac.nz) in the first instance.

All communication with the UAHPEC regarding this application should include this reference number: 7942.

(This is a computer generated letter. No signature required.)

Secretary  
University of Auckland Human Participants Ethics Committee

c.c. Head of Department / School, SOPH General Admin  
Ms Jennifer Utter  
Mr Luke Gemming  
Dr Christopher Bullen

**Additional information:**

1. Should you need to make any changes to the project, write to the Committee giving full details including revised documentation.
2. Should you require an extension, write to the Committee before the expiry date giving full details along with revised documentation. An extension can be granted for up to three years, after which time you must make a new application.
3. At the end of three years, or if the project is completed before the expiry, you are requested to advise the Committee of its completion.
4. Do not forget to fill in the 'approval wording' on the Participant Information Sheets and Consent Forms, giving the dates of approval and the reference number, before you send them out to your participants.
5. Send a copy of this approval letter to the Manager - Funding Processes, Research Office if you have obtained funding other than from UniServices. For UniServices contract, send a copy of the approval letter to: Contract Manager, UniServices.
6. Please note that the Committee may from time to time conduct audits of approved projects to ensure that the research has been carried out according to the approval that was given



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## APPENDIX 3

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**Ethics approval letter for the feasibility study from the Inter-divisional research ethics committee, University of Oxford**



SOCIAL SCIENCES & HUMANITIES  
INTER-DIVISIONAL RESEARCH ETHICS COMMITTEE

Hayes House, 75 George Street, Oxford. OX1 2BQ  
Tel: +44(0)1865 614871 Fax: +44(0)1865 614855  
[ethics@socsci.ox.ac.uk](mailto:ethics@socsci.ox.ac.uk) [www.socsci.ox.ac.uk](http://www.socsci.ox.ac.uk)

Co-ordinator of the IDREC  
Social Sciences Divisional Office



Wednesday, 15 February 2012

Dr Charlie Foster  
Department of Public Health

Dear Dr Foster,

**Research Ethics Approval**

**Ref No.: SSD/CUREC1A/12-008**

**Self-reported dietary intake using passive digital photography**

The above application has been considered on behalf of the Social Sciences and Humanities Inter-divisional Research Ethics Committee (IDREC) in accordance with the procedures laid down by the University for ethical approval of all research involving human participants.

I am pleased to inform you that, on the basis of the information provided to the IDREC, the proposed research has been judged as meeting appropriate ethical standards, and accordingly approval has been granted.

Should there be any subsequent changes to the project, which raise ethical issues not covered in the original application, you should submit details to the IDREC for consideration.

Yours sincerely,

A handwritten signature in black ink, appearing to read 'K. Vernon', with a large loop at the end.

Kerry Vernon

cc: Paul Kelly, Department of Public Health

KV/EB



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## **APPENDIX 4**

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**Participant information sheet and consent form for the feasibility study**



## Participant Information Sheet

**Project title:** Self-reported dietary intake using passive digital photography (**PILOT STUDY**)

**Names of Researchers:** Charlie Foster, Luke Gemming, Cliona Ni Mhurchu, Jennifer Utter, Paul Kelly, and Aiden Doherty

You are invited to take part in a study to evaluate a new method of nutrition assessment, using automated photography.

To help you make a decision about participating in the study, we ask that you read this information sheet.

### **Who is coordinating this study?**

The study is coordinated by Dr Charlie Foster, and this research will be conducted by a PhD student Luke Gemming. This research is collaboration between the British Heart Foundation Health Promotion Research Group, The University of Oxford and the Clinical Trials Research Unit, The University of Auckland, New Zealand.

### **What is the aim of this study?**

The aim of the study is to evaluate a new method of nutrition assessment using passive digital photography. A secondary aim is to assess which dietary habits, such as breakfast eating habits and location of meals the camera can capture effectively.

### **Why am I suitable for the study?**

You are suitable for the study because you:

- Are 18 years of age or older
- You are healthy and do not have any dietary restrictions

You cannot take part in this study if you have any of the following conditions:

- You have a medical condition which severely restricts the foods that you can eat
- You have a medical condition that restricts your ability to freely complete usual activities of daily living

**Where will the study take place?**

Participants for this study will contact the researcher in response to advertisements on community and university notice boards. The assessments will take place at the Department of Public Health, at The University of Oxford.

**How long will the study take?**

Overall, the entire study will run for approximately 12 months, from April 2012 to April 2013. However, each person will only be involved for approximately two days (48hrs).

**How many people will be recruited into the study?**

We are looking to recruit approximately 12 people.

**What is involved if I take part?**

If after reading this information sheet, you decide that you would like to take part in the study, you will meet with the researcher on two occasions: (1) instruction and training session (30mins) (2) nutrition assessment and feedback session (1-1.5 hours).

During the first session will you have the opportunity to ask any questions about the study and be asked to sign a consent form agreeing to take part. You will also receive a digital camera (Vicon Revue, see figure 1.) and provided training on its use. We anticipate the instruction and training session will take approximately 30 minutes.

This digital camera is different from other cameras as it takes photos automatically (every 20-30 seconds) and is worn around the neck on a lanyard. The camera has a special lens which allows it to capture almost everything in front of the person wearing it and is very simple to operate. A privacy button stops photos being captured when confidentiality is required.



**Figure 1.** Vicon Revue digital camera

You will be asked to wear the camera for two days (48hrs) (from wake to sleep) while continuing your usual daily activities. After this period you will meet with the researcher to have your diet assessed.

When you are wearing the camera you will be required to use the privacy button or turn off the camera in certain locations, such as private residences (or public locations that have signage indicating the photography is prohibited). You will be provided with an information sheet detailing the locations in which photography is permitted or prohibited. After the 48h period you will meet with the researcher for the second session and have your diet assessed. You will be provided sufficient time to review all your images privately before they are viewed by the student researcher, and you can request more time if required. You will also be asked to complete a questionnaire to provide feedback on wearing the camera, and the use of images in nutrition assessment. Personal characteristics will also be recorded such as body weight, height, ethnicity, and education level. We anticipate this session will take approximately 1 - 1.5 hours.



**Will there be any costs involved?**

There are no costs involved in taking part in this study.

**Withdrawal from study after data collection**

You may withdraw from the study at any time and withdraw any data you have provided up to two months after your final visit.

**What are the risks and benefits of this study?***Possible benefits*

You will receive an assessment of your diet from a registered dietitian. This may provide valuable information to you about for the foods you eat.

*Possible risks*

Wearing the camera may make you feel uncomfortable in certain situations. A counsellors contact details can be provided if necessary. There are no other anticipated physical risks.

**Will the information about me be kept confidential?**

The study files and all information that you provide will remain strictly confidential. Questionnaires and forms you complete will be numbered 10-XXX and a list will be maintained linking the codes to your personal details. This list will be kept securely by the principal investigator. No material that could personally identify you will be used in any reports on this study and only the student researcher will have access to view the images you capture. The information including the images you capture will be kept securely at the British Heart Foundation Health Promotion Research Group, The University of Oxford, and The Clinical Trials Research Unit, The University of Auckland and destroyed after 15 years according to national research guidelines. All computer records will be password protected. Any information collected, as part of this study will not be used for any other purpose, without my permission and ethical approval, nor given to any other third party outside of the research team. However, if the images you capture indicate a serious crime or illegal activity the researchers will be obliged to report this to the relevant authorities. These authorities may request access to the image files as part of a criminal investigation.

During the study, ethics committee representatives, the student researcher and co-investigators may check your records but will not be able to identify you (only the student researcher will have access to view the images you capture). This will only be done to check the accuracy of the information collected for the study and the information will remain confidential.

**When will the results be available?**

This study will take up to 12 months to conduct, so results will not be available until after April 2013. If you would like to be sent a copy of the overall results you can indicate this on the consent form.

**Use of Data**

The data obtained from this study will be used as part of a PhD thesis, and used for future conference presentations, and scientific publications.

**Has the study received ethical approval?**

Yes, this study has received ethical approval from the Central University Ethics Committee (CUREC) University of Oxford, and the University of Auckland Human Participants Ethics Committee (UAHPEC) New Zealand.

**What is funding this research?**

No funding is required for this research. The student conducting this research is supported by a New Zealand Health Research Council PhD stipend 10/077.

**What are my legal rights?**

Your participation in this study is entirely voluntary (your choice). You do not have to take part. If you choose not to take part in this study you will not be affected in any way. You may withdraw from the study at any time, without having to give a reason. Your withdrawal from the study will not affect your future health care. You are encouraged to ask questions at any time during the study. If you have any questions please contact:

Dr Charlie Foster  
Primary Investigator  
British Heart Foundation Health Promotion Research Group,  
Department of Public Health  
University of Oxford  
Rosemary Rue Building, Old Road Campus, Headington, Oxford OX3  
7LF, United Kingdom  
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Rosemary Rue Building, Old Road Campus, Headington, Oxford OX3  
7LF, United Kingdom  
Ph: +44 (0)1865 289200  
Email: l.gemming@ctr.u.auckland.ac.nz

APPROVED BY CENTRAL UNIVERSITY ETHICS COMMITTEE (CUREC)  
UNIVERSITY OF OXFORD ON 15<sup>th</sup> February 2012. Reference Number:  
SSD/CUREC1A/12-008

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**Study Investigators**

- Charlie Foster, Paul Kelly, and Aiden Doherty, British Heart Foundation Health Research Promotion Group, The University of Oxford
- Luke Gemming, and Cliona Ni Mhurchu Clinical Trials Research Unit, Faculty of Medical and Health Sciences, The University of Auckland
- Jennifer Utter, Faculty of Medical and Health Sciences, The University of Auckland

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**Thank you for taking the time to read about this study.  
Please keep this sheet for your information.**

## CONSENT FORM

This form will be held for a period of 15 years

**Project title:** Self-reported dietary intake using passive digital photography (**PILOT STUDY**)

**Names of Researchers:** Charlie Foster, Luke Gemming, Cliona Ni Mhurchu, Jennifer Utter, Aiden Doherty, Paul Kelly,

I have read and I understand the information sheet dated 13/03/2012 for volunteers taking part in this study. This study is designed to evaluate the potential of a new method of nutrition assessment using passive digital photography. I have had the opportunity to discuss this study with study researchers and I am satisfied with the answers I have been given.

- I understand that I will be passively (automatically) capturing digital photographs from a first person perspective
- I understand that I will meet with the researcher on two separate occasions taking approximately 2.5 hours of my time, and will be required to wear the digital camera for a 48h period.
- I understand that I will have sufficient time to review all my images privately before they are viewed by the student researcher, and I can ask for more time if I require it.
- I understand that taking part in this study is voluntary (my choice) and that I may withdraw at any time and withdraw any data that I have provided up to two months after my final visit.
- I understand that I will be required to be responsible and turn off the camera or use the privacy button in certain locations, such as private residences and anywhere photography is prohibited.
- I understand that my participation in this study is confidential and that no material that could identify me will be used in any reports on this study.
- I know whom to contact if I have any questions about the study.
- I understand that any data collected including the images I capture as part of this study will be stored securely for 15 years at British Heart Foundation Health Promotion Research Group, University of Oxford, and the Clinical Trials Research Unit, University of Auckland, New Zealand in accordance with the Privacy Act, 1993 (NZ). After this time the information will be safely destroyed.
- I understand that any information collected, as part of this study will not be used for any other purpose, without my permission and ethical approval, nor given to any other third party outside of the research team.
- I understand that there may be a significant delay between data collection and publication of the results.
- I understand that the results of the study will be published in scientific journals but none of these publications will contain information about me personally.

- I wish to receive a copy of the results.

YES / NO

**Participant to complete:**

I _____	(print full name)
Agree to take part in this research.	
Date: ___/___/___ day/month/year	

One signed consent form is to be given to the participant and the second signed consent form is to be placed in the study record file.

APPROVED BY THE CENTRAL UNIVERSITY RESEARCH ETHICS (CUREC) COMMITTEE ON 15<sup>TH</sup> FEBRUARY 2012. REFERENCE NUMBER: SSD/CUREC1A/12-008

APPROVED BY THE UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE ON ..... for (3) years, Reference Number .../.....

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## **APPENDIX 5**

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### **Registration form for the feasibility study**





## 2. Inclusion Criteria

2.01	Aged between 18 and 65 years	Yes/No
2.02	Healthy without strict dietary restrictions	Yes/No
2.03	Able to give written informed consent/assent	Yes/No
2.04	Speaks and understands English	Yes/No

## 3. Exclusion Criteria

3.01	Have a medical condition which severely restricts the food they can eat	Yes/No
3.02	Have a medical condition that restricts their ability to freely complete usual activities of daily living	Yes/No

## 4. Assent and Consent

### Participant consent

4.07	consent obtained	Yes/No
	If NO to Q 4.07, participant is not eligible.	
4.08	If YES to Q 4.07, date of consent	Date DD/MM/20YY

## 5. CRF sign off - Signature of Researcher (PI)

Form Submitted: Eligibility Checked and if OK Participant.

5.01	Signature	
	Printed Name	
	Date	Date DD/MM/20YY



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## **APPENDIX 6**

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**Brief information sheet for participants in feasibility study on  
photography in public places**



## Photography in public and private locations

As a participant in the RAD pilot study you will be required to wear to a camera which captures photographs automatically for two days. Use this information sheet as guide and reference for locations in which photography is legally permitted or prohibited.

### Where is photography permitted?

Members of the public do not need a permit to film or photograph in public places (legal advice from the metropolitan police, United Kingdom)

**Photography is permitted in all public places (except when signage indicates otherwise)**

### Where should use the privacy button or turn the camera off?

**Photography is prohibited and may be a criminal offence in the following locations**

- Private residences without explicit permission from the landlord or property owner
- Commercial and governmental premises with signage that indicates photography is prohibited
  - e.g. banks, airports, embassies, customs and certain shops
- Within a court building or its surroundings

**If you're not certain if photography is permitted use the privacy button or the OFF button!**



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## APPENDIX 7

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### Participant contact details for feasibility study





**FORM Z: CONTACT DETAILS**

Participant Initials

LLLL

Participants Date of Birth

LL-LL-19LL

Registration Number

LL-LLLL

Please fill in your contact details, and preferred method of contact.

**1.0 Participant Contact Details**

1.01 Title   
1.02 First Name  Middle Names   
1.03 Surname   
1.03 Preferred method of contact  
Home  Work  Mobile  Email

1.04 Home phone   
1.05 Work phone   
1.06 Mobile phone   
1.07 Email

Postal Address  
1.08 Flat number, street number and name   
1.09 Suburb   
1.10 City, district or town   
1.11 Post Code

**2.0 Alternative Contact Details**

2.01 Title   
2.02 First Name  Middle Names   
2.03 Surname   
2.04 Home phone   
2.06 Mobile phone   
2.07 Email

<b>Postal Address</b>	
2.08 <b>Flat number, street number and name</b>	
2.09 <b>Suburb</b>	
2.10 <b>City, district or town</b>	
2.11 <b>Post Code</b>	

**3.0 Signature of Study Researcher**

3.01 <b>Name</b>	
3.02 <b>Signature</b>	
3.03 <b>Date</b>	



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## **APPENDIX 8**

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### **Baseline demographics for feasibility study**



Participant Initials  
[ ][ ][ ][ ]

Participant DOB  
[ ][ ][ ][ ] | 9 | [ ][ ][ ]  
Day/Month/Year

Registration Number  
[ ][ ][ ][ ][ ]

**Self-reported dietary intake using passive digital photography  
Form B: RAD PILOT STUDY (OXFORD): Baseline Demographics**

### Survey Information Sheet

The purpose of this questionnaire is to collect some background information about you. This survey will take about 5 minutes to complete. If you have any questions then you can ask one of the researchers.

Please answer ALL questions. DO NOT LEAVE BLANK SPACES.  
Tick circles and write numbers in boxes.

The answers that you write are private and will not be shared with anyone other than the researchers. You do not need to tell anyone else what you write on this questionnaire.

If you are worried about anything, or have any questions let the researcher know.

#### 1 Assessment Date

1.01 Date [ ][ ][ ] / [ ][ ][ ] / [ ]\_2[ ]\_0[ ][ ][ ] (dd/mm/yyyy)

#### 2 About you

2.01 Sex  Male  Female

Which ethnic group or groups do you belong to?  
Please indicate Yes or No to every option.

<b>White</b>		<b>Asian or Asian British</b>	
2.02	British	2.08	Indian
2.03	Irish	2.09	Pakistani
2.04	Other white background	2.10	Bangladeshi
	<b>Mixed</b>	2.11	Other Asian background
2.04	White & Black Caribbean		<b>Black or Black British</b>
2.05	White & Black African	2.12	Caribbean
2.06	White & Asian	2.13	African
2.06	<b>Chinese</b>	2.14	Other Black background
		2.15	<b>Any other group</b>

### 3 Work and Education

3.01 At present are you? (select one only)

- Self-employed
- Full time salary or wage earner
- Part-time salary or wage earner (less than 30 hrs/week)
- Retired
- Full-time home-maker
- Student
- Unemployed
- Other beneficiary
- Refuse to answer

*If you answered 'full-time home-maker', 'student', 'unemployed', 'other beneficiary', or 'refuse to answer', go to Q 3.04.*

*For all other answers, go to Q 3.02*

3.02 What is your current occupation?  
Or if retired, what was your previous occupation? (select one only)

- Clerical or sales employee
- Semi-skilled worker
- Technical or skilled worker
- Business manager or executive
- Business owner or self-employed
- Teacher, nurse, police, other trained service worker
- Professional or senior government official
- Labourer, manual, agricultural or domestic worker
- Farmer owner or manager
- Other
- Refuse to answer

3.03 If Other, please specify

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**3.04** What is your highest educational qualification? (select one only)  
If None, select 'No school examinations'

- National Curriculum tests Key Stage 3
- National Curriculum tests Key Stage 4 / GCSE, or GNVQ
- A-levels, International Baccalaureate or Cambridge Pre-U
- Other school qualification (e.g. overseas school)
- National Vocational Certificate / Trade Certificate
- Polytechnic/university course below Bachelors degree
- Bachelors degree
- Degree higher than Bachelor (*Bachelors with honours, Masters, PhD*)
- Other tertiary
- Refuse to answer
- No school examinations

**3.05** If other please specify the qualification

---

**3.06** Which of these categories best describes you? (select one only)

- Married/living with partner
- Separated, divorced, widowed
- Never married
- Refuse to answer

**3.07** Please indicate which of these categories best matches your household's income (select one only)

- Under £5,000
- £5001 to £15,000
- £15,001 to £25,000
- £25,001 to £35,000
- £35,001 to £45,000
- £45,001 to £55,000
- £55,001 to £60,000
- £60,001 to £70,000
- Over £70,000
- Don't know
- Refuse to answer

**4 Nutrition**

**4.01** Are you currently on any specific or special diet?

If yes please specify

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**4.02** Are you restricting yourself from eating any specific foods?

If yes please specify

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**5 Signature of Study Researcher**

**5.01** Signature

---

Printed Name

---

Date

|\_|\_|/|\_|\_|/|\_2|\_0|\_|\_|

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## APPENDIX 9

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### Feedback survey form for the feasibility study





## Self-reported dietary intake using passive digital photography

Initials |\_|\_|\_|\_| DOB |\_|\_|\_|\_|19|\_|\_| Registration Number |\_|\_|-|\_|\_|\_|

This questionnaire asks for your views on passive digital photography assisting dietary assessment. Your responses will provide important information regarding the use of photos for nutrition assessment and practicalities of wearing the camera. *Thank you for completing this questionnaire!*

Rate on the scale your response to the following statements. Tick one circle per row.

		Strongly disagree					Strongly agree	
		1	2	3	4	5	6	7
1.1	The images helped me to remember some foods I had forgotten about	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1.2	The images helped me to remember extra details of how my foods were cooked, prepared or purchased	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1.3	The images helped me to remember the portion size of the foods I ate	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1.4	The images helped me to verify the portion size of foods I ate using the portion size guides	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1.5	The images allowed me to provide more accurate information about the foods I ate	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1.6	The images helped me to remember where I ate foods	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1.7	The images helped me to remember who I ate my foods with	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1.8	The images helped me remember the time that I ate foods	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

		Never	Seldom	Sometimes	Usually	Always
2.1	Wearing the camera affected my eating behaviour	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
		↓ If never skip to question 3.1				
2.2	How was eating behaviour affected (Please write below)					

		Never	Seldom	Sometimes	Usually	Always		
3.1	I felt uncomfortable wearing the camera	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>		
		↓ If never skip to question 5.1						
3.2	In what situations did you feel uncomfortable? (Please write below)							
		Strongly disagree			Strongly agree			
		1	2	3	4	5	6	7
3.3	I would feel more comfortable with a smaller camera that was hidden	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

		Very little burden			Very high burden			
		1	2	3	4	5	6	7
5.1	Was the camera a burden to wear?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5.2	Was reviewing the images on the computer a burden?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5.3	Was the overall method to assess your diet a burden?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

		1 day or less	2-3 days	A week	A fortnight	One month	Longer than a month
6	What is the maximum period you would wear the camera for?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

If you have any other comments in regards to wearing the camera or the assessment of your diet please comment in the box below

***Thank you for completing this questionnaire!***

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## **APPENDIX 10**

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**Ethical approval letter for the PICTURE study, University of  
Auckland Human Participants Ethics Committee**



The University of Auckland  
Private Bag 92019  
Auckland, New Zealand  
Level 10, 49 Symonds Street  
Telephone: 64 9 373 7599  
Extension: 87830 / 83761  
Facsimile: 64 9 373 7432

UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE

**30-Nov-2012**

MEMORANDUM TO:

**Dr Cliona Ni Mhurchu**

**SOPH General Admin**

Re: Application for Ethics Approval (Our Ref. 8701)

**The Committee considered your application for ethics approval for your project entitled Passive Image Capture to record everyday events (PICTurRE).**

**Ethics approval was given for a period of three years.**

**The expiry date for this approval is 30-Nov-2015.**

**If the project changes significantly, you are required to submit a new application to UAHPEC for further consideration.**

**In order that an up-to-date record can be maintained, you are requested to notify UAHPEC once your project is completed.**

**The Chair and the members of UAHPEC would be happy to discuss general matters relating to ethics approvals if you wish to do so. Contact should be made**

through the UAHPEC Ethics Administrators at [humanethics@auckland.ac.nz](mailto:humanethics@auckland.ac.nz) in the first instance.

All communication with the UAHPEC regarding this application should include this reference number: 8701.

(This is a computer generated letter. No signature required.)

**UAHPEC Administrators**

**University of Auckland Human Participants Ethics Committee**

**c.c. Head of Department / School, SOPH General Admin**

**Ms Jennifer Utter**

**Mr Luke Gemming**

Additional information:

- 1. Do not forget to fill in the 'approval wording' on the Participant Information Sheets and Consent Forms, giving the dates of approval and the reference number, before you send them out to your participants.**
- 2. Should you need to make any changes to the project, write to the UAHPEC Administrators by email ([humanethics@auckland.ac.nz](mailto:humanethics@auckland.ac.nz)) giving full details of the proposed changes including revised documentation.**
- 3. At the end of three years, or if the project is completed before the expiry, please advise UAHPEC of its completion.**
- 4. Should you require an extension, write to UAHPEC by email before the expiry date, giving full details along with revised documentation. An extension can be granted for up to three years, after which a new application must be submitted.**
- 5. If you have obtained funding other than from UniServices, send a copy of this approval letter to the Manager - Funding Processes, UoA Research Office. For**

UniServices contracts, send a copy of the approval letter to the Contract Manager, UniServices.

6. Please note that UAHPEC may from time to time conduct audits of approved projects to ensure that the research has been carried out according to the approval that was given.

Bestpfe.com





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## APPENDIX 11

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### Invitation letter for the PICTURE study



DATE



THE UNIVERSITY OF AUCKLAND  
FACULTY OF MEDICAL AND  
HEALTH SCIENCES

National Institute for Health Innovation  
The University of Auckland

Level 4, School of Population Health Bldg  
Tamaki Campus  
Morrin Road, Glen Innes, Auckland  
Private Bag 92019  
Auckland  
NEW ZEALAND  
Telephone: 64 9 373 7599, ext 84612  
Facsimile: 64 9 373 1710  
Email: l.gemming@nihi.auckland.ac.nz  
www.nihi.auckland.ac.nz

Dear NAME

Thank you for expressing interest in the PICTuRE study (Passive Image Capture to Record Everyday Events)

This letter contains the following items:

1. Participant Information Sheet
2. A map of the University of Auckland Tamaki Campus (overleaf)

As discussed in our earlier phone call, I would like you to come to the Auckland University Tamaki Campus, 261 Morrin Rd, Glen Innes (see attached map overleaf) on the **Day, Date and Time** for the baseline assessment. Please come to **Room 100, Building 731**. Enter the Tamaki Campus through Gate 1. Free guest parking is available to your left but alternatively you can park in any of the far rows as there are always spare parks.

Building **731** is the Sport and Exercise Building. This is the second building on your right as you enter through Gate 1. Enter into the building on the ground floor. If you veer right you will see some double doors opposite the elevator (**SES LABORATORIES Room 100**). These doors are locked but please press the doorbell. However, I should already be waiting outside for your arrival. If you have arranged an early time or are coming in on the weekend I may need to let you in at the gate. If so please call and I'll come to the GATE ASAP.

This session will take approximately 1-2 hours in duration.

- **Participants: Please do not eat anything on the day of the assessment, and drink only water. i.e. overnight fast (10-12hrs). Please reschedule your appointment if you have a fever or feel unwell.**
- **Please make sure that you have passed urine in the morning before you come. Then, drink plenty of water so that you can give another urine sample when you arrive at the assessment.**
- **Please wear light clothing and comfortable shoes. (shoes required for the LAB)**

Please read through the Participant Information Sheet again prior to this assessment to give you time to consider the information. I will contact you 1-2 days before the assessment to remind you of the appointment. Alternatively, you are welcome to phone me on 021 434317 (anytime)

If you have trouble finding the location of the room on the day of the assessment, please contact me on 021 434317.

I appreciate the time you have taken to consider your involvement in this study and I look forward to meeting with you.

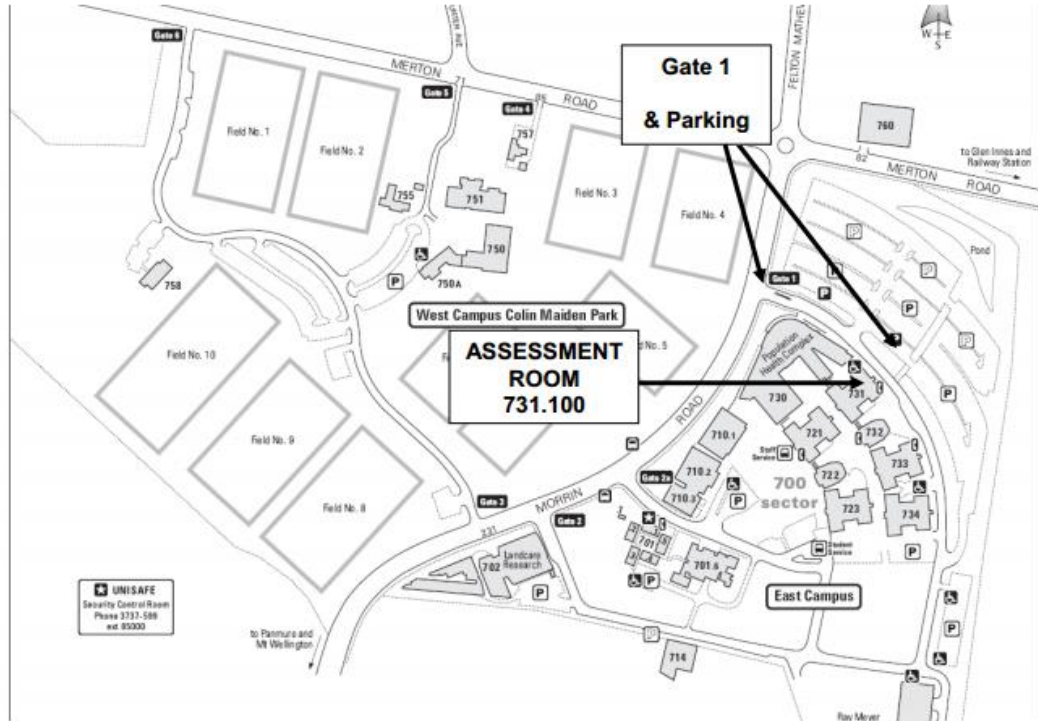
Yours sincerely,

Luke Gemming  
PICTuRE Study Manager



National Institute  
for Health Innovation

# CAMPUS MAP



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## **APPENDIX 12**

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**Participant information sheet and consent form for PICTURE  
study**



## Participant Information Sheet

**Project title:** Passive Image Capture to Record Everyday Events  
(PICTuRE)

**Names of Researchers:** Luke Gemming, Cliona Ni Mhurchu, Jennifer Utter, Elaine Rush, Aiden Doherty.

You are invited to take part in a study using a new digital method to capture everyday events of people's lives with a special camera called SenseCam. To help you make a decision about participating in the study, we ask that you read this information sheet.

**Who is coordinating this study?**

The study is coordinated by Associate Professor Cliona Ni Mhurchu, and this research will be conducted by a PhD student Luke Gemming at the National Institute for Health Innovation, The University of Auckland, New Zealand.

**What is the aim of this study?**

The aim of this study is to record people's usual daily activities and eating episodes using passive image capture. The images captured will be used to evaluate a new method to assess dietary intake, explore the context surrounding eating episodes, and may be used to assess the duration of typical daily activities, such as watching television or traveling to work.

**Why am I suitable for the study?**

You are suitable for the study because you:

- Are 18 - 65 years of age
- You are healthy and do not have any strict dietary restrictions
- You can operate basic functions of a computer
- Can read and understand the English

**You cannot take part in this study if:**

- You plan on travelling during the study period
- You plan to conduct extra (above normal) vigorous exercise during the study
- You have had an recent acute illness
- You who have had blood tests or intravenous fluids two weeks prior or scheduled during the testing period
- You plan to have an increased physical activity level during the testing period
- You have a medical condition which severely restricts the foods that you can eat
- You have a medical condition that restricts your ability to freely complete usual activities of daily living

### Where will the study take place?

Participants for this study will contact the researcher in response to advertisements and the assessments will take place at The School of Population Health, University of Auckland and within your own home if requested.

### How long will the study take?

Each participant will only be involved for 15 days but overall, the entire study will run for approximately 12 months, from February 2013 to February 2014.

### How many people will be recruited into the study?

We are looking to recruit approximately 40 people.

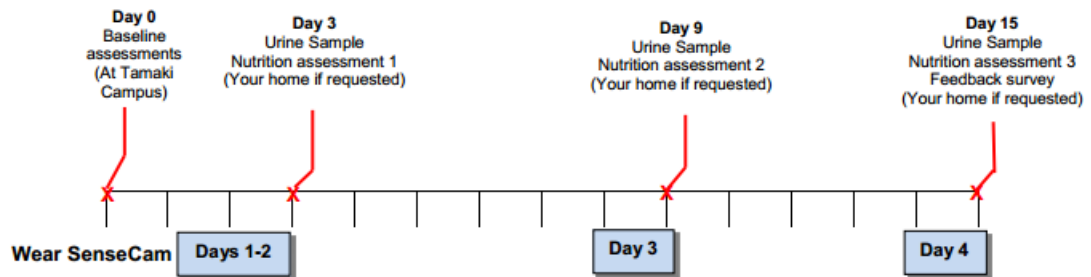
### What is involved if I take part?

If you decide that you would like to take part in the study you will meet with the researcher on four occasions over a 15 day period. You will be required to attend a baseline assessment session, and have your diet assessed three times. The baseline assessment will be at the School of Population Health, University of Auckland in Glen Innes but the other three appointments can be in your own home if requested.

**Day 0:** Baseline assessments – 2hr

**Days 3, 9, 15:** Three nutrition assessments - 1.5h each

### Study Timeline



### Day 0 – Baseline Assessments

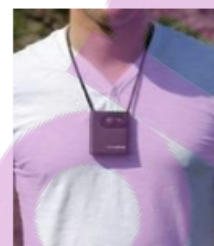
During the first session will you have the opportunity to ask any further questions about the study before providing consent to participate.

You will arrive at the first session after fasting (not eating) over-night to complete baseline assessments including:

- A urine sample
- Assessment of height, body weight, resting energy expenditure, and percentage body fat.
- Background and demographics questionnaire



You will be shown the SenseCam digital camera that is used in the study. SenseCam is different from other cameras as it takes photos automatically every 20-30 seconds and is worn around the neck on a lanyard/strap. The camera has a wide-angle lens which allows it to capture almost everything in front of the person wearing it and is very simple to operate. A privacy button stops photos being captured when confidentiality is required, and you will have the opportunity to screen the photos privately and delete any photo you wish before the researcher views the images.



**SenseCam Digital Camera**

As a participant you will be required to wear the SenseCam for four days from wake to sleep while continuing your usual daily activities. The images will be used to help assess your diet, and the context around which foods are consumed. The images will also be used to assess the time spent in usual activities of daily living, such as time spent watching television or travelling to work.

#### **Screening photos**

After each nutrition assessment you will have a chance to screen the images you have captured privately before they are viewed by the researchers. You will be provided adequate time to screen the images and you can request more time if required. This process usually takes about 10-15 minutes and is usually enjoyed by participants as they watch their own recording of their life similar to a short movie.

#### **Participant obligations**

While wearing the SenseCam you will be required to gain permission to capture images in private locations, such as other people's homes, private clubs, or certain workplaces. If you do not have permission to capture images you must use the privacy button or turn the camera off. An information sheet detailing the locations which photography is permitted or prohibited will be provided and you will be given verbal instructions by the researcher to assist your understanding. You will also be given basic information cards to provide to third parties. This card will help third parties make an informed decision regarding their privacy.

#### **Doubly Labelled Water**

After completion of the baseline assessments you will be provided a small dose (about 150ml) of special water called doubly labeled water to drink. This water tastes like normal water and contains an invisible marker called an isotope that can be traced and measured to assess your energy expenditure. This marker is completely safe and is commonly used to assess body composition and energy expenditure in research. The doubly labelled water will be eliminated naturally from your body in urine, sweat, and the moisture in your breath.

Five hours after consuming the water you will provide a second urine sample. This can be collected by you at your home. You will be provided instructions on how this is done correctly.

#### **Days 3, 9, 15: Nutrition Assessments – 1.5 hours**

On days 3, 9 and 15 you will meet with the researcher to have your diet assessed and provide urine samples which takes about 1.5 hours. On day 15 you will also have your weight re-measured, and complete a feedback survey. On completion of the study you will receive an \$80 Grocery voucher.

#### **Will there be any costs involved?**

There are no direct costs involved in taking part in this study, but there may be some transport costs to attend the baseline session 1.

**Withdrawal from study after data collection**

You may withdraw from the study at any time and withdraw any data you have provided up to two months after your final visit.

**What are the risks and benefits of this study?***Possible benefits*

You will receive three assessments of your diet from a registered dietitian. This may provide valuable information to you about the foods you eat. You will also have your energy expenditure assessed using a gold standard method. This will give you an estimate of the energy you expend each day over a two week period which may be useful for future weight management.

*Possible risks*

Wearing the camera may make you feel uncomfortable in certain situations but you can remove the SenseCam at any time. There are no other anticipated physical risks.

**Will the information about me be kept confidential?**

The study files and all information that you provide will remain strictly confidential. Questionnaires and forms you complete will be numbered 20-XXX and a list will be maintained linking the codes to your personal details. This list will be kept securely by the principal investigator. No material that could personally identify you will be used in any reports on this study and only the researcher directly involved in this study will have access to view the images you capture. All data will be stored securely at The National Institute for Health Innovation, University of Auckland and destroyed after 15 years according to national research guidelines. The images you capture will be destroyed once the analysis has been completed. All computer records will be password protected. Any information collected, as part of this study will not be used for any other purpose, without your permission and ethical approval, nor given to any other third party outside of the research team. However, if the images you capture indicate a serious crime or illegal activity the researchers will be obliged to report this to the relevant authorities. These authorities may request access to the image files as part of a criminal investigation.

During the study, ethics committee representatives, the student researcher and co-investigators may check your records but will not be able to identify you (only the researchers will have access to view the images you capture). This will only be done to check the accuracy of the information collected for the study and the information will remain confidential.

**When will the results be available?**

This study may take up to 12 months to conduct, so results will not be available until mid-2014. If you would like to be sent a copy of the overall results you can indicate this on the consent form.

**Use of Data**

The data obtained from this study will be used as part to form part of a PhD thesis, and used for future conference presentations, and scientific publications.

**Has the study received ethical approval?**

Yes, this study has received ethical approval from The University of Auckland Human Participants Ethics Committee (UAHPEC) New Zealand.

**Who is funding this research?**

The funding is provided by the National Institute for Health Innovation. The student conducting this research is supported by a New Zealand Health Research Council of New Zealand PhD stipend (10/077).

**What are my legal rights?**

Your participation in this study is entirely voluntary (your choice). You do not have to take part. If you choose not to take part in this study you will not be affected in any way. You may withdraw from the study at any time, without having to give a reason. Your withdrawal from the study will not affect your future health care. You are encouraged to ask questions at any time during the study. If you have any questions please contact Luke or other investigators:

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For any queries regarding ethical concerns you may contact the  
Chair, The University of Auckland Human Participants Ethics Committee, The University  
of Auckland, Research Office, Private Bag 92019, Auckland 1142. Telephone 09 373-7599  
extn. 87830/83761. Email: [humanethics@auckland.ac.nz](mailto:humanethics@auckland.ac.nz)

APPROVED BY THE UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS  
COMMITTEE ON 30<sup>th</sup> November for (3) years, Reference Number 8701.

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**Study Investigators**

- Cliona Ni Mhurchu, Luke Gemming, National Institute for Health Innovation, Faculty of Medical and Health Sciences, The University of Auckland
- Jennifer Utter, Faculty of Medical and Health Sciences, The University of Auckland
- Elaine Rush, Faculty of Health and Environmental Sciences, Auckland University of Technology
- Aiden Doherty, British Heart Foundation Health Research Promotion Group, The University of Oxford

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**Thank you for taking the time to read about this study.**  
**Please keep this sheet for your information.**





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## **APPENDIX 13**

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**Brief information sheet on photography for the PICTURE study**





# Photography in public and private locations

As a participant in the PICTuRE study you will be required to wear to a camera which captures photographs automatically for four days. Use this information sheet as a reference and guide for locations in which photography is legally permitted or prohibited.

## Where is photography permitted?

Members of the public do not need a permit to film or photograph in public places.

**i.e. Photography is permitted in all public places (except when signage indicates otherwise)**

- You can capture images in private locations (e.g. homes, workplaces, clubs) **BUT** only if you have permission first! Ask the home owner/tenant or senior member of the premises for permission. **(use the study information cards to help explain)**

## Where should use the privacy button or turn the camera off?

**Photography is prohibited and may be a criminal offence in the following locations**

- Private residences without explicit permission from the landlord or property owner
- Commercial and governmental premises with signage that indicates photography is prohibited
  - e.g. banks, airports, embassies, customs and certain shops
- Within a court building or its surroundings

## Other locations we recommend using privacy button or turning the camera off!

- Close proximity to public bathrooms or changing rooms
- Schools or childcare centres
- Public swimming pools or the beach
- Any other location that you feel photos should not be captured

**If you're not certain if photography is permitted ask for permission first  
otherwise use the privacy button or the OFF button!**





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## **APPENDIX 14**

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### **SenseCam user instructions for PICTURE study**



## Using the SenseCam

**Turning on/off** – you can turn the SenseCam on or off by pressing the button in the top of the device for a few seconds. When it is turning on it will make a beep sound and an orange light will appear beside the button.

Turn the SenseCam off when you are not wearing it to save the battery. You will most likely only need to turn it off when you are going to bed or if you decide you do not want it to record anything for an extended period.

**Privacy button** – press this button to temporarily stop the device from taking pictures. It will reactivate automatically after 7 minutes.

**Activate button** – this button allows you to take a picture manually or to reactivate the device if you had previously pressed the privacy button.

**Status lights** – an orange flashing light will indicate every time an image is captured. A red light indicates that the privacy button has been pressed and the device is not taking any images at this time.

### Charging

You will be given a charger lead with a plug on one end and a small square plug on the other end. It is recommended that you charge SenseCam at night when you are sleeping so that the battery will be full for the next day.

To charge the SenseCam, put the small end into the SenseCam in the slot on its side (see picture below) and plug the other end into your domestic plug socket.



PICTuRE Study



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## APPENDIX 15

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### Participant registration form for PICTURE study



# PICTuRE Study

## Form A: Participant Registration, Consent and Attendance at the Instruction and Training Session

Participant Initials    Participants Date of Birth    Registration Number  
 [ ][ ][ ][ ]    [ ][ ][ ][ ][ ][ ][ ][ ][ ][ ]    [ ][ ][ ][ ][ ]

This form is designed to assess the potential participant's eligibility for and interest in participating in the study, and to document assent, consent and attendance at the initial instruction and training session.

- Answer all questions. DO NOT LEAVE BLANK SPACES
- Refer to the Manual of Procedures for complete instructions

Please give the participant an explanation about what the study involves, using the PIS provided.

Explain to the participant that there are certain criteria for taking part in the study, which you need to check.

### PART 1: Initial Assessment

#### 1. Participant Details

1.01	Screening date	Date DD/MM/20YY
1.02	DOB	Date DD/MM/20YY
1.03	Sex	Male/Female (circle one)
1.04	height (m)	__ . __ m
1.05	weight (kg)	__ . __ kg
1.06	BMI (=weight/height <sup>2</sup> ; kg/m <sup>2</sup> )	__ . __ kg/m <sup>2</sup>

#### 2. Inclusion Criteria

2.01	Aged between 18 and 65 years	Yes/No
2.02	Healthy without strict dietary restrictions	Yes/No
2.03	Able to give written informed consent/assent	Yes/No
2.04	Speaks and understands English	Yes/No

### 3. Exclusion Criteria

3.01	Have a medical condition which severely restricts the food they can eat	Yes/No
3.02	Have a medical condition that restricts their ability to freely complete usual activities of daily living	Yes/No
3.03	Have had an recent acute illness	Yes/No
3.04	Intend to travel during the testing period	Yes/No
3.05	Have had blood tests or intravenous fluids two weeks prior or scheduled during the testing period	Yes/No
3.06	Plan to have an increased physical activity level during the testing period	Yes/No

### 4. Assent and Consent

#### Participant consent

4.07	consent obtained	Yes/No
	If NO to Q 4.07, participant is not eligible.	
4.08	If YES to Q 4.07, date of consent	Date DD/MM/20YY

### 5. CRF sign off - Signature of Researcher (PI)

Form Submitted: Eligibility Checked and if OK Participant.

5.01	Signature	
	Printed Name	
	Date	Date DD/MM/20YY



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## **APPENDIX 16**

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### **Participant contact details form for PICTURE study**



**FORM Z: CONTACT DETAILS**

Participant Initials

Participants Date of Birth

Registration Number

|||

||-||-|19||

||-||

Please fill in your contact details, and preferred method of contact.

**1.0 Participant Contact Details**

1.01 Title   
 1.02 First Name  Middle Names   
 1.03 Surname

1.04 Home phone   
 1.05 Work phone   
 1.06 Mobile phone   
 1.07 Email

Postal Address  
 1.08 Flat number, street number and name   
 1.09 Suburb   
 1.10 City, district or town   
 1.11 Post Code

**2.0 Alternative Contact Details**

2.01 Title   
 2.02 First Name  Middle Names   
 2.03 Surname

2.04 Home phone   
 2.06 Mobile phone   
 2.07 Email

Postal Address  
 2.08 Flat number, street number and name   
 2.09 Suburb   
 2.10 City, district or town   
 2.11 Post Code

**3.0 Signature of Study Researcher**

3.01	<b>Name</b>	
3.02	<b>Signature</b>	
3.03	<b>Date</b>	

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## APPENDIX 17

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Participant characteristics form for PICTURE study

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**PICTuRE Study  
Anthropometric Data**

**Form P**

Participant Initials	
Date of birth (dd/mm/yyyy)	
Registration Number	

**Section 1  
Anthropometric data baseline**

1.01	Date of baseline assessment	dd/mm/yyyy
1.02	Height (cm)	-----
1.03	Weight (kg)	-----

**Section 2  
DLW dosing, resting metabolic rate**

2.01	<b>Baseline urine sample time</b>	hh:mm
2.10	<b>Impedance 1 (Z)</b>	-----
2.11	Phase 1 (P)	-----
2.12	Resistance 1 (R)	-----
2.02	Reactance 1 (Xc)	-----
2.02	<b>Impedance 2 (Z)</b>	-----
2.02	Phase 2 (P)	-----
2.02	Resistance 2 (R)	-----
2.02	Reactance 2 (Xc)	-----
2.02	If difference between resistance 1 and resistance 2 is >1 ohm, take a third measure:	
2.02	<b>Impedance 3 (Z)</b>	-----
2.02	Phase 3 (P)	-----
2.02	Resistance 3 (R)	-----
2.02	Reactance 3 (Xc)	-----
2.02	<b>% body fat (Using Excel Spreadsheet)</b>	-----
<b>TURN OVER FOR DLW DOSING</b>		

PICTuRE  
Form P  
Version 2.0 26/03/2013



DLW DOSING		
2.03	Fat mass (kg)	-----
2.04	Fat free mass (kg)	-----
2.05	Body water (kg) ( <b>Dosing calculator</b> )	-----
2.06	Dose calculated (g) ( <b>Dosing calculator</b> )	-----
2.07	Dose given (g)	-----
2.08	Time of dose	hh:mm
2.09	Any dose lost	Yes/No
	<b>MOXUS: VO2</b>	-----
	<b>MOXUS: VCO2</b>	-----
2.10	Resting metabolic rate	-----

**Section 3**  
**Anthropometric data 15 days**

4.01	Weight (kg)	-----
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## **APPENDIX 18**

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**Urine log form for PICTURE study**



Participant initials [ ] [ ] [ ] [ ]	Participant date of birth [ ] [ ] [ ] [ ]   1   9   [ ] [ ] [ ] <small>day month year</small>	Registration number [ ] [ ] - [ ] [ ]
---	---	--

We will be asking you to collect urine samples over the following days:

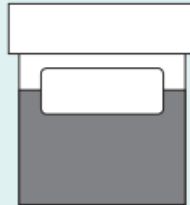
Sample	Date			Time	
	<i>day</i>	<i>month</i>	<i>year</i>	<i>HH</i>	<i>MM</i>
Baseline	[ ] [ ] [ ]	2   0	[ ] [ ]		
5 hours	[ ] [ ] [ ]	2   0		at	[ ] [ ] : [ ] [ ]
Day 3	[ ] [ ] [ ]	2   0	[ ] [ ]		
Day 9	[ ] [ ] [ ]	2   0	[ ] [ ]		
Day 15	[ ] [ ] [ ]	2   0	[ ] [ ]		

### Instructions

With this form, we will give you four labeled yellow jars for collecting urine.

The first time you empty your bladder in the morning (into the toilet) record the time and date. **Do not collect this sample.**

The next time you go to the toilet, collect your urine in the white container provided. Transfer your urine from the white container into the yellow jar (filling it to two thirds). Then pour the left over urine into the toilet and record the time and date. Place the lid on the jar firmly, place the jar in the plastic bag provided and refrigerate, or if possible freeze the urine. It is important that no water from the toilet is mixed with this urine sample.



Participant initials

Participant date of birth

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
		1	9				
day		month		year			

Registration number

 - 

### 1. Baseline Sample

1.01         Date  
day month year

**Instructions:** Please record the time you first passed urine in the morning. Please then record the time you took the urine sample.

1.02 Today, I first passed urine at:

:   AM  PM (Tick one only)  
HH MM

1.03 Today, I took my urine sample at:

:   AM  PM (Tick one only)  
HH MM

### 2. Five Hour Sample

2.01         Date  
day month year

**Instructions:** Please record the time you took the dose of doubly labeled water. Please then record the time you took the urine sample.

2.02 Today, I took the doubly labeled water at :

:   AM  PM (Tick one only)  
HH MM

2.03 Today, I took my urine sample at:

:   AM  PM (Tick one only)  
HH MM

### 3. Day 3 Sample

3.01         Date  
day month year

**Instructions:** Please record the time you first passed urine in the morning. Please then record the time you took the urine sample.

3.02 Today, I first passed urine at:

:   AM  PM (Tick one only)  
HH MM

3.03 Today, I took my urine sample at:

:   AM  PM (Tick one only)  
HH MM





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## APPENDIX 19

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24-hour dietary recall data sheet for PICTURE study

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**FORM C: 24h Recall Dietary Information**

**Passive Image Capture to Record Everyday Events (PICTuRE)**

Participant Initials: |\_|\_|\_|\_|  
DOB: |\_|-|-|-|-|-|-|-|-|-|  
Registration Number: |\_|-|-|-|-|-|-|-|-|-|

The purpose of this form is to collect all dietary intake data during the nutrition assessments. The 24h recall is collected once for the pilot and twice for the main study.

Nutrition Assessment No. 1 / 2/3      Time of Image Review: \_\_\_\_\_      DAY 15    Body Weight: \_\_\_\_\_

Day of week                      MON TUE WED THUR FRI SAT SUN

Give the participant a brief explanation of what the recall involves (quick list, detailed description and review):

“I will be asking you to tell me about all the food and drink that you had yesterday, from the time that you got up to the time that you went to bed. First I will ask you to try and remember all the food and drink that you had yesterday as a list. Once we have all of the foods recorded we will go through the list and discuss further details about the foods, such as what time you ate the foods, how much of the food you ate, how these foods were prepared, and the location of the meals. Then we will go through the list again to check we haven’t missed anything. After this assessment you will review the images that you have captured on the digital camera and remove any image you do not wish to disclose. Once this is complete we will view the images together that involve the consumption of food. I will ask you if there are any changes to the information you have already provided for each eating occasion”.

No Change = - or NC

Methods: MPR = 24h recall, RAD = Revue-assisted

Time of Meal = 24hr

Meal Code 1-6 (1 = breakfast, 2 = mid meal, 3 = Lunch, 4 = mid meal, 5 = dinner, 6 = Supper)

Food or dish = food or dish eaten

Brand= Brand or type of purchased food

Quantity = quantity of food prepared or purchased

% consumed = percentage of quantity consumed

Cooking method = method used to prepare food or dish

Portion Size Codes = X-X

Additions = Additional items added such as sugar or sauces

Method	Time of Meal	Location	Meal Code	Food or dish	Brand/Type	Quantity	Wastage?	Portion size code	Additions
MPR									
RAD									

Method	Time of Meal	Location	Meal Code	Food or dish	Brand/Type	Quantity	Wastage?	Portion size code	Additions
<b>MPR</b>									
<b>RAD</b>									

Method	Time of Meal	Location	Meal Code	Food or dish	Brand/Type	Quantity	Wastage?	Portion size code	Additions
MPR									
RAD									
CONTINUED.....									

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