An age- and sex-specific dietary guidelines index is a valid measure of diet quality in an Australian cohort during youth and adulthood.

Johanna E Wilson[a], Leigh Blizzard[a], Seana L Gall[a], Costan G Magnussen[a,b], Wendy H Oddy[a], Terence Dwyer[a,c], Alison J Venn[a], Kylie J Smith[a,*]

[a] Menzies Institute for Medical Research, University of Tasmania, Private Bag 23, Hobart, Tasmania, Australia, 7001

[b] Research Centre of Applied and Preventive Cardiovascular Medicine, University of Turku, Turku, Finland, FIN-20520

[c] The George Institute for Global Health, University of Oxford, Oxford, UK, OX1 3QX

*****Corresponding author: Dr Kylie J Smith, Menzies Institute for Medical Research University of Tasmania, Private Bag 23, Hobart. Tasmania, Australia, 7001. Email: k.j.smith@utas.edu.au, Phone: +61 3 6226 7780 , Fax: +61 3 6226 7704

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Abbreviations

ASHFS; Australian Schools Health and Fitness Survey

BMI; Body mass index

CDAH: Childhood Determinants of Adult Health

DGI; Dietary Guidelines Index

FFQ; Food frequency questionnaire

FHQ; Food habits questionnaire

HDL; High-density lipoprotein

HOMA-IR; Homeostatic Model Assessment of Insulin Resistance

kJ; Kilojoule

LDL; Low-density lipoprotein

MJ; Megajoule

NDSS; National Dietary Survey of Schoolchildren

PCA; Principal components analysis

SES; Socioeconomic status

Abstract

Measuring diet quality over time is important due to health impacts, but to our knowledge, a Dietary Guideline Index (DGI) with consistent scoring across childhood/adolescence (youth) and adulthood has not been validated. We hypothesized that a DGI that reflected age- and sex-specific guidelines would be a valid measure of diet quality in youth and adulthood. The DGI is based on the 2013 Australian Dietary Guidelines to reflect current understanding of diet quality, and comprises nine indicators, with a maximum score of 100 points. DGI scores were calculated for participants of the Australian Childhood Determinants of Adult Health study, which included a 24-hour food record during youth (1985, n=5043, age: 10-15 years), and a 127-item food frequency questionnaire during adulthood (2004-06, n=2689, age: 26-36 years). We evaluated construct validity (distribution of scores, principal components analysis, correlation with nutrient density of intakes) and criterion validity (linear regression with population characteristics). DGI scores were multidimensional in underlying structure and normally distributed. Among youth, a lower DGI was significantly associated ($p<0.05$) with smoking, and lower academic achievement and socioeconomic status. DGI scores were negatively correlated with energy, sugar and fat, and positively correlated with fiber, protein and micronutrients. Among adults, a lower DGI was associated with lower education and self-reported health, and higher waist circumference, insulin resistance, and total and LDL serum cholesterol. The DGI is an appropriate measure of diet quality in youth and adulthood as higher scores reflect nutrient-dense, rather than energy-dense intake, and discriminate between population characteristics consistent with the literature.

Keywords

Nutritional quality

Adolescent

Socioeconomic factors

Metabolic syndrome

Validity

Child

1. Introduction

Understanding diet quality over the life course is important due to associations between diet and highly prevalent health conditions including obesity related illness and mental disorders [1, 2]. Diet in observational studies is often assessed using a dietary index, which applies pre-conceived concepts of diet quality such as evidence-based dietary guidelines, to calculate an overall score from food and drink intake [3]. An advantage over methods such as dietary pattern analysis, is that an index is a standard measure that compares what participants are eating to what is recommended for good health, and allows comparison of diet quality over time and between populations [4].

Dietary guidelines differ between countries according to food cultures, but commonly aim to achieve adequate nutrition and reduce risk of diet related disease [5]. Similar to other western countries such as the US and UK, the Australian Dietary Guidelines are food-based guidelines encouraging intakes of core food groups ("eat more": vegetables, fruit, wholegrains, reduced fat dairy, and lean meat), while recommending limited intake of discretionary foods ("eat less": alcohol and foods high in saturated fat, added sugar or salt) [6]. The Australian "eat more" and "eat less" guidelines differ in the number of recommended servings by sex and age group but are otherwise consistent from the age of two years onwards. However, existing validated Australian dietary guideline indexes for children/adolescents (youth) and adults are not directly comparable due to their different composition [7-10]. Validation of a consistent index for application among both youth and adults is lacking in Australia and internationally [11, 12]. Furthermore, although analyses of data collected several years or even decades ago is common in epidemiology, there has been little focus on the challenges posed in applying dietary indexes retrospectively. Whereas other data types are objective (e.g. weight), dietary measures require interpretation if researchers wish to examine effects of overall diet quality rather than single food groups or nutrients.

The aim of this study was to revise a previously validated Australian dietary guidelines index and evaluate its appropriateness as a measure of diet quality in both youth and adulthood in an Australian cohort. Our index, hereafter referred to as the DGI, reflects the evidence-based 2013 Australian Dietary Guidelines to assess food intake against a current understanding of a healthy and nutritionally adequate diet. Appropriateness of the index was determined by evaluating measures of construct validity as to whether the DGI adequately reflects variation in diet quality according to measured intake, and is associated with dietary and population characteristics as would be predicted based on existing literature [13, 14]. We hypothesized that our Dietary Guidelines Index (DGI), which reflected age- and sex-specific guidelines, would be a valid measure of diet quality in both childhood/adolescence (youth) and adulthood. To test the hypothesis, we used several validation methods recognized within nutritional epidemiology [13]. Construct validity was evaluated by distribution of index scores, index dimensionality (whether variation in dietary intake among the sample is explained by more than one linear combination of components), and in youth, associations between DGI and nutritional quality of diet. A further type of construct validity, concurrent criterion validity, was evaluated by assessing discrimination between population characteristics including sociodemographic variables, and cardio-metabolic risk factors by DGI scores according to known differences, such as the social gradient of diet in which lower diet quality is often associated with lower socioeconomic status (SES) [13-15]. Internal consistency of the index was also examined.

2. Methods and materials

2.1 Study design and sample

In 1985, the Australian Department of Community Services and Health conducted the Australian Schools Health and Fitness Survey (ASHFS) of schoolchildren aged 7-15 years. A two-stage probability design was used to achieve a nationally representative sample across all Australian states and territories, with 109 schools participating (90.1% response rate) [16]. A sample size target of 500 students of each sex at each of the age levels 7 to 15 years was determined to be able to permit estimates from the questionnaire data that were within 10% of the population means. The overall student response rate from the 12578 students approached was 67.6% (N=8498) [16]. Students aged 10-15 years (N=5589) were invited to participate in the concurrent National Dietary Survey of Schoolchildren (NDSS).

During 2001-02, ASHFS participants were traced and invited to take part in the Childhood Determinants of Adult Health (CDAH) study, resulting in enrolment of 5170 (61.0%) participants [17]. During 2004-06, the first CDAH follow-up was conducted comprising questionnaires (n=3967) and study clinics for physical measurements (n=2410).

The State Directors General of Education approved the ASHFS, and signed parental consent was required. The CDAH study protocol was approved by the Southern Tasmanian Health and Medical Ethics Committee, operating in accordance with National Health and Medical

Research Council requirements, and all participants gave informed written consent. All protocols conformed to the ethical guidelines of the 1975 Declaration of Helsinki.

2.2 Measurements

2.2.1 Dietary measures in youth

In 1985, NDSS participants recorded the time and estimated amount of each food or drink item consumed during a 24-hour period. Trained data collectors showed students in groups of four or five how to measure and record their intake in the food record booklet with the aid of circles, rulers, and metric cups and spoons. The students did a practice exercise and the 24-hour recording period started immediately after the session. When the food records were collected, each student was interviewed to check and clarify the entries.

Survey design, collection and processing of NDSS data was coordinated by the Department of Community Services and Health with assistance from the Dieticians Association of Australia [18]. Energy, and macro and micronutrient compositions were determined in 1985 according to the edible weight of each item (e.g. peeled orange), from a specially compiled database based on the British *McCance and Widdowson's The composition of foods*, and adjusted for differences in Australian foods with *Metric tables of composition of Australian foods* [19-21].

To score the DGI, all items consumed were converted to a proportion of a standard serving as defined in the 2013 Australian Dietary Guidelines [6]. Servings were determined by grams for the core food groups (fruit, vegetables, grains, lean meats/fish or alternatives, and dairy or alternatives), with the exception of cooked grains which were calculated by kilojoules (450kJ) due to variations in weight [6]. For example, if a participant reported consuming 60g of toast at breakfast, this was equated to 1.5 standard 40g servings of bread. For mixed dishes (e.g. casserole, stir-fry) or discretionary items (high in saturated fat, or added sugars or salt, e.g. processed meats, cakes, potato chips, sugar-sweetened drinks), one serving was defined as a portion equivalent to 600kJ [6]. For example, a 1200kJ serving of hot potato chips equated to two servings of discretionary food.

Total daily energy density of food intake was calculated by a participant's total daily energy in kJ, divided by their total daily grams of food consumed. Energy adjusted daily macro and micronutrient density intakes for each participant were calculated as total daily nutrient values divided by total daily energy intake, reported as units per 1MJ (1000kJ).

2.2.2 Dietary measures in adulthood

Participants completed a 127-item food frequency questionnaire (FFQ), and a food habits questionnaire (FHQ) which were modified versions of those previously used in the 1995 National Nutrition Survey and based on validated FFQ and FHQ developed for Australian populations [22, 23]. The multiple choice FFQ asked for the average number of times each food or beverage was consumed daily, weekly, or monthly during the previous 12 months. Nine response options ranged from "Never or less than once a month" to "6+ times per day".

Daily equivalents were calculated for each FFQ item, assuming one standard serving was consumed at each eating occasion [7, 24]. For example, if a participant responded that they ate fresh fish “Once per week”, their daily serving of fresh fish was calculated as one seventh of a 100g standard serving of fish (28.3g). Average daily servings of fruit and vegetables were estimated from two multiple-choice questions in the FHQ that asked participants to report how many servings of fruit and vegetables they usually consumed each day and provided examples of serving sizes. The FHQ also asked about type of milk usually consumed (e.g. full fat, reduced fat), type of spread usually used, and how often fat was trimmed from meat. Energy intake was not calculated as the FFQ only collected data on the frequency of consumption, not the amount consumed.

2.2.3 DGI composition

The DGI comprises nine indicators reflecting the 2013 Australian Dietary Guidelines. Current guidelines were used for interpretability of results, as they reflect current understanding of food-based nutritional intakes required for good health. The indicators and scoring criteria are described in detail in **Table 1.** Seven indicators, worth 10 points each, related to recommended minimum intakes (dietary variety, vegetables, fruit, grains, lean meats and alternatives, low fat dairy and alternatives, water). Two indicators were for limiting intake of discretionary foods (worth 20 points) and replacing saturated fats with unsaturated fats (10 points). Previous versions of the adult DGI included separate indicators for alcohol, added sugar, and added salt [7, 10]. However, in our DGI, these were combined into the single discretionary foods indicator, consistent with the youth index, as processed foods may be high in combinations of these ingredients. The maximum possible DGI score was 100, with a higher score indicating higher diet quality. As outlined in **Table 1**, cut-offs for achieving maximum and minimum scores for each indicator were determined according to the age- and sex-specific serving recommendations, or the nutritional quality of the food (e.g. proportion of wholegrains to all grains) [6, 25, 26]. Proportionate scores were given for partially meeting recommendations, for example if a participant reported one daily serving of fruit rather than the recommended minimum of two serves, they received five of the potential 10 points.

2.2.4 Covariates in youth

The ASHFS questionnaire included questions on demographics, lifestyle, health attitudes, and sport and exercise history. Trained data collectors administered the questionnaires to small groups of four or five students and assisted with reading or explaining questions as needed. The following data were used in this analysis: age in years; ever smoked (never, less than 10 cigarettes, 10 or more cigarettes); breakfast eating (usually eat, don't usually eat), self-reported health status (very good, good, average, poor, very poor), and total hours of physical activity per week calculated from physical activity to, from, outside and during school over the previous week.

Socioeconomic status (SES) quarters (high, medium-high, medium-low, low) were determined by postal area code of place of residence according to the Australian Bureau of Statistics Socio-Economic Index for Areas and 1981 census data [27]. Scholastic level was reported by each student's school (excellent, above average, average, below average, poor).

Height and weight were measured with participants wearing light clothing and no shoes or socks. Height was measured to the nearest 0.1cm using KaWe height tape or rigid measuring tape. Weight was measured to the nearest 0.5 kg using beam or medical spring scales. BMI was calculated as weight (kg)/ (height (m))^2.

2.2.5 Covariates in adulthood

Participants were mailed questionnaires, which were returned at study clinics or by post. Collected data included age in years, marital status (married/living as married, single/separated/divorced), highest level of education (university, vocational, school), occupational status (professional, non-manual (e.g. office work), manual, not working), smoking status (never/ex, current smoker), and self-reported health status (very good, good, average, poor, very poor). Total hours of physical activity per week were measured using the validated International Physical Activity Questionnaire long form (IPAQ) [28].

Weight was measured to the nearest 0.1kg in light clothing using Heine portable digital scales, and height was measured to the nearest 0.1cm with a Leicester stadiometer. Waist circumference was measured to the nearest 0.1cm with non-stretch tape at the narrowest point between the lower costal border and iliac crest. BMI was calculated as above. For those who did not attend clinics, BMI was calculated from self-reported height and weight and a correction factor applied [29].

Systolic and diastolic blood pressure (mmHG) were measured from the right brachial artery using the Omron HEM907 digital automatic monitor (Omron Healthcare Co, Ltd, Kyoto, Japan), after the participant had been sitting quietly for five minutes. The mean of three readings was used. Insulin, glucose, total cholesterol, HDL cholesterol, and triglycerides were measured from blood samples collected after an overnight fast [30]. An Olympus AU5400 automated analyzer (Olympus Optical, Tokyo, Japan) was used to measure fasting insulin (mIU/l); glucose (mmol/l); total and HDL cholesterol (mmol/l) and triglycerides (mmol/l) [30]. LDL cholesterol was calculated using the Friedewald equation [31]. Insulin resistance was estimated using the homoeostatic model assessment (HOMA-IR) index [32]. In 2009, samples from female participants that had been stored at -70°C since 2004-06, were analyzed for serum folate using a chemiluminescent microparticle folate binding protein assay on an Abbott Architect Analyzer (Abbott, IL, USA) [33].

2.3 Statistical analyses

Analysis was stratified by sex. To assess construct validity and distribution of DGI scores, at each time point, means ± standard deviations (SD) and percentiles were calculated for the overall population and each sex. Also at each time point, principal components analysis (PCA) on the nine index indicators assessed underlying dimension that explain variation in DGI score [13, 14]. Orthogonal varimax rotation was applied for interpretability of uncorrelated components. The number of components were selected based on visual examination of the scree plot, and eigenvalues >1. Cronbach's coefficient α assessed internal consistency between index indicators, which were standardized due to the difference in scale for the discretionary foods indicator (20 points compared to 10 points for the other indicators) [34].

Linear regression was used to determine significance (*P*-value<0.05) of cross-sectional associations at each time-point between DGI and energy and nutrient density of intakes (construct validity) and cohort characteristics (criterion validity). Multiple imputation and inverse probability weighting were used to account for missingness of data at baseline and loss to follow-up [35]. Where necessary, transformations (e.g. logarithmic) of the response variable were used to remove skewness. Beta coefficients (β) and 95% confidence intervals (CI) are reported for associations between DGI and population characteristics, adjusted for all other characteristics relevant to each time-point to minimize potential confounding. Among youth, the covariates were age, SES quarter, scholastic level, breakfast eating, smoking, self-reported health, BMI, physical activity, and total energy intake. Among adults, the covariates were age, education level, occupational status, marital status, smoking, self-reported health, BMI and physical activity. Correlation coefficients (r) and level of significance are reported for the associations between DGI and nutrient density of intakes among youth, and cardio-metabolic risk factors among adults.

Analysis was performed with Stata Version 15.0 (StataCorp, College Station, Texas, 2017).

3. Results

3.1 Participants

Of the 5589 10-15 year-old ASHFS participants, N=5043 (90.2%) completed the NDSS 24-hour food record. Reasons for non-completion included refusal to participate, absence from school on the day of food record distribution or collection, or did not return the food record. No participants were excluded based on reported energy intake due to the variation that could occur during a single 24-hour period.

In adulthood 2868 participants returned the CDAH dietary questionnaires, however 82 females were excluded due to pregnancy and a further 97 participants were excluded due to missing >10% of FFQ item responses or key responses in the FHQ e.g. type of milk usually consumed. DGI was calculated for the remaining N=2689 participants. Of the adults with a DGI score, n=2135 attended CDAH clinics for physical and fasting blood measurements.

Participants missing covariate measures were excluded from the population characteristics linear regression analyses (youth: n=508; adulthood: n=275). Therefore, the samples used for the linear regression of DGI scores with population characteristics was n=4535 in youth, and n=2414 in adulthood.

3.2 Construct validity

The evaluation of associations with score distribution, nutrient densities (youth only), PCA and Cronbach’s coefficient analysis was performed on the full DGI sample (youth, n=5043; adulthood, n=2689).

DGI was normally distributed at both time points, although with a slight right skew, more apparent in youth (youth skewness: 0.43; adult skewness: 0.20). DGI means and percentiles are shown in **Table 2**. Among youth, the mean ± standard deviation (SD) DGI was 43.9 ± 11.9 for females and 45.3 ± 12.2 for males. Among adults, the mean ± SD DGI was 58.5 ± 11.3 for females and 51.3 ± 11.0 for males.

Regression correlation coefficients between youth DGI and nutrient density intakes are reported in **Table 3**. Total energy density (total kJ/total grams of food), sugar, total fat, saturated fat, monounsaturated fat and carbohydrate intake densities were negatively correlated with DGI, while protein, fiber, polyunsaturated fat and cholesterol were positively correlated. All measured micronutrients, except retinol among females, were positively correlated with DGI.

The PCA indicated there were four components underlying the youth DGI, cumulatively explaining 61.2% of the variation, while in adulthood there were three components cumulatively explaining 53.6% of the variation. The eigenvalues, variance explained, and factor loadings >|2| for these components are shown in **Table 4**. The Cronbach's coefficient α was 0.47 for youth and 0.68 for adults.

3.3 Concurrent criterion validity

Associations between DGI and sociodemographic, lifestyle, and weight status characteristics, adjusted for all other reported variables are shown for youth (1985) in **Table 5**. In the adjusted analyses, significant linear trends were observed between lower DGI and lower self-reported health among males, and lower SES, lower scholastic achievement and smoking status among both males and females. A lower DGI was also associated with being younger, lower self-reported health and not usually eating breakfast among males, and slightly fewer hours of weekly physical activity among females. There was no association between DGI and BMI or total energy intake.

Fully adjusted associations, adjusted for all other reported variables, between DGI and population characteristics are reported for adults (2004-06) in **Table 6**. Linear trends were observed between lower DGI and lower level of education and self-reported health. A lower DGI was associated with smoking among females but not males. There was no significant association between DGI and age group, marital status, or weekly physical activity for either sex. In the unadjusted analysis, a lower DGI was associated with lower occupational status (linear trend males: β=-1.43, 95% CI: -2.13, -0.72; females: β= -1.14, 95% CI: -1.71, -0.57). This association was attenuated in the adjusted analysis and the only significant difference remaining was a lower DGI score among males employed in manual work compared with those in professional roles (Table 6). A weak inverse association between DGI and BMI among women (β=-0.13, 95% CI: -0.25, -0.01) was also attenuated after adjustment.

Cross-sectional linear regression results between adult DGI and cardio-metabolic risk factors are reported for CDAH clinic participants in **Table 7**. For both sexes, DGI was negatively correlated with waist circumference and fasting total cholesterol, LDL cholesterol, insulin and HOMA-IR score. Among males, DGI was also negatively correlated with diastolic blood pressure, while among females DGI was negatively correlated with triglycerides, and positively correlated with HDL cholesterol and serum folate.

4. Discussion

This study demonstrates that retrospective application of the DGI is a valid measure of diet quality among youth and adults in this cohort. The correlations with nutrient density of intakes in youth and distribution of DGI scores affirms the hypothesis that our age- and sex-specific index reflects variation in dietary intake and importantly, reflects higher scores for nutrient dense, not energy dense dietary intake. The DGI also appropriately discriminates between groups based on sociodemographic and lifestyle characteristics in both youth and adulthood. For example, associations between DGI and SES, smoking, scholastic level in youth, and education in adulthood, reflect known differences based on existing empirical research, particularly the “social gradient” of diet where higher diet quality is associated with indicators of higher SES [13, 15, 36]. Among adults, higher diet quality was negatively correlated with several cardio-metabolic risk factors (total cholesterol, LDL cholesterol, insulin, waist circumference, triglycerides (women only), and diastolic blood pressure (men only)), reflecting health outcomes the dietary guidelines are designed to achieve [6].

Evidence of construct validity supports the use of the DGI as a diet quality measure. In both youth and adulthood, DGI was normally distributed and of a sufficient range to allow meaningful differences in scores. The PCA demonstrates that the index is multidimensional and variation in the data is explained by more than one linear combination of index indicators. Four components in youth, and three components in adulthood have eigenvalues greater than one, meaning they account for at least the same amount of variance as a single variable and therefore have structure. This suggests that variations in scores may arise from different combinations of DGI indicators. For example, among youth, one component had high loadings for the fruit, vegetables and lean meat/alternatives indicators, while another had high loadings for grains, discretionary foods, and dairy/alternatives. The Cronbach's coefficient α for internal consistency of scores was low for the youth DGI indicators, but approached the generally recognized level of adequacy (0.7) for the adult DGI indicators and was consistent with other dietary indices such as the Healthy Eating Index [13]. The multidimensional aspect of diet explored through the PCA could contribute to the low α, as a participant would not necessarily score at consistent levels across all indicators due to individual dietary preferences. The particularly low α in childhood may be due to the single 24-hour food record and high amount of variation between indicators at the individual level, as well as the food context of 1985 affecting scores in some indicators (e.g. use of reduced fat milk was less common).

Characterization of diet on nutritional quality was consistent with a previous cross-sectional study among children where a DGI based on the 2003 Australian dietary guidelines was positively associated with fiber and protein intake, and negatively associated with sugar and saturated fat intake [8]. The negative correlations between DGI and carbohydrates, sugars, total fat, saturated fat, and monounsaturated fat reflects the indicators for reduced fat dairy, lean meat, and limiting discretionary foods. The slight positive correlation of DGI with cholesterol may be due to points for overall servings of dairy, meat and eggs irrespective of fat composition. The strong positive correlation between DGI and fiber intakes reflects the emphasis on high-fiber foods in the fruit, vegetables and wholegrains indicators. The inverse correlation with energy density, and lack of association between DGI and overall energy intake, indicates that the index appropriately distinguishes between energy-dense and nutrient-dense intake [8].

Although nutrient and energy composition were not calculated in adulthood due to the non-quantitative aspects of the FFQ, serum folate in women was associated with higher DGI. Folate is found in whole foods such as legumes and dark leafy greens, which contribute positively to the DGI. High serum folate cannot be attributed to folic acid fortification of bread flour as this became mandatory in Australia in 2009 and was not in place at the time of the 2004-06 data collection.

Means of the DGI were low in both youth and adulthood. This is consistent with previous studies that have highlighted low intakes of fruit, vegetables, and water as areas of concern, particularly among children [8, 37-40]. Different food contexts in 1985 compared to 2013, may have contributed to low youth scores. However, this study evaluates quality of the reported diet as number of servings deemed appropriate for good health, not cognizant adherence to guidelines on the part of participants. Therefore, retrospective application is no more problematic than using a Mediterranean dietary index in non-Mediterranean populations. Temporal context would influence associations with population characteristics such as SES if concepts around healthy diets had changed considerably or if there was insufficient variation in diet (e.g. if processed and convenience foods were not in use at the time). However, the adequate intake of the core food groups and limiting saturated fat and added sugars were key components of the 1982 Dietary Guidelines for Australians [41]. We would therefore expect that groups previously demonstrated to exhibit healthier diets of wider variety and whole foods (e.g. higher SES, non-smokers, breakfast eaters), would have higher DGI, as we saw in our analysis.

Our observed associations with population characteristics showed good agreement with previous studies. In cross-sectional analyses among children, the 2003 DGI for Children and Adolescents was positively associated with markers of SES [8], while poorer overall diet quality has been associated with poorer academic achievement [42], and among adolescents, smoking has been cross-sectionally associated with unhealthy dietary habits [43, 44]. Among adults, higher index scores arising from the 2003 and 2013 versions of the DGI were associated with higher education and SES [45], higher health-related quality of life [46], not smoking, and lower obesity and cardio-metabolic risk [7, 10, 47, 48]. In our study, the social gradient of diet was reflected in the strong associations between DGI and education level, with adults who had school as their highest education level having a DGI score ~6 points lower than university educated adults. Correlations between higher DGI and lower waist circumference and lower diastolic blood pressure (males only), was consistent with prior applications of Australian DGIs [47, 48]. In adulthood, women had a significantly higher mean score than men, which accords with other Australian and international dietary guideline studies [7, 11, 13, 48, 49]. This could be influenced by gender differences in education, occupation, social factors and health consciousness. In this particular cohort, women have been shown to be more likely to meet healthy lifestyle guidelines than men [50].

Limitations of this study were as follows. Firstly, the methods of dietary measurement may have introduced bias. Dietary data from free-living individuals in the community is often biased, mainly towards under-reporting of intakes [51]. Also, the FFQ used in adulthood only collected data on the frequency of consumption, not serving sizes. The difference in mean scores by sex may reflect women having greater dietary variety or instances of eating partial servings of foods, as opposed to more standard servings. However, frequency alone has been shown to explain the major variance in food intake, and having participants estimate portion sizes can be problematic and introduce measurement error [52]. In youth, only a single 24-hour food record was taken, whereas repeat or multi-day food records are the preferred approach [53], as they may be more reflective of usual diet and strengthened discrimination between group characteristics. Instead, as with the premise of the original "snapshot" study, we have relied on the large sample size to represent average intakes in the population. For the purposes of assessing construct validity of the index using the nutritional composition of the food and beverage items actually consumed, the data is fit for purpose.

A second limitation was that although the sample was nationally representative of Australian schoolchildren at baseline, the large loss to follow-up may have had some effect on the associations with population characteristics among adults in the concurrent criterion validity analysis. However, despite the adult sample being of higher SES than the general population, our sample remained diverse with a range of characteristics. Bias was partially mitigated with inverse probability weighting. Furthermore, as those lost to follow-up are more likely to have lower SES [54], observed associations may be more conservative than if the full cohort was included.

A possible third limitation was the structure of the DGI and point allocation to each of the indicators. To an extent, this was an arbitrary process, with a maximum of 10 points allocated to each indicator apart from the discretionary foods indicators which had a maximum of 20 points. It may be that some food groups or dietary practices warrant higher weighting than others, but this would require further extensive empirical research and sensitivity analyses which is beyond the scope of this study.

Our study also had several strengths. Although the differing dietary measurement methods used in youth and adulthood may limit inferences of diet quality over time for this particular cohort, our results indicate that the DGI is adaptable to different dietary data and collection methods. Another strength is validation of a food-based index that captures important nutrient and non-nutrient qualities of diet, which may have synergistic health effects [5]. The study sample is quite large, and the unique dataset includes a range of sociodemographic, lifestyle, and objective physical measures, facilitating evaluation of the DGI in the same cohort of individuals in two distinct life phases. To our knowledge, this is the first study to assess the appropriateness of a uniformly structured diet quality index for use among children, adolescents and adults.

In conclusion, this study provides evidence that our DGI, aligned to age- and sex-specific dietary guidelines, is a nuanced and appropriate measure of diet quality in youth and adulthood as higher scores reflect nutrient-dense, rather than energy-dense intake, and discriminate between population characteristics consistent with the literature. Furthermore, our results indicate that retrospective application of the DGI to our data collected prior to the release of the current Australian Dietary Guidelines is appropriate, with the DGI reflecting variations in the cohort's diet according to current evidence-based understanding of diet quality. The DGI provides an interpretable measure of overall diet with which to assess associated factors over time. Further research using dietary indexes in cohorts from youth into adulthood is needed, particularly longitudinal studies using consistent and repeat dietary measurement methods at each follow-up. This would help determine associations between diet quality, sociodemographic factors, and health outcomes over the life course, and work to support and inform future dietary guidelines.

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Table 1. Age and sex specific Dietary Guidelines Index (DGI) scoring matrix, based on the 2013 Australian Dietary Guidelines

Dietary Guideline	Indicator and Description	Max score	Criteria for maximum score by sex and age in years: Boys 9-11	Boys 12-13	Boys 14-18	Girls 9-11	Girls 12-13	Girls 14-18	Men 19-50	Women 19-50	Criteria for minimum score
Adequate intake											
1. Variety of nutritious foods.	1. Intake of foods from each of the five core food groups.	10	Two points for a serving from each of the five core food groups. <1 serving receives appropriate proportion of the 2 points.								0 serves from any of the core food groups
2. Vegetables, including legumes/beans.	2. Servings of vegetables per day including legumes/beans.	10	≥5	≥5.5	≥5.5	≥5	≥5	≥5	≥6	≥5	0 servings
3. Fruit.	3. Servings of fruit per day (max 125ml 100% fruit juice, one serving of dried/sweetened fruit).	10	≥2	≥2	≥2	≥2	≥2	≥2	≥2	≥2	0 servings
4. Grains, mostly whole-grain and/or high fiber.	4a. Servings of breads and cereals per day.	5	≥5	≥6	≥7	≥4	≥5	≥7	≥6	≥6	0 servings
	4b. Wholegrains as a proportion of total grains.[a]	5	100%	100%	100%	100%	100%	100%	100%	100%	0%
5. Lean meat and poultry, fish, eggs, tofu, nuts/seeds, and legumes/beans.	5a. Servings of meats or alternatives per day (excluding processed meats).	5	≥2.5	≥2.5	≥2.5	≥2.5	≥2.5	≥2.5	≥3	≥2.5	0 servings
	5b. Lean meats/ alternatives to total meat/ alternatives.	5	100%	100%	100%	100%	100%	100%	100%	100%	0%
6. Dairy and/or alternatives, mostly reduced fat.	6a. Servings per day of total dairy or alternatives.	5	≥2.5	≥3.5	≥3.5	≥3	≥3.5	≥3.5	≥2.5	≥2.5	0 servings
	6b. Reduced fat dairy or alternatives to total dairy or alternatives.	5	100%	100%	100%	100%	100%	100%	Skim, low, or reduced fat milk or alternatives		0% Whole milk

7. Drink plenty of water[b]	7a. Servings per day of fluids, excluding alcohol.[c]		5	≥6	≥6	≥7	≥5	≥5	≥6	≥10	≥8	0 servings	
	7b. Proportion of water to total fluid intake per day, excluding alcohol.[c]		5	≥50%	≥50%	≥50%	≥50%	≥50%	≥50%	≥50%	≥50%	0%	
Limit intake													
8. Limit intake of saturated fat, alcohol and added salt and sugars.	8. Servings per day of foods high in saturated fat, added sugars or salt.[d] Alcohol was included for adults.		20	≤1.5	≤1.5	≤2.5	≤1.5	≤1.25	≤1.25	≤1.5	≤1.25	Males 9-13/19-50: >3, Males 14-18: >5, Females 9-11: >3, Females 12-50: >2.5	
9. Replace saturated fats with unsaturated fats.	Child: 9. kJ from healthy fats/oils as proportion of total fats/oils.	Adult: 9a. Trimming fat from meat.	5	80%[e]	80%	80%	80%	80%	80%	Usually		No un-saturated fats eaten	Never/ rarely
		9b. Type of spread usually used.	5							Spreads low in saturated fat			Spreads high in saturated fats
	Total:		**100**										

[a]Childhood: included bread and breakfast cereals. Adulthood: calculated for bread only. This was due to the different data available from the different measurement methods.
[b]The water intake cut-offs are based on Nutrient Reference Values for Australia and New Zealand and the proportion of water to total fluids was derived by McNaughton et al. from the US Beverage Guideline Panel recommendations [7,25,26].
[c]Childhood: tea and coffee excluded from overall fluid intake as not recommended for children.
[d]Additional servings of discretionary choices are only recommended for active, taller children or adults, or older children in the age range, and where possible extra foods should be eaten from the five core food groups [6]. Therefore, the number of servings for the maximum score for discretionary items is less than or equal to half the recommended servings for the age group and sex.
[e]80% is used as the maximum, in recognition that eggs and cheese which contain saturated fat are included in recommended food groups [6]. Nutrient Reference Values for Australia and New Zealand recommended that saturated and trans fat comprise no more than 10% of daily energy intake [26].

Table 2. DGI means and percentiles for the youth (1985) and adult (2004-06) populations

			Percentile								
DGI	N	Means ± SD	1st	5th	10th	25th	50th	75th	90th	95th	99th
Youth	5043	44.6 ± 12.0[a]	19.9[b]	26.2	30.2	36.3	43.6	51.6	61.0	66.9	75.9
Female	2507	43.9 ± 11.9	19.2	26.3	30.0	35.8	42.6	50.5	60.3	66.4	75.8
Male	2536	45.3 ± 12.2	20.9	26.1	30.9	36.9	44.3	52.9	61.7	67.3	76.7
Adulthood	2689	55.2 ± 11.7	29.7	36.5	40.3	47.0	54.8	62.8	69.9	75.6	85.7
Female	1462	58.5 ± 11.3	34.3	40.3	44.1	50.8	58.4	65.6	72.9	78.8	87.0
Male	1227	51.3 ± 11.0	27.4	34.4	37.7	43.7	50.8	58.0	65.7	70.0	78.7

[a]Means ± SD of Dietary Guidelines Index (DGI) score with possible range 0-100.
[b]Percentiles of the Dietary Guidelines Index (DGI) score with possible range 0-100.

Table 3. Correlations between DGI scores and daily nutrient density intakes among youth.

	Male (n=2536)	Female (n=2507)
	r^a	r^a
Total energy density (kJ/g)	–0.346***	–0.332***
Nutrient densities		
Carbohydrates (g/MJ)	–0.042*	–0.079***
Sugars (g/MJ)	–0.062**	–0.061**
Starch (g/MJ)	0.026	–0.014
Fiber (g/MJ)	0.417***	0.403***
Protein (g/MJ)	0.366***	0.404***
Total fats (g/MJ)	–0.150***	–0.142***
Saturated fat (g/MJ)	–0.260***	–0.241***
Monounsaturated fat (g/MJ)	–0.161***	–0.169***
Polyunsaturated fat (g/MJ)	0.140***	0.125***
Cholesterol (mg/MJ)	0.146***	0.124**
Vitamin C (mg/MJ)	0.171***	0.122***
Calcium (mg/MJ)	0.179***	0.229***
Iron (mg/MJ)	0.354***	0.355***
Zinc (mg/MJ)	0.320***	0.349***
Thiamin (mg/MJ)	0.188*	0.266***
Riboflavin (mg/MJ)	0.186***	0.241***
Niacin (mg/MJ)	0.237***	0.236***
Magnesium (mg/MJ)	0.421***	0.453***
Beta–carotene (µg/MJ)	0.252***	0.244***
Retinol (µg/MJ)	0.039*	0.064

*P-value<0.05 **P-value<0.01 ***P-value<0.001

[a]Correlation coefficient from univariate linear regression.

Table 4. Results of Principal Components Analysis on the Youth (1985) and Adult (2004-06) Dietary Guidelines Index (DGI) scores.

	Youth (n=5043) components				**Adult (n=2689) components**		
DGI indicator	**1**	**2**	**3**	**4**	**1**	**2**	**3**
Dietary variety	0.63[a]				0.53		–0.25
Vegetables	0.52		–0.26		0.38		0.26
Fruit	0.31			–0.51	0.43		
Grains and cereals			0.72		0.38		
Lean meats/alternatives	0.48				0.33	0.29	
Dairy/alternatives		–0.60	0.44			0.53	
Drink plenty of water				0.77	0.34	–0.21	0.24
Limit discretionary foods		0.34	0.37	-0.20			0.87
Limit saturated fat		0.69				0.76	
Eigenvalue[b]	2.02	1.35	1.09	1.05	2.69	1.12	1.01
Variance explained (%)[c]	21.0	14.7	13.5	12.0	27.8	13.9	12.0

[a]To highlight the strongest associations, only factor loadings >|0.2| are shown.
[b]Only components with eigenvalues >1 were extracted.
[c]Percentage of common variance explained by the corresponding component.

Table 5. Youth participant population characteristics (1985) and multivariate associations with Dietary Guidelines Index (DGI) scores.

	Male			Female		
Variable	**n**	**Means ± SD**	**β[a] (95% CI)**	**n**	**Means ± SD**	**β (95% CI)**
SES[b]						
High	519	46.4 ± 12.2[c]	Reference	569	45.1 ± 12.1	Reference
Medium high	640	44.4 ± 11.7	**-2.15 (-3.56, -0.75)**	713	43.0 ± 11.8	**-1.77 (-3.16, -0.38)**
Medium low	891	45.7 ± 12.2	-1.16 (-2.51, 0.19)	936	44.1 ± 11.5	-0.41 (-1.75, 0.92)
Low	214	41.7 ± 11.9	**-4.69 (-6.65, -2.74)**	198	41.5 ± 12.0	**-3.75 (-5.91, -1.58)**
Linear trend			***P*-value=0.001**			***P*-value=0.048**
Usually eat breakfast						
Yes	1973	45.4 ± 12.1	Reference	1855	44.2 ± 11.7	Reference
No	291	43.0 ± 11.6	**-2.30 (-3.76, -0.83)**	416	42.1 ± 12.4	-1.21 (-2.64, 0.21)
Scholastic level						
Excellent	153	48.3 ± 11.4	Reference	280	46.4 ± 11.6	Reference
Above average	556	46.9 ± 12.3	-1.19 (-3.25, 0.88)	730	44.7 ± 11.8	-1.26 (-2.97, 0.45)
Average	1015	44.5 ± 11.8	**-2.83 (-4.78, -0.89)**	874	43.3 ± 11.8	**-2.39 (-4.09, -0.69)**
Below average	416	43.2 ± 12.1	**-3.80 (-6.00, -1.59)**	306	42.0 ± 11.7	**-3.69 (-5.70, -1.68)**
Poor	124	44.5 ± 13.0	-2.94 (-5.90, 0.03)	81	40.5 ± 12.1	**-4.58 (-7.91, -1.24)**
Linear trend			***P*-value<0.001**			***P*-value<0.001**
Self-reported health						
Very good	791	46.5 ± 12.2	Reference	787	45.0 ± 11.7	Reference
Good	1023	44.9 ± 12.1	**-1.17 (-2.32, -0.01)**	974	43.5 ± 11.8	-0.95 (-2.13, 0.23)
Average	412	43.4 ± 11.7	**-2.11 (-3.58, -0.63)**	483	42.6 ± 12.0	-1.43 (-2.88, 0.01)
Poor	31	38.3 ± 9.4	**-5.13 (-9.60, -0.66)**	23	41.4 ± 11.0	-0.04 (-5.44, 5.36)
Very poor	7	44.2 ± 15.6	-2.54 (-11.26, 6.18)	4	46.7 ± 10.6	1.61 (-8.98, 12.21)
Linear trend			***P*-value=0.001**			*P*-value=0.070
Ever smoked						
Never	1110	45.8 ± 12.3	Reference	1228	44.7 ± 11.8	Reference
<10 cigarettes	793	44.6 ± 11.4	-1.11 (-2.22, 0.00)	706	43.1 ± 11.6	**-1.38 (-2.58, -0.19)**

≥10 cigarettes	361	44.0 ± 12.7	**-2.39 (-4.03, -0.75)**	337	42.2 ± 12.1	**-2.29 (-4.05, -0.53)**
Linear trend			***P*-value=0.003**			***P*-value=0.003**
Age (years)	2264	12.4 ± 1.7[d]	**0.39 (0.05, 0.74)**	2271	12.4 ± 1.7	-0.18 (-0.56, 0.21)
BMI (kg/m^2)	2264	18.9 ± 2.9	-0.08 (-0.27, 0.12)	2271	19.2 ± 2.9	0.08 (-0.13, 0.30)
Physical activity (hours/week)	2264	8.3 ± 7.4	-0.03 (-0.10, 0.03)	2271	7.0 ± 6.8	**0.08 (0.00, 0.17)**
Total energy (MJ)	2264	9.6 ± 3.6	0.10 (-0.06, 0.26)	2271	7.6 ± 2.4	0.07 (-0.16, 0.30)

[a]β is the difference in DGI calculated from linear regression of the DGI score as the outcome against the variable characteristic as the predictor, adjusted for all other variables in the table. Statistical significance of *P*<0.05 highlighted in bold.
[b]Area-level socioeconomic status.
[c] Means ± SD of Dietary Guidelines Index (DGI) score with possible range 0-100.
[d]Means ± SD of variable.

Table 6. Adult participant population characteristics (2004-06) and multivariate associations with Dietary Guidelines Index (DGI) scores.

	Male			Female		
Variable	**n**	**Means ± SD**	**β[a] (95% CI)**	**n**	**Means ± SD**	**β (95% CI)**
Highest education						
University	425	54.7 ± 10.9[b]	Reference	614	61.2 ± 10.2	Reference
Vocational	384	49.8 ± 10.2	**-4.33 (-6.12, -2.55)**	335	57.8 ± 11.4	**-3.03 (-4.66, -1.39)**
School	278	48.1 ± 10.6	**-6.13 (-8.02, -4.25)**	378	54.5 ± 11.3	**-6.08 (-7.76, -4.40)**
Linear trend			***P*-value<0.001**			***P*-value<0.001**
Occupation						
Professional	639	52.7 ± 10.9	Reference	654	60.1 ± 10.1	Reference
Non-manual	83	49.3 ± 9.8	-1.14 (-3.58, 1.30)	713	56.6 ± 11.7	0.41 (-1.33, 2.15)
Manual	323	48.7 ± 10.8	**-2.00 (-3.72, -0.29)**	936	55.9 ± 13.1	-0.21 (-3.70, 3.27)
Not in workforce	42	54.6 ± 10.1	3.30 (-0.09, 6.69)	198	57.3 ± 11.9	0.14 (-1.69, 1.98)
Linear trend			*P*-value=0.304			*P*-value=0.962
Marital status						
Living as single	348	51.9 ± 11.7	Reference	401	59.0 ± 11.4	Reference
Living as married	739	51.0 ± 10.6	-0.76 (-2.28, 0.76)	926	58.2 ± 11.1	-1.12 (-2.51, 0.27)
Self-reported health						
Very good	182	54.7 ± 10.7	Reference	213	63.1 ± 10.0	Reference
Good	436	51.7 ± 10.9	**-2.29 (-4.28, -0.31)**	576	59.1 ± 10.5	**-3.69 (-5.39, -1.98)**
Average	382	49.9 ± 10.6	**-3.58 (-5.69, -1.46)**	445	56.6 ± 11.6	**-5.58 (-7.47, -3.70)**
Poor	74	48.3 ± 10.5	**-5.50 (-8.71, -2.28)**	81	53.3 ± 11.6	**-7.80 (-11.09, -4.52)**
Very poor	13	48.7 ± 13.8	-5.12 (-10.9, 0.66)	12	49.0 ± 13.7	**-12.69 (-21.11, -4.26)**
Linear trend			***P*-value<0.001**			***P*-value<0.001**
Smoking status						
Never/Ex	826	51.9 ± 10.9	Reference	1038	59.7 ± 11.0	Reference
Current smoker	261	49.5 ± 10.7	-0.71 (-2.42, 1.00)	289	53.9 ± 10.7	**-3.37 (-4.91, -1.84)**
Age (years)	1087	31.7 ± 2.6[c]	0.09 (-0.17, 0.34)	1327	31.5 ± 2.6	0.20 (-0.04, 0.44)

BMI (kg/m^2)	1087	26.4 ± 4.3	0.01 (-0.15, 0.17)	1327	25.0 ± 5.3	0.06 (-0.06, 0.17)
Physical activity (hours/week)	1087	13.2 ± 9.0	0.04 (-0.04, 0.12)	1327	12.5 ± 8.1	0.01 (-0.06, 0.09)

[a] β is the difference in DGI calculated from linear regression of the DGI score as the outcome against the variable characteristic as the predictor, adjusted for all other variables in the table. Statistical significance of *P*<0.05 highlighted in bold.
[b]Means ± SD of Dietary Guidelines Index (DGI) score with possible range 0-100.
[c]Means ± SD of variable.

Table 7. Correlations between DGI score and cardio-metabolic risk factors among adult participants 26-36 years old.

	Male		Female	
Variable	**n**	**r[a]**	**n**	**r[a]**
Waist circumference (cm)[b]	1023	–0.080*	1100	–0.079*
Blood pressure (mmHG)[b]				
Systolic	1025	–0.010	1099	–0.046
Diastolic	1025	–0.087*	1099	0.040
Fasting blood				
Triglycerides (mmol/L)	1029	–0.033	1106	–0.075*
Total cholesterol (mmol/L)	1029	–0.147***	1106	–0.097**
HDL-C[c] (mmol/L)	1029	0.046	1106	0.067*
LDL-C[d] (mmol/L)[b]	1016	–0.166***	1102	–0.118***
Insulin (mIU/L)[b]	1025	–0.095**	1096	–0.145***
Glucose (mmol/L)[b]	1027	–0.010	1105	–0.036
HOMA-IR[b,e]	1024	–0.093**	1095	–0.141***
Folate (nmol/L)[b,f]	–	–	904	0.258***

**P*-value<0.05 ***P*-value<0.01 ****P*-value<0.001

[a]Correlation coefficient from univariate linear regression.

[b]Some participants were missing data for these measures, therefore the total is not 1029 for males and 1106 for females.

[c]High-Density Lipoprotein cholesterol.

[d]Low-Density Lipoprotein cholesterol.

[e]Homeostatic Model Assessment of Insulin Resistance index: (fasting glucose x fasting insulin)/22.5.

[f]Serum folate was only measured among females.