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Original article

The comparative validity of a brief diet screening tool for adults: The Fruit And Vegetable VAriety index (FAVVA)

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Background & aims: A brief assessment tool on frequency and variety of fruit and vegetable intake could provide a cost-effective and sustainable approach to improving diet. The primary aim was to evaluate the comparative validity of a brief index of Fruit And Vegetable VAriety (FAVVA) relative to food and nutrient intakes derived from a comprehensive food frequency questionnaire (FFQ). The secondary aim was to evaluate the FAVVA index in relation to fasting plasma carotenoid concentrations.
Methods: Dietary intakes and fasting plasma carotenoid concentrations of 99 overweight and obese adults (49.5% female; 44.6 ± 9.9 years) were assessed at baseline and 3-months. Food and nutrient intakes were assessed using the Australian Eating Survey (AES) FFQ. The FAVVA index was derived from a sub-set of 35 AES questions related to fruit and vegetable intake frequency and variety. Associations were assessed using Spearman's correlation coefficients and linear regression analysis, and agreement using weighted kappa (K_w).
Results: Total FAVVA score demonstrated moderate to strong, significant (all $p < 0.01$) correlations with total daily intakes of vegetables ($r = 0.75$), vitamin C ($r = 0.71$), fruit ($r = 0.66$), vitamin A ($r = 0.49$), fibre ($r = 0.49$), potassium ($r = 0.46$), magnesium ($r = 0.39$), iron ($r = 0.26$), riboflavin ($r = 0.24$), calcium ($r = 0.23$), zinc ($r = 0.20$) and niacin equivalent ($r = 0.20$). These associations remained significant in the adjusted regression analyses and agreement testing. Total FAVVA was significantly correlated with plasma carotenoid concentrations (μg/dL) of α−carotene ($r = 0.22$, $p < 0.01$), β−carotene ($r = 0.26$, $p < 0.001$), β−cryptoxanthin ($r = 0.22$, $p < 0.01$) and total carotenoids ($r = 0.18$, $p < 0.05$). The associations with α−carotene ($\beta = 0.09$, $p < 0.001$), β−carotene ($\beta = 0.42$, $p < 0.05$) and total plasma carotenoids ($\beta = 0.85$, $p < 0.05$) remained significant in the adjusted regression analyses and for agreement testing.
Conclusions: FAVVA is suitable as a brief tool to rank frequency and variety of fruit and vegetable intake.
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1. Introduction

Regular consumption of a wide variety of fruit and vegetables (F&V) is a key component of a healthy diet [1]. However, a large proportion of people internationally do not consume sufficient quantities of total F&V [2,3]. For instance, 77.6% of men and 78.4% of women across 52 countries consumed less than the minimum US-recommended five daily servings of fruits and vegetables [2], while

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overall combined mean fruit, vegetable and legume intake was 3.91 (SD 2.77) servings per day [3]. Additionally, in a nationally representative sample of US adults it was found that low energy density diets, which are comprised of foods high in water content such as F&V are much lower in adults that are obese compared to those that are lean [4]. Low F&V intake is among the top 10 global risk factors for mortality, contributing to around 1.7 million deaths worldwide [5]. Insufficient intakes are estimated to cause around 14% of gastrointestinal cancer deaths, 11% of ischaemic heart disease deaths and around 9% of stroke deaths [5].

The two leading causes of death worldwide include cardiovascular disease (CVD) and cancer [6]. Systematic reviews highlight that adequate consumption of F&V can reduce risk of these diseases [7,8]. A meta-analysis of 95 prospective studies observed that every 200 g/day increment in intake of fruits or vegetables or F&V combined was associated with an 8–13% risk reduction in CVD, 13–18% risk reduction in stroke, 3–4% risk reduction of total cancer and 10–15% reduced risk of all-cause mortality [8]. Results from the meta-analysis also found that specific F&V intakes were more strongly inversely associated with disease risk. For example, apples/pears, citrus fruits, cruciferous vegetables, green leafy vegetables, tomatoes and beta-carotene-rich and vitamin C-rich F&V were individually associated with reduced risk of CVD (RR ranged from 0.76 to 0.96), while cruciferous vegetables (RR 0.84 95%CI 0.72–0.97) and green-yellow vegetables (RR 0.88 95%CI 0.77–1.00) were associated with reduced risk for total cancer [8]. While the benefits of frequency of F&V intake have been widely established, these results also highlight the importance of variety within F&V intake on health. The focus on F&V variety is reinforced with the World Cancer Research Fund [9] and dietary guidelines in the US, Australia and the UK [1,10,11] all advocating for greater variety. F&V contain numerous nutrients and phytochemicals, including fibre, antioxidants and carotenoids which act synergistically through several biological mechanisms to reduce risk of chronic diseases and premature mortality [12]. In addition to absolute intakes of F&V, greater F&V variety might allow exposure to a more diverse range of antioxidants and carotenoids with potential protective effects. In the few cross-sectional studies, higher F&V variety was associated with lower odds of metabolic syndrome, obesity, hypercholesterolemia, and hypertension [13,14].

Although there is limited research exploring the combined effects of greater frequency of F&V intake and a greater variety of F&V intake on disease risk, a large cohort study in almost 4000 adults revealed that frequency (at least 3.5 portions of F&V per day) and variety (at least 12 different F&V items per week) in F&V intake were inversely associated with type two diabetes [15]. These findings support current public health recommendations encouraging both greater frequency and variety of F&V intakes.

A systematic review of interventions designed to increase adult F&V intakes concluded that future research needs to develop and test cost-effective and efficient ways of increasing population F&V intake [16]. This highlights the need for a brief F&V assessment tool that is publically available and provides immediate feedback on both frequency and variety of F&V intake. This could potentially provide a more cost-effective, sustainable and efficient approach compared to current generic dietary advice and in person counselling [17,18]. Therefore, the primary aim of this study was to carry out a secondary analyses on a 12-week weight management randomized controlled trial [19,20] and evaluate the comparative validity of a brief index of Fruit And Vegetable VAriety (FAVVA) relative to food and nutrient intakes derived from a comprehensive food frequency questionnaire. The secondary aim was to evaluate the FAVVA index in relation to fasting plasma carotenoid concentrations.

2. Methods

2.1. Study design and participants

This is a secondary data analysis of a subset of overweight and obese adults (n = 99) from a 12-week, weight management randomized controlled trial (Clinical Trials Registry – ANZCTR, number: ACTRN12610000197033), conducted in the Hunter Region of New South Wales, Australia [19]. Participants were part of the intervention arms which included; 1) a basic, or 2) an enhanced web-based weight loss intervention. Both groups of intervention participants were advised to consume more F&V [19] and there were no significant differences between intervention groups from baseline to 3-months in either fruit or vegetable intake [20]. Those eligible for inclusion in the current analysis were adults aged 18–60 years, had completed the Australian Eating Survey Food Frequency Questionnaire (AES FFQ) and provided a blood sample for assessment of plasma carotenoid concentrations at both baseline and after three months follow-up. To ensure the data included individuals across the range of low to high intakes of F&V, a subset of participants were selected from within each quartile of baseline total F&V intakes. This study was conducted according to the guidelines laid down in the Declaration of Helsinki. Procedures involving participants were approved by the University of Newcastle, Human Research Ethics Committee (Approval No. H-2010-1170), with written informed consent obtained from all participants.

2.2. Australian Eating Survey Food Frequency Questionnaire (AES FFQ)

The AES FFQ is a self-administered 120 item semi-quantitative FFQ which assesses usual dietary intake over the past 6 months [21]. Previously this FFQ demonstrated suitable reproducibility and/or comparative validity at ≤3 months and at 6 months in assessing usual dietary intake in adults compared to weighed food records [21] and biomarkers [22,23]. The AES contains 25 questions on vegetables, including an additional question on frequency of vegetables served with evening meals at night. This additional question was chosen because in Australia the evening meal is when most vegetables are consumed [24]. Twelve questions relate to fruit, including an additional question for number of pieces of fruit per week. Response options to each question vary depending on the item; in general, fruit and vegetable questions had a frequency ranging from *"never"* to *"5 or more per week"*, however frequently consumed fruit (apples, bananas and oranges) and vegetables (peas, broccoli, carrots and lettuce) had more expansive response options ranging from *"never"* to *"2 or more times per day"*. Five of the 12 fruit questions were focused on seasonal fruit. The frequency categories were listed as for other food items, with the question, *"when the following fruit is in season, how often do you usually eat it?"* to capture the usual consumption of the fruit when it is in season. Seasonal availability was determined by contacting the food markets, Sydney, NSW and obtaining information about the wider availability in other markets and supermarkets during the year, in addition to referring to supermarket literature that indicated the months of the year different seasonal fruit was available. In addition to questions on fruit and vegetables, the AES FFQ also assesses breads/cereals, dairy foods, lunch/main meal food items, beverages, snack foods/dessert and sandwich spreads/dressings and sauces. The response for each nutrient intake question from the FFQ was computed from the AusNut 1999 database (All Foods) Revision 17 and AusFoods (Brands) Revision 5 (FoodWorks version 3.02.581, Xyris Software, Brisbane, Queensland, Australia) by summing overall food items, the portion size in grams and the amount of the nutrient in a gram of that food. Total grams of F&V and key nutrients (including protein, saturated fat, cholesterol, sugars, fibre, vitamin A, retinol, riboflavin, niacin, folate, Vitamin C, calcium, iron, magnesium, potassium, sodium, zinc) were extracted for comparison with FAVVA. Serves of fruit and vegetables were based on the National standard serve sizes in the Australian Healthy Eating Guidelines [25] where a serve of vegetable is defined as 75 g/day, a serve of fresh fruit defined as 150 g/day, and a serve of dried fruit defined as 30 g/day.

2.3. Fruit And Vegetable VAriety index (FAVVA)

The FAVVA index is derived from the AES FFQ [21], using a subset of 35 questions related to F&V intake frequency and variety, and covers a comprehensive range of those F&V consumed by the general Australian population. The FAVVA index was developed and modelled based on a previous fruit and vegetable index [26], with the key difference between the two measures being the different FFQ's used to generate the score. FAVVA used the AES [21] and the previous fruit and vegetable index used the Dietary Questionnaire for Epidemiological Studies Version 2 [27], which has a list of 37 food items related to F&V frequency and variety and as such the different response options and F&V items reflected the difference in scoring. Importantly, the study population in the current analysis includes both men and women, whereas the previous study included only adult women and did not have biomarker data available.

FAVVA uses all the F&V questions from the AES FFQ except for the two vegetable questions relating to 'hot chips/fries', and is calculated by summing the points from the fruit and vegetable sub-scales. The total score ranges from 0 to a maximum of 190 points (maximum score is 68 for the fruit sub-scale and 122 for the vegetable sub-scale), with a higher score awarded for those with greater frequencies and wider variety of F&V. Supplementary Table 1 details the scoring method for items in the FAVVA. Briefly, for most foods no points were awarded for those reporting *'Never'* and then incremental points were awarded for more frequent intake, with 1 point for '*< once per week'* 2 points for *'1–3 times per month'*, 3 points for '*once per week*', 4 points for '*2–4 times per week*' and 5 points for those reporting '*≥ 5 times per week*'. Frequently consumed F&V with additional response options had 6 points awarded for *'once per day'* and 7 points for '*2 or more times per day*'. Additional points were awarded for more frequent consumption of vegetables with evening meals at night and for higher daily total consumption of fruit (Supplementary Table 1).

2.4. Plasma carotenoids

F&V's are considered the primary source of dietary carotenoids, and carotenoids cannot be synthesised by humans [28]. Hence, plasma carotenoids are considered to be the best candidate biomarkers of F&V intake and can be used to establish comparative validity, as an objective marker of F&V intake. Participant blood samples were drawn after an overnight fast by phlebotomists and collected in EDTA-coated tubes. The samples were processed and plasma stored at −80 °C until thawed for analysis. To isolate the carotenoids from the plasma, ethanol was added to allow deproteination followed by ethyl acetate containing internal standards (canthaxanthin), then vortexed and centrifuged (3000 r.p.m. for 5 min at 4 °C). The supernatant was collected in separate tubes and stored on ice. This process was repeated three times, adding ethyl acetate twice, then hexane to the pellet. Milli-Q (Milli-Q Advantage A10, Merck Millipore, Melbourne, VIC, Australia) water was then added to the pooled supernatant and the mixture vortexed and centrifuged. The supernatant was decanted and placed on a nitrogen evaporator until completely evaporated. The dried extract was reconstituted in dichloromethane:methanol (1:2 vol/vol). Plasma carotenoid concentrations of α-carotene, β-carotene, lycopene, β-cryptoxanthin, and lutein/zeaxanthin were analysed using high-performance liquid chromatography. Chromatography was performed on Agilent 1200 series gas chromatograph (Agilent Technologies, Santa Clara, CA, USA, Part No. G1311-90011) including Chemstation (Chemstation OpenLab CDS software, Agilent Technologies, Melbourne, VIC, Australia) data analysis software at a flow rate of 0.3 ml/min. Carotenoids were analyzed using a mobihave a le phase of acetonitrile:dichloromethane:methanol 0.05% ammonium acetate (85:10:5), and integrated and analysed at a wavelength of 450 nm. Plasma total carotenoid concentrations were calculated by summing β-carotene, lycopene, α-carotene, β-cryptoxanthin and lutein/zeaxanthin concentrations. Plasma carotenoids have a short half-life (26–76 days) so the reference period needs to be short [29], hence the data was obtained from a 12-week trial.

2.5. Statistical methods

Data were analysed using Stata Version 12 (StataCorp. 2011. Stata Statistical Software: College Station, TX: StataCorp LP) using an alpha level of 0.05. Data from each participant at baseline and 3-months were treated as independent variables and clustered for regression analysis to account for interpersonal variation. The strength of association between FAVVA and i) food and nutrient intake from the AES FFQ, and ii) plasma carotenoids were assessed in a number of ways: Firstly, Spearman's correlations coefficients were used due to non-normal distribution of plasma carotenoid concentrations. Correlation strength was described as poor <0.20, moderate 0.2–0.6 or strong >0.6, as these levels have been used previously in nutrition validation studies [23,30]. Secondly, linear regression models were used, with standard errors clustered on unique participant identifiers and 95% confidence intervals, to examine associations while adjusting for known influential factors including baseline values for total energy intake, age and sex. R^2 values and coefficients (95% CI) are also reported. Finally, the precision of the agreement between categorical assessments of FAVVA and i) foods and nutrients from the AES FFQ, and ii) plasma carotenoid values was tested using weighted Kappa (K_w) statistics to assess whether the FAVVA score classified participants into the correct tertiles of intake. Strength of agreement for Kappa was described as ≤0 = poor, 0.01–0.20 = slight, 0.21–0.40 = fair, 0.41–0.60 = moderate, 0.61–0.80 = strong, and 0.81–1 = almost perfect [31].

3. Results

In total, 99 overweight and obese adults (49.5% female) aged 44.6 ± 9.9 years and BMI 31.8 ± 3.8 kg/m^2 completed the AES FFQ and provided blood samples for plasma carotenoid analysis at both baseline and three months. Most were non-smokers (94.9%), with a mean total FAVVA score of 88 ± 20 points from a maximum of 190 (range 41–131). Table 1 summarises participant baseline characteristics and nutrient intake profiles. Baseline mean daily intakes of fruit (mean 268 ± 212 g, range 22–1210 g) and vegetables (mean 353 ± 143 g, range 63–672 g) were higher in comparison to nationally representative samples of Australian adults, with the most recent National Nutrition Survey showing mean fruit intakes to be 142 g and mean vegetable intake as 172 g [32]. This may explain the higher mean intakes of vitamins A and C and the minerals: potassium and iron compared to the averages for Australian adults [33]. Plasma carotenoid concentrations were comparable to weighted mean plasma carotenoid concentrations from a meta-analysis of 142 predominantly cross-sectional studies [34] (156 vs 169 μg/dL). The highest concentrations were for lutein/zeaxanthin (60 ± 54 μg/dL) and lycopene (44 ± 31 μg/dL). Although mean intakes were higher when compared to Australian adults there was still a broad range of intake of F&V between self-reported intake and plasma

Table 1
Baseline characteristics of participants and nutrient profiles (n = 99).

Characteristic	Mean ± SD (RDI/AI/UL[a]) or n (%)
Age (years)	44.6 ± 9.9
Female	49 (49.5%)
Anthropometric	
Weight (kg)	93.2 ± 14.5
Height (cm)	171.0 ± 8.7
BMI (kg/m^2)	31.8 ± 3.8
Overweight[b]	39 (39.4%)
Obese I[b]	40 (40.4%)
Obese II[b]	18 (18.2%)
Obese III[b]	2 (2.0%)
Smoking status	
Non-smoker	94 (94.9%)
AES FFQ	
Energy intake (kJ/day)	10550 ± 3581
Protein (g/day)	109 ± 33 (RDI: 64)
Saturated fat (g/day)	37 ± 18[c]
Cholesterol (mg/day)	349 ± 148[c]
Carbohydrate (g/day)	282 ± 112[c]
Sugars (g/day)[d]	145 ± 68[c]
Fibre (g/day)	28 ± 9 (AI: 30)
Vitamin A (μg/day)	1336 ± 988 (RDI: 900)
Retinol (μg/day)	529 ± 835 (UL: 3000)
Riboflavin (mg/day)	2.59 ± 1.0 (RDI: 1.3)
Niacin equiv (mg/day)	49 ± 14 (RDI: 16)
Folate (μg/day)	362 ± 109 (RDI:420)
Vitamin C (mg/day)	176 ± 70 (RDI: 45)
Calcium (mg/day)	1169 ± 476 (RDI: 1000)
Iron (mg/day)	15 ± 5 (RDI: 8)
Magnesium (mg/day)	426 ± 114 (RDI: 420)
Potassium (μg/day)	3962 ± 1108 (AI: 3800)
Sodium (mg/day)	2615 ± 934 (UL 920)
Zinc (mg/day)	15 ± 4 (RDI: 14)
Fruit (g/day)	268 ± 212
Vegetables (g/day)	353 ± 143
Fruit (serves/day)	1.9 ± 1.2
Vegetable (serves/day)	4.6 ± 2.0
FAVVA (total possible score)	
Total Score (190)	88 ± 20
Vegetables (122)	60 ± 13
Fruit (68)	28 ± 10
Plasma Carotenoid concentrations (μg/dL)	
α -Carotene	7.4 ± 6.1
β -Carotene	29.7 ± 22.7
Lycopene	44.0 ± 31.2
Lutein/zeaxanthin	59.6 ± 53.7
β-Cryptoxanthin	10.5 ± 7.6
Total carotenoids	156.0 ± 82.4

[a] Australian Recommended Dietary Intakes (RDI), Adequate Intake (AI), Upper Limit (UL) [35].
[b] Defined using World Health Organization cut offs [36]: Overweight: 25.0–29.99 kg/m2, Obese I: 30.0–34.99 kg/m2, Obese II: 35.0–39.99 kg/m2, Obese III: 40.0 kg/m2.
[c] There are no RDI or AI in grams/day for these nutrients. However, the Acceptable Macronutrient Distribution Range (AMDR) for carbohydrates is 45–65% and it is suggested to have <10% for saturated fat [35].
[d] Defined as a free sugars (includes added sugars and the sugar component so honey, fruit juice and fruit juice concentrates) and intrinsic and milk sugars (includes natural sugars from fruits, vegetables and milk) [37].

carotenoid concentrations, allowing for an evaluation of the relationship across the spectrum.

Table 2 summarises crude Spearman's correlations between FAVVA scores and (i) mean nutrient intakes from the AES FFQ and ii) plasma carotenoid concentrations. There were statistically significant strong positive correlations between total FAVVA score and mean daily intake of fruit (g) (r = 0.66), vegetables (g) (r = 0.75), and vitamin C (mg) (r = 0.71), and statistically significant moderate correlations (r = 0.2–0.6) between FAVVA score and total mean intake of dietary fibre, vitamin A, riboflavin, niacin equivalent, folate, calcium, iron, magnesium, potassium, zinc, and plasma carotenoid concentrations of α –carotene, β-carotene, and β-cryptoxanthin. There were other statistically significant correlations found between total FAVVA score and protein and plasma total carotenoids, however these were classified as poor (r < 0.20). Similar findings were evident with FAVVA sub-scales for fruit and vegetables, but a notable difference was that the FAVVA fruit sub-scale had a significant moderate correlation with carbohydrates (r = 0.21, p < 0.001). and total sugars (r = 0.26, p < 0.001).

Table 2
Spearman rank correlations between FAVVA scores and (i) mean food and nutrient intakes from the AES FFQ and ii) plasma carotenoid concentrations (n = 198).

	Total FAVVA	FAVVA Fruit	FAVVA Veg
AES FFQ			
Protein (g/day)	0.18*	0.18*	0.15*
Saturated fat (g/day)	−0.10	−0.02	−0.10
Cholesterol (mg/day)	0.10	0.06	0.14
Carbohydrate (g/day)	0.05	0.21**	−0.05
Sugars (g/day)	0.10	0.26***	−0.02
Fibre (g/day)	0.49***	0.36***	0.49***
Fruits (g/day)	0.66***	0.90***	0.34***
Vegetables (g/day)	0.75***	0.41***	0.82***
Fruits and vegetables (g/day)	0.80***	0.77***	0.63***
Vitamin A (μg/day)	0.49***	0.30***	0.55***
Retinol (μg/day)	0.02	0.01	0.07
Riboflavin (mg/day)	0.24***	0.24***	0.19**
Niacin equiv (mg/day)	0.20**	0.20**	0.17*
Folate (μg/day)	0.46***	0.40***	0.41***
Vitamin C (mg/day)	0.71***	0.62***	0.62***
Calcium (mg/day)	0.23***	0.21**	0.19**
Iron (mg/day)	0.26***	0.31***	0.19**
Magnesium (mg/day)	0.39***	0.39***	0.33***
Potassium (μg)	0.46***	0.44***	0.37***
Sodium (mg/day)	−0.04	0.04	−0.07
Zinc (mg/day)	0.20**	0.20**	0.18*
Plasma carotenoids (ug/dl)			
α -Carotene	0.22**	0.25***	0.14*
β -Carotene	0.26***	0.25***	0.21**
Lycopene	−0.07	0.04	−0.11
Lutein/Zeaxanthin	0.05	0.05	0.04
β-cryptoxanthin	0.22**	0.25***	0.16*
Total carotenoids	0.18*	0.21**	0.12

*p-value <0.05; **p-value <0.01; ***p-value <0.001.

Table 3 summarises the adjusted linear regression analyses between FAVVA scores and nutrients and plasma carotenoid concentrations. After adjustment for age sex, and total energy intakes, the total FAVVA score significantly explained the variation in mean daily protein (β = 0.30, p < 0.001), fibre (β = 0.25, p < 0.001), total grams of fruit (β = 5.98, p < 0.001), total grams of vegetables (β = 5.49, p < 0.001), F&V grams combined (β = 11.47, p < 0.001), vitamin A (β = 12.74, p < 0.001), riboflavin (β = 0.01, p < 0.05), niacin equivalent (β = 0.15, p < 0.001), folate (β = 2.56, p < 0.001), vitamin C (β = 2.51, p < 0.001), iron (β = 0.06, p < 0.001), magnesium (β = 2.17, p < 0.001), potassium (β = 24.06, p < 0.001) zinc (β = 0.04, p < 0.001) and plasma carotenoids concentrations for α –carotene (β = 0.09, p < 0.001), β –carotene (β = 0.42, p < 0.05) and total carotenoids (β = 0.85, p < 0.05). These relationships accounted for between 3% and 71% of the variation (R^2 = 0.03–0.71) in FAVVA score. Similar findings were evident with FAVVA sub-scales for fruit and vegetables (see Table 3).

Table 4 summarises the analyses examining the extent of agreement between tertiles of FAVVA score and (i) tertiles of food and nutrient intakes from the AES FFQ and (ii) tertiles of FAVVA score and tertiles of specific plasma carotenoid concentrations. For the food and nutrients, there was a strong level of agreement indicated by Kappa statistics for total FAVVA compared to F&V grams combined (K_w 0.66, $p < 0.001$). Moderate agreement was evident for total FAVVA compared to fruit grams (K_w 0.52, $p < 0.001$), vegetable grams (K_w 0.56, $p < 0.001$) and vitamin C (K_w 0.52, $p < 0.001$), while fair

Table 3
Adjusted[a] regression analyses between FAVVA scores and (i) mean food and nutrient intakes from the AES FFQ and ii) plasma carotenoid concentrations (based on 198 paired observations).

	Total FAVVA			FAVVA Fruit			FAVVA Veg		
	β	95% CI	R^2	β	95% CI	R^2	β	95% CI	R^2
AES FFQ									
Protein (g/day)	0.30***	0.14, 0.45	0.59	0.31	−0.01, 0.63	0.57	0.51***	0.26, 0.75	0.60
Saturated fat (g/day)	−0.14**	−0.23, 0.05	0.59	−0.30***	−0.46, −0.14	0.60	−0.14*	−0.27, 0.02	0.58
Cholesterol (mg/day)	0.46	−0.43, 1.35	0.37	−0.50	−2.37, 1.38	0.37	1.38*	0.12, 2.63	0.39
Carbohydrate (g/day)	0.02	−0.41, 0.45	0.61	0.84	−0.05, 1.73	0.61	−0.45	−1.13, 0.22	0.61
Sugars (g/day)	−0.04	−0.48, 0.40	0.47	0.55	−0.32, 1.42	0.47	−0.42	−1.07, 0.22	0.47
Fibre (g/day)	0.25***	0.20, 0.29	0.67	0.47***	0.37, 0.57	0.65	0.29***	0.20, 0.38	0.57
Fruits (g/day)	5.98***	4.44, 7.53	0.40	15.76***	13.03, 18.50	0.68	4.46**	1.53, 7.38	0.14
Vegetables (g/day)	5.49***	4.80, 6.19	0.60	6.01***	3.78, 8.26	0.24	9.18***	8.26, 10.10	0.70
Fruits & vegetables (g/day)	11.47***	9.86, 13.09	0.68	21.78***	18.01, 25.54	0.64	13.64***	10.21, 17.06	0.44
Vitamin A (μg/day)	12.74***	6.68, 18.79	0.22	15.88*	2.09, 29.66	0.17	20.13***	12.72, 27.55	0.23
Retinol (μg/day)	−1.40	−4.34, 1.58	0.10	−3.64	−8.34, 1.07	0.11	−1.08	−5.86, 3.70	0.10
Riboflavin (mg/day)	0.01**	0.00, 0.01	0.42	0.01	−0.00, 0.02	0.40	0.01**	0.00, 0.02	0.42
Niacin equiv (mg/day)	0.15***	0.08, 0.22	0.63	0.18*	0.03, 0.32	0.60	0.23***	0.12, 0.34	0.63
Folate (μg/day)	2.56***	2.09, 3.03	0.65	3.62***	2.28, 4.96	0.56	3.79***	3.03, 4.54	0.64
Vitamin C (mg/day)	2.51***	2.20, 2.81	0.62	4.15***	3.27, 5.03	0.48	3.34***	2.74, 3.94	0.51
Calcium (mg/day)	2.98	−0.09, 6.06	0.29	2.70	−3.66, 9.05	0.28	5.33*	1.12, 9.54	0.29
Iron (mg/day)	0.06***	0.04, 0.08	0.69	0.11***	0.07, 0.15	0.68	0.08***	0.05, 0.11	0.67
Magnesium (mg/day)	2.17***	1.68, 2.66	0.66	3.44***	2.24, 4.64	0.61	3.00***	2.13, 3.86	0.64
Potassium (μg/day)	24.06***	20.46, 27.66	0.71	38.34***	28.40, 48.27	0.65	33.01***	26.30, 39.63	0.68
Sodium (mg/day)	−3.15	−8.60, 2.29	0.56	−6.14	−16.82, 4.55	0.56	−3.66	−11.30, 3.98	0.55
Zinc (mg/day)	0.04***	0.02, 0.06	0.62	0.05*	0.01, 0.09	0.60	0.07***	0.04, 0.10	0.62
Plasma carotenoids (ug/dl)									
α -Carotene	0.09***	0.04, 0.14	0.04	0.22***	0.10, 0.35	0.06	0.07*	0.00, 0.14	0.01
β -Carotene	0.42*	0.04, 0.81	0.05	0.93**	0.25, 1.61	0.06	0.43	−0.15, 1.00	0.04
Lycopene	0.04	−0.20, 0.28	0.02	0.32	−0.21, 0.85	0.02	−0.11	−0.45, 0.24	0.02
Lutein/Zeaxanthin	0.24	−0.19, 0.67	0.01	0.38	−0.33, 1.10	0.01	0.34	−0.36, 1.04	0.01
β-cryptoxanthin	0.05	−0.00, 0.11	0.02	0.12*	0.02, 0.22	0.03	0.05	−0.04, 0.14	0.01
Total carotenoids	0.85*	0.18, 1.52	0.03	1.98**	0.65, 3.31	0.04	0.78	−0.26, 1.82	0.01

Abbreviation: β, Regression coefficient; CI, Confidence Interval; R^2, Partial Correlation coefficient; FAVVA, Fruit and Vegetable VAriety.
*p-value <0.05; **p-value <0.01; ***p-value <0.001.
[a] Models were adjusted for baseline values for energy intake, sex, age.

agreement was evident for total FAVVA compared to fibre (K_w 0.35, $p < 0.001$), vitamin A (K_w 0.39, $p < 0.001$), folate (K_w 0.35, $p < 0.001$), iron (K_w 0.21, $p < 0.001$), magnesium (K_w 0.26, $p < 0.001$) and potassium (K_w 0.31, $p < 0.001$). There was a statistically significant but ‘slight’ agreement for total FAVVA compared to protein (K_w 0.12, $p < 0.05$), riboflavin (K_w 0.20, $p < 0.001$), niacin equivalents (K_w 0.11, $p < 0.05$), calcium (K_w 0.17, $p < 0.01$), and zinc (K_w 0.10, $p < 0.05$). (Table 4). Significant but ‘slight’ agreement was identified for total FAVVA score and plasma concentrations of α−carotene (K_w 0.11, $p < 0.05$), β-carotene (K_w 0.19, $p < 0.001$), β-cryptoxanthin (K_w 0.15, $p < 0.01$) and total carotenoids (K_w 0.15, $p < 0.01$). The FAVVA fruit sub-scale demonstrated significant but slight agreement with plasma concentrations of α-carotene (K_w 0.14, $p < 0.01$), β-carotene (K_w 0.15, p < 0.01), β-cryptoxanthin (K_w 0.17, $p < 0.01$) and total carotenoids (K_w 0.16, $p < 0.01$). Significant but slight agreement was also identified for FAVVA vegetable sub-scale score and β-carotene (K_w 0.16, p < 0.01), β-cryptoxanthin (K_w 0.10, $p < 0.01$) and total carotenoids (K_w 0.11, $p < 0.05$).

4. Discussion

The current study examined the comparative validity of a brief index of Fruit And Vegetable VAriety (FAVVA) in relation to i) food and nutrient intakes from the AES FFQ and ii) plasma carotenoid concentrations in a sample of overweight and obese adults. The total FAVVA score was significantly associated with most food and nutrient intakes from the AES FFQ, as shown by moderate to strong positive correlations that remained statistically significant in the fully-adjusted regression analyses. Also, only a small proportion of values were misclassified within tertiles of FAVVA score when food and nutrient intakes were assessed using the AES FFQ. Although associations were weaker, statistically significant associations were observed between FAVVA and plasma carotenoid concentrations. For example, total FAVVA score was significantly correlated with plasma concentrations of α−carotene, β −carotene, β −cryptoxanthin and total carotenoids. All except β−cryptoxanthin remained significant in the fully-adjusted regression analyses accounting for energy intake, sex and age. These results demonstrate that the FAVVA index is a valid tool to use as a brief indicator of overall fruit and vegetable frequency and variety relative to comprehensive assessment using the AES FFQ to assess F&V. International researchers may wish to use this method to adapt full FFQ's to similar brief tools for their respective countries' and use plasma carotenoid assessment within the approach to validity and reliability.

The FAVVA score was positively correlated and demonstrated fair to moderate agreement using weighted Kappa statistics to rank intakes of F&V and nutrients found abundantly in F&V, particularly fibre, vitamin A, vitamin C, iron, magnesium and potassium [1]. These results indicate that the FAVVA index reflects the intake of a variety of nutrients known to be associated with health outcomes and lower risk of chronic diseases such as cancer, cardiovascular disease, as well as all-cause mortality [7,38,39]. Similar findings were identified in two larger validation studies conducted in healthy weight adults that also used a food based diet quality index relative to a FFQ [40,41]. For dietary instruments to be used to examine associations between diet and disease outcomes, it has been suggested that correlations (r) between the instrument and the reference method need to be in the range of at least 0.3 or 0.4 for key nutrients [42]. The current study found correlations significantly greater than 0.3 for nine of the 21 foods and nutrients assessed (and fair to strong agreement in ranked intake for 10 foods and nutrients), indicating

Table 4
Extent of the agreement between tertiles of FAVVA score with (i) tertiles for food and nutrients from the AES FFQ and ii) plasma carotenoid concentrations (n = 198).

Variable	n = 198 (100%)			Kappa (K_w)	*P*-value
	Same tertile	*Adjacent tertile*	*Misclassified*		
Protein					
Total FAVVA	79 (40%)	85 (43%)	34 (17%)	0.12	**<0.05**
FAVVA - vegetables	73 (37%)	86 (43%)	39 (20%)	0.08	0.09
FAVVA - fruit	84 (42%)	87 (44%)	27 (14%)	0.20	<**0.001**
Sat fat					
Total FAVVA	45 (23%)	111 (56%)	42 (21%)	−0.12	0.98
FAVVA - vegetables	56 (28%)	92 (46%)	50 (25%)	−0.08	0.93
FAVVA - fruit	71 (36%)	85 (43%)	42 (21%)	0.04	0.25
Cholesterol					
Total FAVVA	76 (38%)	85 (43%)	37 (19%)	0.09	0.06
FAVVA - vegetables	84 (42%)	74 (37%)	40 (20%)	0.13	**<0.01**
FAVVA - fruit	79 (40%)	81 (41%)	38 (19%)	0.11	**<0.05**
Carbohydrates					
Total FAVVA	61 (31%)	103 (52%)	34 (17%)	0.02	0.37
FAVVA - vegetables	64 (32%)	84 (42%)	50 (25%)	−0.04	0.75
FAVVA - fruit	84 (42%)	85 (43%)	29 (	0.19	<**0.001**
Sugars					
Total FAVVA	67 (34%)	97 (49%)	34 (17%)	0.05	0.17
FAVVA - vegetables	59 (30%)	92 (46%)	47 (24%)	−0.05	0.81
FAVVA - fruit	82 (41%)	91 (46%)	25 (13%)	0.20	**<0.001**
Fibre					
Total FAVVA	101 (51%)	81 (41%)	16 (8%)	0.35	**<0.001**
FAVVA - vegetables	85 (43%)	86 (43%)	27 (14%)	0.21	**<0.001**
FAVVA - fruit	113 (57%)	69 (35%)	16 (8%)	0.43	**<0.001**
Fruit (g)					
Total FAVVA	126 (64%)	61 (31%)	11 (6%)	0.52	**<0.001**
FAVVA - vegetables	95 (48%)	76 (38%)	27 (14%)	0.27	**<0.001**
FAVVA - fruit	158 (80%)	39 (20%)	1 (1%)	0.77	**<0.001**
Veg (g)					
Total FAVVA	126 (64%)	67 (34%)	5 (3%)	0.56	**<0.001**
FAVVA - vegetables	133 (67%)	60 (30%)	5 (3%)	0.61	**<0.001**
FAVVA - fruit	90 (45%)	85 (43%)	23 (12%)	0.25	**<0.001**
Fruit + veg (g)					
Total FAVVA	144 (73%)	49 (25%)	5 (3%)	0.66	**<0.001**
FAVVA - vegetables	119 (60%)	66 (33%)	13 (7%)	0.48	**<0.001**
FAVVA - fruit	128 (65%)	65 (33%)	5 (3%)	0.57	**<0.001**
Vit A					
Total FAVVA	112 (57%)	65 (33%)	21 (11%)	0.39	**<0.001**
FAVVA - vegetables	109 (55%)	74 (37%)	15 (8%)	0.41	**<0.001**
FAVVA - fruit	96 (48%)	69 (35%)	33 (17%)	0.23	**<0.001**
Retinol					
Total FAVVA	61 (31%)	97 (49%)	40 (20%)	−0.02	0.61
FAVVA - vegetables	71 (36%)	86 (43%)	41 (21%)	0.05	0.18
FAVVA - fruit	70 (35%)	87 (44%)	41 (21%)	0.04	0.25
Riboflavin					
Total FAVVA	88 (44%)	81 (41%)	29 (15%)	0.20	**<0.001**
FAVVA - vegetables	69 (35%)	92 (46%)	37 (19%)	0.06	0.13
FAVVA - fruit	92 (46%)	79 (40%)	27 (14%)	0.24	**<0.001**
Niacin equiv					
Total FAVVA	72 (36%)	97 (49%)	29 (15%)	0.11	**<0.05**
FAVVA - vegetables	70 (35%)	92 (46%)	36 (18%)	0.08	0.09
FAVVA - fruit	82 (41%)	89 (45%)	27 (14%)	0.19	**<0.001**
folate					
Total FAVVA	101 (51%)	81 (41%)	16 (8%)	0.35	**<0.001**
FAVVA - vegetables	87 (44%)	90 (45%)	21 (11%)	0.26	**<0.001**
FAVVA - fruit	106 (54%)	71 (36%)	21 (11%)	0.36	**<0.001**
Vit C					
Total FAVVA	123 (62%)	67 (34%)	8 (4%)	0.52	**<0.001**
FAVVA - vegetables	114 (58%)	70 (35%)	14 (7%)	0.45	**<0.001**
FAVVA - fruit	120 (61%)	65 (33%)	13 (7%)	0.48	**<0.001**
Calcium					
Total FAVVA	80 (40%)	91 (46%)	27 (14%)	0.17	**<0.01**
FAVVA - vegetables	74 (37%)	88 (44%)	36 (18%)	0.10	**<0.05**
FAVVA - fruit	91 (46%)	75 (38%)	32 (16%)	0.21	**<0.001**
Iron					
Total FAVVA	87 (44%)	85 (43%)	26 (13%)	0.21	**<0.001**
FAVVA - vegetables	76 (38%)	90 (45%)	32 (16%)	0.13	**<0.01**
FAVVA - fruit	90 (45%)	85 (43%)	23 (12%)	0.25	**<0.001**
Magnesium					
Total FAVVA	86 (43%)	95 (48%)	17 (9%)	0.26	**<0.001**
FAVVA - vegetables	84 (42%)	86 (43%)	28 (14%)	0.20	**<0.001**
FAVVA - fruit	97 (49%)	79 (40%)	22 (11%)	0.30	**<0.001**
Potassium					

Table 4 (*continued*)

Variable	n = 198 (100%)			Kappa (K_w)	*P*-value
	Same tertile	*Adjacent tertile*	*Misclassified*		
Total FAVVA	89 (45%)	97 (49%)	12 (6%)	0.31	<0.001
FAVVA - vegetables	89 (45%)	84 (42%)	25 (13%)	0.24	<0.001
FAVVA - fruit	105 (53%)	73 (37%)	20 (10%)	0.36	<0.001
Sodium					
Total FAVVA	58 (29%)	97 (49%)	43 (22%)	−0.05	0.81
FAVVA - vegetables	53 (27%)	96 (48%)	49 (25%)	−0.09	0.95
FAVVA - fruit	70 (35%)	89 (45%)	39 (20%)	0.05	0.19
Zinc					
Total FAVVA	73 (37%)	93 (47%)	32 (16%)	0.10	<0.05
FAVVA - vegetables	69 (35%)	94 (47%)	35 (18%)	0.08	0.09
FAVVA - fruit	81 (41%)	89 (45%)	28 (14%)	0.17	<0.001
α -carotene					
Total FAVVA	72 (36%)	97 (49%)	29 (15%)	0.11	<0.05
FAVVA - vegetables	75 (38%)	84 (42%)	39 (20%)	0.09	0.06
FAVVA - fruit	76 (38%)	93 (47%)	29 (15%)	0.14	<0.01
β -carotene					
Total FAVVA	81 (41%)	92 (46%)	25 (13%)	0.19	<0.001
FAVVA - vegetables	80 (40%)	87 (44%)	31 (16%)	0.16	<0.01
FAVVA - fruit	79 (40%)	88 (44%)	31 (16%)	0.15	<0.01
Lycopene					
Total FAVVA	58 (29%)	94 (47%)	46 (23%)	−0.07	0.89
FAVVA - vegetables	62 (31%)	85 (43%)	51 (26%)	−0.06	0.84
FAVVA - fruit	66 (33%)	94 (47%)	38 (19%)	0.03	0.30
Lutein/ Zeaxanthin					
Total FAVVA	68 (34%)	96 (48%)	34 (17%)	0.06	0.15
FAVVA - vegetables	73 (37%)	83 (42%)	42 (21%)	0.06	0.16
FAVVA - fruit	75 (38%)	82 (41%)	41 (21%)	0.06	0.13
β -cryptoxanthin					
Total FAVVA	79 (40%)	90 (45%)	29 (15%)	0.15	<0.01
FAVVA - vegetables	75 (38%)	87 (44%)	36 (18%)	0.10	<0.05
FAVVA - fruit	82 (41%)	86 (43%)	30 (15%)	0.17	<0.01
Total carotenoids					
Total FAVVA	76 (38%)	95 (48%)	27 (14%)	0.15	<0.01
FAVVA - vegetables	75 (38%)	88 (44%)	35 (18%)	0.11	<0.05
FAVVA - fruit	80 (40%)	89 (45%)	29 (15%)	0.16	<0.01

that the FAVVA index may be an appropriate tool with potential to be used to evaluate relationships between diet and health status.

A statistically significant relationship between protein intake with total FAVVA score and with the vegetable sub-scale in the correlation and regression analyses may be driven by the consumption of foods that accompany them that are a rich source of protein such as meat dishes served with vegetables (i.e., roast dinner or chicken and vegetable curry). This supports previous research indicating that higher intakes of unprocessed red meat, chicken, and fish are associated with higher intakes of vegetables [43].

Correlations were generally weaker with plasma carotenoid concentrations, with none of the associations greater than r = 0.3. However, three of the six associations were above r = 0.2 and classified as a moderate level of association for nutrition validation studies [23,30]. In particular, the FAVVA score was significantly correlated with α −carotene, β-carotene and total carotenoids, and remained associated after regression analyses adjusted for energy intake, sex and age. Therefore, FAVVA appears to be able to quantify the intake of F&V that are high sources of α−carotene (i.e., orange juice, pumpkin) and β-carotene (i.e., carrots, apricots, sweet potato and spinach) [44,45]. This is important because consumption of diets rich in carotenoids have been associated with a lower risk for several diseases, including cancer, in epidemiological research [28], with the antioxidant properties of carotenoids likely to be playing an important protective role. The weaker correlations between FAVVA score and other plasma concentrations of carotenoids are consistent with the extent of associations found in a systematic review of 142 biomarker studies comparing plasma carotenoid concentrations and dietary carotenoid intakes. The review found mean correlation values from the meta-analysis of FFQ studies ranged from 0.26 to 0.39. As FAVVA score was derived from a self-report FFQ there are a number of possible explanations for weak associations with some plasma carotenoids, namely i) there are a limited range of included food items within FFQ food lists, ii) FFQ's assess food intake over a long period of time (i.e., six months) whereas the half-life of plasma carotenoids is 26–76 days [29] and therefore more reflective of shorter term intake, and iii) overweight and obese individuals are more likely to over-report healthy foods such a fruit and vegetables [46], which may influence results.

The fruit sub-scale of FAVVA demonstrated better associations with plasma carotenoid concentrations than the vegetable sub-scale. Since fruits are often eaten in specific contexts such as a snack or a dessert, they may be easier to recall and quantify than vegetables [47] and may explain the observation in the current study. In addition, the lack of association between total FAVVA score (and both FAVVA sub-scales) with lycopene or lutein/zeaxanthin may be due to the high content of these carotenoids in other foods, such as tomato-based sauces with meat/pasta, soup, and pizza [44], which were not accounted for in the FAVVA index. Limited associations with lutein may be due to the increased variety of non-F&V sources foods containing this carotenoid (e.g., eggs) that were not accounted for in the FAVVA score [48], making it difficult to detect an association.

Limitations in the current study need to be acknowledged, including the use of overweight and obese subjects, as previous research suggests that people who are overweight or obese have lower plasma concentrations of carotenoids than healthy weight people [49]. Plasma carotenoid concentrations can be influenced by a number of dietary, metabolic and lifestyle factors including the intra and inter variability in an individual's digestion and absorption, and the amount of fat in the diet [34]. Adjustments were made in the regression analyses to account for potential confounders where possible. Further, responses from the AES FFQ were self-reported and therefore subject to reporting bias, and the FFQ was not able to determine how food was consumed (i.e., raw, cooked with fat, etc.), which may influence the bioavailability of carotenoids from food [50]. Finally, as this was a secondary analysis, the sample size (n = 99) may have been too small with insufficient power to achieve the aims. However, it has been acknowledged that a sample size of 100–200 should be sufficient for generation of correlation coefficients in dietary validation studies using food frequency questionnaires [42].

5. Conclusion

This study demonstrated that the brief Fruit And Vegetable VAriety (FAVVA) score is an acceptable index that may be used independently to provide immediate feedback on both frequency and variety of F&V intake in adults. FAVVA demonstrated moderate to strong associations with a comprehensive FFQ in assessing food and nutrient intakes. Although associations were weaker, significant associations were evident with plasma carotenoids concentrations of α −carotene, β −carotene, β −cryptoxanthin and total carotenoids. Further research is required to evaluate use of the FAVVA index in epidemiologic research, public health interventions and in clinical practice as a brief continuous measure of diet quality, including in more diverse populations.

Statement of authorship

C.C. and T.B. designed the current study. L.A. and C.C. drafted the manuscript. L.A. undertook the statistical analysis with assistance from T.S. and R.W., L.A., R.W., L.W., T.S., T.B., M.R., K.P., R.C. and C.C. contributed to data interpretation, commented on drafts and approved the final manuscript. All authors are in agreement with the manuscript and the content has not been published elsewhere.

Conflicts of interest

The authors have no conflicts of interest to declare.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clnesp.2018.10.007.

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