British Journal of Nutrition (2016), **116**, 913–923
doi:10.1017/S0007114516002749

A national FFQ for the Netherlands (the FFQ-NL 1.0): validation of a comprehensive FFQ for adults

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(Submitted 2 February 2016 – Final revision received 11 May 2016 – Accepted 23 June 2016 – First published online 25 July 2016)

Abstract

A standardised, national, 160-item FFQ, the FFQ-NL 1.0, was recently developed for Dutch epidemiological studies. The objective was to validate the FFQ-NL 1.0 against multiple 24-h recalls (24hR) and recovery and concentration biomarkers. The FFQ-NL 1.0 was filled out by 383 participants (25–69 years) from the Nutrition Questionnaires plus study. For each participant, one to two urinary and blood samples and one to five (mean 2·7) telephone-based 24hR were available. Group-level bias, correlation coefficients, attenuation factors, de-attenuated correlation coefficients and ranking agreement were assessed. Compared with the 24hR, the FFQ-NL 1.0 estimated the intake of energy and macronutrients well. However, it underestimated intakes of SFA and *trans*-fatty acids and alcohol and overestimated intakes of most vitamins by >5 %. The median correlation coefficient was 0·39 for energy and macronutrients, 0·30 for micronutrients and 0·30 for food groups. The FFQ underestimated protein intake by an average of 16 % and K by 5 %, relative to their urinary recovery biomarkers. Attenuation factors were 0·44 and 0·46 for protein and K, respectively. Correlation coefficients were 0·43–0·47 between (fatty) fish intake and plasma EPA and DHA and 0·24–0·43 between fruit and vegetable intakes and plasma carotenoids. In conclusion, the overall validity of the newly developed FFQ-NL 1.0 was acceptable to good. The FFQ-NL 1.0 is well suited for future use within Dutch cohort studies among adults.

Key words: 24-h recall: Concentration biomarkers: FFQ: Measurement errors: Recovery biomarkers: Validation studies

In nutritional epidemiology, prospective cohort studies constitute the strongest observational design to study associations between diet and health outcomes[1]. FFQ are the common choice for assessing dietary intake in large observational studies: they are able to capture usual, individual, long-term dietary intake, and participant burden is low[2]. However, FFQ rely on long-term memory and are subject to socially desirable answers[1]. Moreover, certain foods may be neglected because of the fixed food list[1]. As a result of these types of measurement errors, FFQ may not be useful to detect weak associations between dietary intake and health outcomes[3,4].

In order to stimulate standardised assessment of dietary intake in large-scale studies in the Netherlands, a new FFQ has been developed – the FFQ-NL 1.0. This FFQ aims to provide comprehensive and standardised data collection of usual energy, food and nutrient intakes in Dutch adults. The questionnaire has been developed to suit current and future research objectives for epidemiological research in the Netherlands. Moreover, to incorporate changes in dietary habits and food products over time, the most recent Dutch National Food Consumption Survey and food composition table were used. The development of the FFQ-NL 1.0 and its compatibility with other Dutch FFQ will be

Abbreviations: 24hR, 24-h recall; EPIC, European Prospective Investigation into Cancer and Nutrition; ICC, intraclass correlation coefficient; PABA, *para*-aminobenzoic acid.

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described separately (SJPM Eussen, MCJM van Dongen, NEG Wijckmans-Duysens, *et al.*, unpublished results). The FFQ-NL 1.0 will become nationally available for use in future Dutch epidemiological studies and as such it may serve as a national reference FFQ. Validation of this newly developed FFQ is essential to provide insight to which extent the measurement errors distort observed diet–disease relationships[5]. The objective of this study was to validate the FFQ-NL 1.0 in adults against multiple 24-h dietary recalls (24hR), 24-h N and K excretion in urine, and plasma carotenoids and fatty acids measured in cholesteryl esters.

Methods

Study design and population

The validation study was embedded in the Nutrition Questionnaires plus (NQplus) study, an ongoing longitudinal study in the city of Wageningen and surroundings, the Netherlands[6]. Between 2011 and 2013, 2048 men and women aged 20–70 years were included. The NQplus study was approved by the ethics committee of Wageningen University and conducted according to the guidelines laid down in the Declaration of Helsinki. Participants filled out general and health questionnaires at baseline, year 1 and year 2. Moreover, a physical examination including blood and urine collection was performed at baseline, year 1 and year 2, and multiple 24hR were administered throughout the 2-year study period. All participants provided their written informed consent. For the present validation study, a sample of 445 participants aged 25–69 years was invited to fill out the FFQ-NL 1.0, of which 386 (87 %) responded. A random subsample of 150 people agreed to repeat urine and blood tests. Fig. 1 gives an overview of the measurements and the time frame for the purpose of this validation study.

FFQ-NL 1.0

The National FFQ for the Netherlands, the FFQ-NL 1.0, was developed to obtain comprehensive and standardised data on food intake in large samples of Dutch adults. The FFQ-NL 1.0 was developed with FFQTOOL™, an online tool to develop tailor-made FFQ, and was designed for use in the general population. The food items in the FFQ covered ≥85 % of the absolute intake of energy and thirty-nine nutrients, ≥88 % of the inter-individual variation in intake of energy and macronutrients and 45–93 % of the inter-individual variation in intake of micronutrients as assessed by two non-consecutive 24hR in the Dutch National Food Consumption Survey 2007–2010[7]. The FFQ-NL 1.0 consists of 160 food items with questions on frequency and consumed amounts with a 1-year reference period. Average daily energy and nutrient intakes were calculated by multiplying frequency of consumption by consumed amounts and nutrient content per item using the Dutch food composition table of 2011[8]. Of the 386 participants, three were excluded on the basis of their energy intakes: <2092 kJ/d (<500 kcal/d) or >14 644 kJ/d (>3500 kcal/d) in women and <3347 kJ/d (<800 kcal/d) or >16 736 kJ/d (>4000 kcal/d) in men[9]. A total of 278 persons filled out the FFQ again after about 12 months.

24-h recalls

As part of the overall NQplus study, multiple, telephone-based 24hR were administered. Dates were randomly selected and scheduled evenly across the year and days of the week. The 24hR were administered by dietitians trained in interviewing skills using a five-step, multiple-pass method, which is a validated technique to increase accuracy[10–12]. Recalls were transcribed into food codes and food groups of the 2011 Dutch food composition table[13]. For each person, individually, recalls that were assessed within 12 months before that person filled out the FFQ-NL 1.0 for the first time were selected, resulting in 1038 24hR. For seven persons, no 24hR were available, whereas for the remaining 376 persons, an average of 2·7 (range 1–5) 24hR was included in the current analyses.

Urine collection and analyses

The 24-h urine collections started with the second voiding after waking up and were completed with the first voiding after waking up the next day. Urine samples were handed in at the hospital and transported to the study centre, where they were mixed, weighed, aliquoted and stored at −20°C until further analysis. The participants received three 80-mg *para*-aminobenzoic acid (PABA) tablets to check for completeness of the urine collections. PABA recovery was measured using the HPLC method[14]. A recovery of at least 78 % of the ingested PABA was considered as complete urine collection. Within the Observing Protein and Energy Nutrition Study, the exclusion of participants with incomplete urine samples had little or no effect on the correlation with true intake and the attenuation factors derived for the FFQ[15]. Hence, the analyses were performed on all urine samples. In a sensitivity analysis, persons with a PABA recovery <78 % (*n* 82) were excluded. Total 24-h N excretion was determined by the Kjeldahl technique (Foss Kjeltec™ 2300 analyser; Foss Analytical). Urinary protein content was calculated using the following formula: 6·25 × (urinary N/0·81)[16], accounting for approximately 19 % faecal and skin losses. Urinary K concentration measurements were performed with an ion-selective electrode on a Roche 917 analyser; urinary excretion of 81 % was assumed[17]. Urinary N and K were available for 363 persons, of which 139 provided a replicate urine sample to determine urinary N and K.

Blood collection and analyses

After a 10-h overnight fast, 24 ml of blood was drawn from an antecubital vein using venepuncture. Blood was immediately centrifuged, and plasma was stored at −80°C until further analyses. Carotenoids were determined using HPLC and UV-vis detection[18]. Fatty acids from plasma cholesteryl esters were quantified by GLC using the solid-phase extraction method to separate the cholesteryl esters with acidified methanol. Peak retention times and area percentages of total fatty acids were determined by using known cholesteryl ester standards and analysed using Agilent Technologies ChemStation software (Agilent)[19]. Plasma carotenoids were available for 360 persons and plasma fatty acids for 358 persons, of which fatty acids and carotenoids were determined in replicate blood samples of 141 persons.

Other variables

Height was measured without shoes using a stadiometer (SECA 213; SECA Corp.). Weight was measured without shoes and heavy clothing and with empty pockets on a digital scale (SECA 877; SECA Corp.). Questionnaires assessed educational level, presence of diseases, smoking status and whether the participants followed a diet regimen.

Measurement error models

It was assumed that dietary intake estimated using multiple 24hR as well as protein and K intakes estimated by urinary analysis were the best standards to approximate true intake[20]. For the replicate FFQ-NL 1.0, a constant bias, intake-related bias and person-specific bias were assumed to be present. The following measurement error models were used:

$$\text{24-h recall } (R): \quad R = T + e(R)$$

$$\text{Urinary biomarker } (G): \quad G = T + e(G)$$

$$\text{FFQ-NL 1.0 } (Q): \quad Q = A(Q) + B(Q) \times T + q + e(Q),$$

where A is the constant bias, B the intake-related bias; e the random error, q the person-specific bias, FFQ-NL 1.0 and T the true (unknown) intake.

Statistical analyses

All statistical analyses were performed using SAS 9.3. Linear mixed models with a random intercept for participants were applied taking into account multiple measurements per person. Macronutrients and alcohol were additionally expressed in energy densities to adjust for energy. Absolute differences between self-reported intakes in the FFQ-NL 1.0 and intakes estimated from the reference methods – that is 24hR, urinary biomarker or replicate FFQ – were expressed as group-level bias: (mean intake FFQ-NL 1.0/mean intake reference method) × 100 − 100; differences larger than 5 % were considered relevant. For protein and K, bias in mean intake was evaluated by comparing the distributions of reported intake and intake based on urinary excretion. The attenuation factor was estimated as the slope in the linear regression of the reference method on the reported intake according to the FFQ-NL 1.0. The validity coefficient or de-attenuated correlation coefficient is defined as the correlation between the observed intake as measured using the FFQ and the 'true' intake as measured using the biomarkers and 24hR. The de-attenuated correlation coefficient was estimated as the correlation coefficient between the FFQ-NL 1.0 and the reference instrument divided by the square root of the intraclass correlation coefficient (ICC) of replicates of the reference method[21,22]. The validity of the FFQ-NL 1.0 was judged based on comparison with other published FFQ and whether the correlation coefficients fell within the range of 0·4–0·7 as mentioned by Willett[23]. Validity was first evaluated by attenuation factors and de-attenuated correlation coefficients for protein and K using recovery biomarkers and for other nutrients and foods using 24hR as the reference method, followed by reproducibility and ranking ability. The replicate FFQ-NL 1.0 was used to study reproducibility only. In addition to the unstratified analysis, stratified analyses were performed for men and women, persons aged 25–56 and 57–69 years (median split), according to educational status (low/middle: no, lower or lower vocational education; intermediate: intermediate vocational; and high: higher vocational or university), and for persons with BMI <25 and ≥25 kg/m^2.

Results

Timing of the measurements and general characteristics

The FFQ-NL 1.0 was administered throughout the year, with a minor higher frequency during winter (Fig. 1). The FFQ-NL 1.0 was repeated after approximately 1 year. Blood and urine sample collections and 24hR were spread out equally over the seasons. The mean age of the participants was 53·9 (SD 10·4) years and 61 % were women (Table 1). In total, 45 % of the subjects were overweight or obese. Most of the participants were highly educated (60 %), and a few participants had prevalent diseases (13 %).

Validation of nutrients using 24-h recall

Compared with the 24hR, group-level bias was small for energy, most macronutrients, water and dietary fibre (Table 2). The FFQ-NL 1.0 underestimated the intake of total fat (g), SFA, *trans*-fatty acids and Ca and overestimated the intake of alcohol, EPA, DHA, haem-iron and most vitamins. For energy, macronutrients, dietary fibre and water, de-attenuated correlation coefficients ranged from 0·26 for *trans*-fatty acids to 1·18 for dietary fibre. For micronutrients, correlations ranged from 0·38 for vitamin B_1 to 0·65 for Mg. For energy, macronutrients, dietary fibre and water, attenuation factors ranged from 0·32 for MUFA to 0·73 for alcohol and for micronutrients from 0·27 for vitamin B_1, folic acid and haem-iron to 0·48 for Mg. Group-level bias of nutrients was higher in older than in younger subjects (data not shown). Attenuation factors were similar between age categories and men and women, but higher in highly educated subjects and subjects with a normal BMI (online Supplementary Table S1). De-attenuated correlations were higher in men, in highly educated subjects and in subjects with overweight and obesity (online Supplementary Table S2).

Validation of food groups using 24-h recall

For food groups, group-level bias was small (defined as <5 %) for the intakes of non-alcoholic beverages, bread, fruit, nuts/seeds/snacks, soup and fats/oils/sauces (Table 3). The FFQ-NL 1.0 underestimated the intakes of cake/cookies, vegetables, cheese, composite dishes and sugar/honey/jams/candy and overestimated the intakes of potatoes, eggs, cereals, savoury sandwich fillings, milk and milk products, legumes, soya and vegetarian products, fish and meat. Attenuation factors varied between 0·13 (legumes) and 0·72 (soya and vegetarian products).

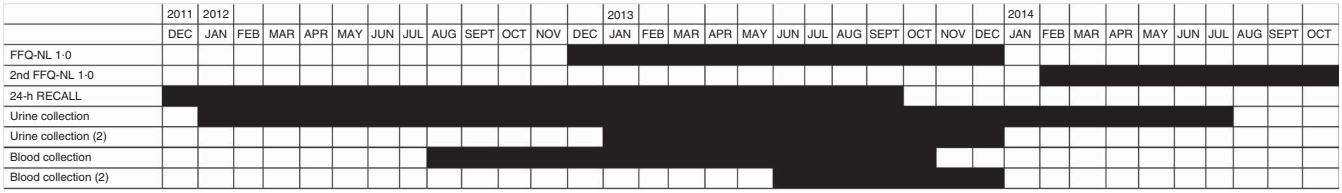

Fig. 1. Time frame and overview of measurements of the FFQ-NL 1.0 validation study.

Table 1. General characteristics of the 383 NQplus participants, aged 25–69 years, included in the FFQ-NL 1.0 validation study (Mean values and standard deviations; numbers and percentages)

	All		Men		Women	
	Mean	SD	Mean	SD	Mean	SD
n	383		149		234	
Age (years)	53·9	10·4	56·9	9·2	52·0	10·7
BMI (kg/m^2)	25·4	4·1	26·0	3·3	24·9	4·5
Waist (cm)	89·6	12·3	95·5	10·4	85·7	11·8
Waist:hip ratio	0·87	0·09	0·93	0·07	0·83	0·07
	n	%	*n*	%	*n*	%
BMI						
Normal weight (<25 kg/m^2)	208	54	65	44	143	61
Overweight (25–29·9 kg/m^2)	131	34	65	44	66	28
Obese (≥30 kg/m^2)	44	11	19	13	25	11
Educational attainment						
Low	14	4	6	4	8	3
Medium	137	36	45	30	92	40
High	230	60	98	66	132	57
Smoking status						
Former	171	51	55	42	116	56
Never	146	43	63	48	83	40
Current	21	6	12	9	9	4
Disease history						
None	334	87	125	86	209	89
Myocardial Infarction	7	2	5	3	2	1
Stroke	6	2	6	4	0	0
Diabetes	13	3	7	5	6	3
Cancer	26	7	8	5	18	8
Diet regimen						
Yes, always	13	3	5	4	8	3
Sometimes	13	3	5	4	8	3
No	348	93	133	93	215	92

Validation of protein and potassium using urinary biomarkers

Compared with the urinary recovery biomarkers, the FFQ-NL 1.0 underestimated protein intake by 15·9 % and K intake by 4·8 % at the group level (Table 4); this is confirmed in Fig. 2 and 3. The attenuation factors for protein and K were 0·46 (95 % CI 0·35, 0·57) and 0·44 (95 % CI 0·32, 0·55), respectively. De-attenuated correlation coefficients were 0·69 (95 % CI 0·53, 0·83) for protein and 0·58 (95 % CI 0·43, 0·73) for K. Including only subjects with a PABA recovery ≥78 % (*n* 280) yielded lower validity measures: attenuation factors were 0·42 (95 % CI 0·29, 0·55) for protein and 0·39 (95 % CI 0·25, 0·53) for K, and de-attenuated correlation coefficients were 0·59 (95 % CI 0·42, 0·74) for protein and 0·47 (95 % CI 0·31, 0·63) for K. Attenuation factors for protein and K tended to be higher among younger subjects, in men and in subjects with higher education and normal BMI (online Supplementary Tables S1 and S2). The underestimation of protein and K intakes at a group level was larger in younger persons and slightly higher among subjects with higher BMI and higher education. Group-level bias for protein was higher in men and for K higher among women (data not shown).

Validation of (fatty) fish, fruit and vegetable intakes using concentration biomarkers

Correlation coefficients between (fatty) fish intake and plasma *n*-3 fatty acids were 0·43–0·47 (Table 5). Correlation coefficients between plasma carotenoids and fruit and vegetable intakes ranged between 0·24 and 0·43 (Table 5). Cross-classification showed that more than 60 % of the participants were allocated to the same or adjacent quintile of intake or plasma concentration. The correlations between fruit and vegetable intake and total carotenoids were somewhat higher among younger subjects and women. For fish intake and plasma

Table 2. Absolute intakes of nutrients in the FFQ-NL 1.0 and telephone-based 24-h recalls (24hR) and the relative difference, correlation coefficients, attenuation factors, de-attenuated correlation coefficients and cross-classification between the FFQ-NL 1.0 and the telephone-based 24-h recalls*
(Mean values with their standard errors; group-level bias, correlation coefficient, attenuation factor, de-attenuated correlation coefficient and 95 % confidence intervals)

	Absolute intake												Cross-classification	
	FFQ-NL 1.0		24hR											
	Mean	SE	Mean	SE	Group-level bias (%)	95 % CI	Correlation coefficient	95 % CI	Attenuation factor	95 % CI	De-attenuated correlation coefficient	95 % CI	Same or adjacent *Q* (%)	Extreme *Q* (%)
n	383		376		376		376		376		376		376	376
Energy (kJ)	840	490	8657	96	−9·2	−15·4, −2·5	1·80	1·26, 2·14	1·67	1·38, 2·01	2·30	1·12, 2·51	280	13
Energy (kcal)	2025	28	2069	23	−2·2	−3·7, −0·6	0·43	0·36, 0·51	0·40	0·33, 0·48	0·55	0·44, 0·65	67	3
Protein (en%)	16·2	0·1	16·1	0·2	0·7	0·6, 0·8	0·44	0·37, 0·51	0·62	0·52, 0·71	0·59	0·48, 0·70	67	2
Protein (g)														
Total	82	1	81	1	1·8	1·4, 2·1	0·38	0·31, 0·46	0·33	0·27, 0·40	0·54	0·41, 0·66	68	3
Vegetable	34	1	34	1	1·6	1·3, 1·8	0·57	0·49, 0·64	0·55	0·47, 0·62	0·72	0·63, 0·80	72	2
Animal	48	1	47	1	2·0	1·6, 2·4	0·40	0·33, 0·47	0·38	0·32, 0·45	0·56	0·44, 0·67	68	2
Fat (en%)	32·7	0·3	33·3	0·3	−1·7	−1·8, −1·5	0·27	0·20, 0·35	0·37	0·27, 0·46	0·37	0·24, 0·50	60	5
Fat (g)														
Total	74	1	79	1	−6·2	−6·6, −5·9	0·30	0·23, 0·37	0·35	0·27, 0·44	0·44	0·30, 0·57	61	4
SFA	26	0	29	0	−13·1	−13·4, −12·9	0·29	0·22, 0·36	0·40	0·30, 0·50	0·40	0·27, 0·53	63	4
MUFA	26	1	27	0	−1·8	−2·0, −1·5	0·25	0·18, 0·32	0·32	0·23, 0·40	0·36	0·22, 0·49	58	5
PUFA	16	0	16	0	0·8	0·6, 1·0	0·34	0·27, 0·42	0·41	0·32, 0·49	0·48	0·35, 0·60	64	4
ALA	2	0	2	0	2·4	2·3, 2·4	0·26	0·19, 0·33	0·34	0·24, 0·44	0·37	0·23, 0·50	64	5
Linoleic acid	13	0	13	0	1·3	1·1, 1·5	0·34	0·26, 0·41	0·40	0·31, 0·48	0·48	0·35, 0·60	58	6
EPA	0·13	0·01	0·11	0·01	13·8	13·8, 13·9	0·33	0·27, 0·39	0·67	0·54, 0·79	0·60	0·43, 0·76	58	6
DHA	0·19	0·01	0·16	0·02	19·1	19·0, 19·2	0·28	0·22, 0·34	0·60	0·47, 0·73	0·53	0·35, 0·70	64	1
Trans-fatty acids	1·1	0·0	1·3	0·0	−18·5	−18·6, −18·4	0·16	0·09, 0·22	0·39	0·22, 0·56	0·26	0·10, 0·42	61	5
Cholesterol (mg)	208	5	204	5	2·2	1·2, 3·2	0·27	0·21, 0·34	0·42	0·33, 0·52	0·46	0·30, 0·62	61	4
Carbohydrates (en%)	46·7	0·3	44·0	0·3	−0·7	−0·8, −0·6	0·51	0·44, 0·59	0·59	0·50, 0·67	0·65	0·55, 0·74	67	3
Carbohydrates (g)														
Total	220	3	224	3	−1·5	−2·1, −0·9	0·54	0·46, 0·62	0·51	0·44, 0·59	0·72	0·62, 0·81	71	2
Polysaccharides	122	2	122	2	0·2	−0·3, 0·7	0·59	0·52, 0·67	0·53	0·46, 0·60	0·76	0·67, 0·84	73	2
Mono/ disaccharides	98	2	101	2	−3·5	−4·0, −3·1	0·44	0·37, 0·52	0·50	0·41, 0·59	0·58	0·47, 0·69	66	3
Dietary fibre (g)	24	0	24	0	2·5	2·3, 2·7	0·92	0·90, 0·93	0·56	0·48, 0·63	1·18	1·16, 1·20	72	2
Water (g)	2662	35	2653	33	0·6	−1·3, 2·4	0·50	0·42, 0·58	0·49	0·41, 0·56	0·61	0·51, 0·69	70	3
Alcohol (en%)	4·5	0·2	3·9	0·2	15·8	15·5, 16·2	0·83	0·75, 0·90	0·72	0·65, 0·78	1·01	0·97, 1·04	83	0
Alcohol (g)	13·0	0·7	12·1	0·7	7·9	7·4, 8·5	0·77	0·70, 0·84	0·73	0·67, 0·80	0·95	0·89, 1·00	82	0
Ca (mg)	990	18	1058	16	−6·5	−7·9, −5·1	0·42	0·34, 0·49	0·47	0·39, 0·55	0·60	0·48, 0·71	66	3
Fe (mg)														
Total	11·9	0·2	11·4	0·2	4·8	4·7, 4·9	0·30	0·23, 0·38	0·34	0·25, 0·42	0·55	0·37, 0·71	66	4
Haem	1·2	0·0	0·8	0·0	43·2	43·1, 43·4	0·29	0·22, 0·35	0·27	0·21, 0·34	0·51	0·34, 0·66	66	3
Non-haem	10·7	0·2	10·5	0·2	1·9	1·8, 2·1	0·35	0·27, 0·43	0·41	0·32, 0·50	0·63	0·46, 0·78	67	3
K (mg)	3543	48	3424	40	3·7	1·5, 5·8	0·44	0·37, 0·52	0·42	0·35, 0·49	0·59	0·48, 0·70	66	3
Mg (mg)	378	5	368	5	3·0	2·3, 3·7	0·48	0·40, 0·55	0·48	0·40, 0·56	0·65	0·54, 0·75	66	2
Retinol (μg)	511	18	531	22	−3·2	−5·6, −0·8	0·20	0·13, 0·26	0·34	0·22, 0·45	0·41	0·21, 0·60	61	5
Vitamin B_1 (mg)	1·1	0·0	1·0	0·0	6·7	6·6, 6·7	0·21	0·14, 0·28	0·27	0·17, 0·36	0·38	0·20, 0·55	62	4
Vitamin B_2 (mg)	1·6	0·0	1·5	0·0	5·8	5·7, 5·9	0·34	0·26, 0·42	0·36	0·28, 0·45	0·46	0·33, 0·58	66	2
Vitamin B_6 (mg)	1·9	0·0	1·7	0·0	11·0	10·9, 11·1	0·28	0·20, 0·36	0·34	0·24, 0·43	0·39	0·25, 0·51	66	3
Vitamin B_{12} (μg)	5·1	0·1	4·7	0·2	9·2	9·0, 9·4	0·28	0·22, 0·35	0·46	0·36, 0·56	0·55	0·36, 0·73	62	4
Vitamin C (mg)	112	3	102·5	2·7	9·8	9·0, 10·5	0·34	0·27, 0·41	0·45	0·36, 0·55	0·63	0·46, 0·79	64	4
Vitamin D (μg)	3·8	2·1	3·3	0·1	14·5	14·4, 14·7	0·27	0·20, 0·34	0·38	0·28, 0·48	0·43	0·28, 0·58	62	3
Vitamin E (mg)	13·4	0·3	12·5	0·3	7·4	7·2, 7·6	0·27	0·19, 0·34	0·34	0·25, 0·43	0·46	0·30, 0·62	61	5
Folic acid (μg)	301	5	256	4	17·8	17·0, 18·6	0·30	0·23, 0·38	0·27	0·20, 0·34	0·45	0·31, 0·58	64	3

ALA, *α*-linolenic acid; ICC, intraclass correlation coefficient.
* % Group-level bias = (mean intake FFQ-NL 1.0/mean value 24hR) × 100 − 100; attenuation factor (95 % CI) estimated as the slope in the linear regression of the reported intake from 24hR on the reported intake from FFQ; de-attenuated correlation coefficient (95 % CI) estimated as the correlation coefficient/$\sqrt{ICC_{24hR}}$.

https://doi.org/10.1017/S0007114516002749 Published online by Cambridge University Press

Table 3. Absolute intakes of food groups in the FFQ-NL 1.0 and the telephone-based 24-h recalls (24hR) and the relative difference, correlation coefficients and cross-classification between the FFQ-NL 1.0 and telephone-based 24hR*
(Mean values with their standard errors; group-level bias, correlation coefficient, attenuation factors, de-attenuated correlation coefficient and 95 % confidence intervals)

	Absolute intake (g)													
	FFQ-NL 1.0		24hR										Cross-classification (%)	
	Mean	SE	Mean	SE	Group-level bias (%)	95 % CI	Correlation coefficient	95 % CI	Attenuation factors	95 % CI	De-attenuated correlation coefficient	95 % CI	Same or adjacent *Q*	Extreme *Q*
n	383		376		376		376		376		376		376	376
Potatoes	81	3	65	3	23·3	22·2, 24·5	0·27	0·21, 0·34	0·44	0·34, 0·54	0·28	0·18, 0·38	62	2
Non-alcoholic beverages	1723	31	1765	31	−2·1	−4·1, 0·0	0·59	0·51, 0·67	0·59	0·51, 0·67	0·60	0·53, 0·66	70	2
Bread and bread products	133	3	138	3	−3·9	−4·7, −3·1	0·61	0·54, 0·68	0·58	0·51, 0·65	0·62	0·55, 0·68	78	2
Eggs	19	1	13	1	44·7	43·9, 45·5	0·31	0·25, 0·37	0·47	0·37, 0·56	0·32	0·22, 0·41	65	2
Fruits	190	6	181	7	4·8	3·4, 6·2	0·66	0·59, 0·74	0·69	0·62, 0·77	0·67	0·61, 0·72	70	3
Cake and cookies	28	1	40	2	−31·9	−32·5, −31·3	0·31	0·24, 0·38	0·65	0·51, 0·80	0·33	0·23, 0·42	64	5
Cereals	75	3	54	3	37·5	36·3, 38·8	0·23	0·16, 0·30	0·33	0·23, 0·42	0·24	0·14, 0·33	67	2
Vegetables	140	4	158	5	−11·1	−12·1, −10·1	0·29	0·21, 0·36	0·48	0·36, 0·60	0·53	0·36, 0·69	61	5
Savoury sandwich fillings	3	0	3	0	16·4	15·8, 16·9	0·48	0·40, 0·56	0·52	0·44, 0·61	0·49	0·40, 0·56	84	0
Cheese	18	1	35	1	−55·6	−55·9, −55·2	0·15	0·08, 0·22	0·33	0·18, 0·48	0·16	0·05, 0·26	59	6
Milk and milk products	369	12	316	10	16·9	15·1, 18·7	0·61	0·53, 0·68	0·51	0·44, 0·57	0·61	0·55, 0·67	73	1
Nuts, seeds, snacks	23	1	23	1	−1·4	−2·1, −0·7	0·20	0·14, 0·27	0·34	0·23, 0·44	0·20	0·10, 0·30	62	2
Legumes	22	2	6	1	274·2	272·2, 276·1	0·13	0·07, 0·19	0·13	0·07, 0·20	0·13	0·03, 0·23	62	0
Composite dishes	11	1	39	3	−72·0	−72·7, −71·4	0·06	0·00, 0·12	0·44	0·00, 0·90	0·06	0·00, 0·16	75	0
Soups	61	4	62	4	−0·8	−2·3, 0·8	0·18	0·11, 0·24	0·25	0·16, 0·35	0·25	0·11, 0·38	67	2
Soya, vegetarian products	20	3	17	3	17·9	15·7, 20·1	0·99	0·95, 1·12	0·72	0·66, 0·77	0·84	0·77, 0·90	87	0
Sugar, honey, jams, candy	26	1	29	1	−9·8	−10·3, −9·2	0·38	0·31, 0·46	0·54	0·44, 0·65	0·38	0·29, 0·47	71	4
Fats, oils, sauces	40	1	39	1	3·4	2·9, 4·0	0·18	0·12, 0·25	0·25	0·16, 0·34	0·18	0·08, 0·28	59	4
Fish	28	2	26	2	7·6	6·6, 8·7	0·27	0·20, 0·34	0·52	0·39, 0·65	0·28	0·18, 0·37	65	1
Meat	105	4	74	3	41·1	39·9, 42·2	0·38	0·31, 0·45	0·34	0·28, 0·40	0·38	0·29, 0·47	68	2

ICC, intraclass correlation coefficient.
* % Group-level bias = (mean intake FFQ-NL 1.0/mean value 24hR) × 100 − 100; attenuation factor (95 % CI) estimated as the slope in the linear regression of the reported intake from 24hR on the reported intake from FFQ; de-attenuated correlation coefficient (95 % CI) estimated as the correlation coefficient/$\sqrt{ICC_{24hR}}$.

https://doi.org/10.1017/S0007114516002749 Published online by Cambridge University Press

Table 4. Validity measures of reported intakes of protein and potassium by FFQ-NL 1.0 as compared with their urinary recovery biomarkers*
(Mean values with their standard errors; estimates and 95 % confidence intervals)

	Protein (g/d)		K (mg/d)	
	Mean	SE	Mean	SE
n	362		363	
Intake FFQ-NL 1.0	82·2	1·3	3568	48
Intake based on excretion	97·7	1·4	3747	58
	Estimate	95 % CI	Estimate	95 % CI
% Group-level bias	−15·9	−16·3, −15·5	−4·8	−7·1, −2·4
Pearson's correlation coefficient	0·40	0·31, 0·48	0·35	0·26, 0·44
Attenuation factor	0·46	0·35, 0·57	0·44	0·32, 0·55
Adjusted attenuation factor	0·28	0·18, 0·38	0·39	0·26, 0·51
ICC recovery biomarker	0·34	0·22, 0·47	0·36	0·24, 0·50
De-attenuated correlation coefficient	0·69	0·53, 0·83	0·58	0·43, 0·73

ICC, intraclass correlation coefficient.
* % Group-level bias = (mean intake FFQ-NL 1.0/mean value recovery biomarker) × 100 − 100; attenuation factor (95 % CI) estimated as the slope in the linear regression of the biomarker on the reported intake; attenuation factor adjusted for age, sex, BMI and educational attainment (low/medium/high); de-attenuated correlation coefficient (95 % CI) estimated as the correlation coefficient/$\sqrt{ICC_{recovery\ biomarker}}$.

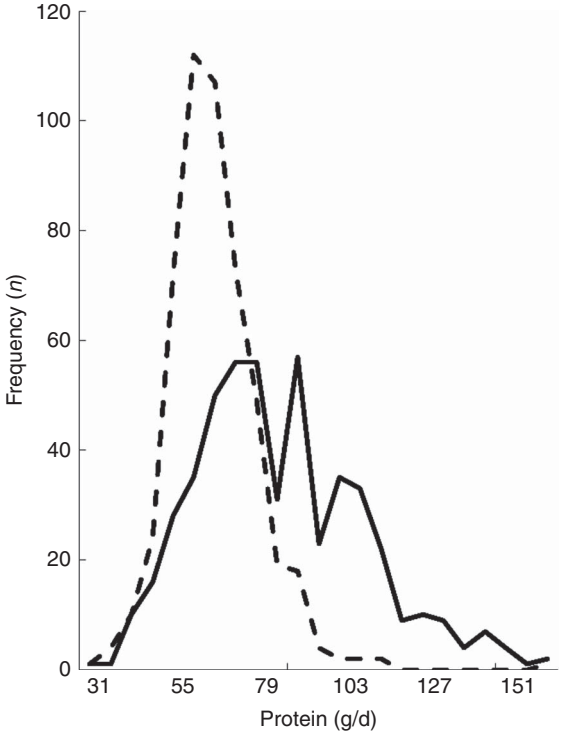

Fig. 2. Estimated distribution of protein intake from FFQ-NL 1.0 (g/d, ——) and intake based on excretion (g/d, ·····).

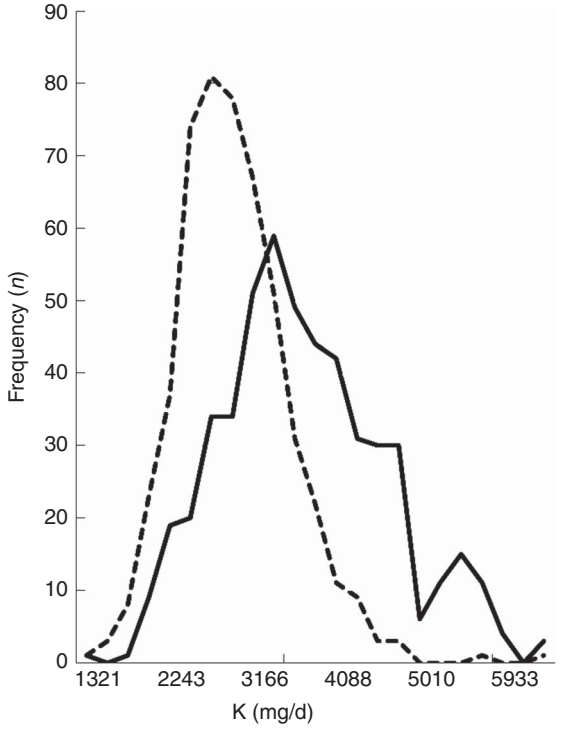

Fig. 3. Estimated distribution of potassium intake from FFQ-NL 1.0 (mg/d, ——) and intake based on excretion (mg/d, ·····).

n-3 fatty acids, correlations were higher among subjects with BMI <25 kg/m^2; for fatty fish, correlations were higher among men and subjects with higher educational level (data not shown).

Reproducibility of the FFQ-NL 1.0

At the group level, the replicate FFQ showed comparable intakes of most food groups (Table 6). On average, intakes of cake and cookies, savoury sandwich fillings, legumes, nuts, seeds and snacks, and fish were higher in the replicate FFQ, but intakes of soup and soya and vegetarian products were lower. Correlation coefficients showed good agreement, ranging from 0·43 for legumes to 0·85 for soya and vegetarian products. For nutrient intakes (data not shown), relative differences in intakes between the first and the second assessment of the FFQ were negligible, and correlation coefficients were high for almost all nutrients (range 0·55–0·89).

Table 5. Pearson's correlation coefficients and cross-classification of reported intakes of (fatty) fish, fruits and vegetables in the FFQ-NL 1.0 and the related blood concentration biomarkers
(Correlation coefficients and 95 % confidence intervals)

	n	Correlation coefficient	95 % CI	Same or adjacent quintile (%)	Extreme quintile (%)
Fish intake and EPA + DHA	356	0·43	0·34, 0·51	67	2
Fatty fish intake and EPA + DHA	356	0·47	0·39, 0·55	69	2
Fruit and vegetable intake and sum of carotenoids	358	0·43	0·34, 0·51	69	3
Fruit intake and sum of carotenoids	358	0·37	0·28, 0·46	66	3
Vegetable intake and sum of carotenoids	358	0·29	0·19, 0·38	62	3
Fruit and vegetable intake and *α*-carotene	358	0·24	0·14, 0·34	64	4
Fruit and vegetable intake and *β*-carotene	358	0·34	0·25, 0·43	64	3
Fruit intake and *β*-cryptoxanthin	358	0·41	0·32, 0·49	65	4
Vegetable intake and lutein + zeaxanthin	358	0·31	0·21, 0·40	63	3

Discussion

The present study investigated the validity of the FFQ-NL 1.0, a comprehensive, standardised, semi-quantitative FFQ for Dutch adults. Compared with the 24hR, absolute differences were small (<5 %) for energy and macronutrients; however, the FFQ underestimated the intake of fat and overestimated the intakes of alcohol, EPA, DHA and most vitamins. For food groups, we observed only some underestimation and overestimation. Compared with their recovery markers, the FFQ underestimated protein intake by 16 % and K by 5 %; the attenuation factors showed good agreement. Correlation of fruits plus vegetables and fish intakes with plasma carotenoids and *n*-3 fatty acids, respectively, was good. Overall, the validity measures were well within the range of agreement that could be expected based on the literature.

The current findings can be compared with a number of other Dutch FFQ that have been previously validated. Within 128 men and women from the Leiden Longevity Study, Streppel *et al.*[24] evaluated an FFQ against three 24hR. Correlation coefficients varied between 0·21 and 0·78 for nutrients and for food groups between 0·00 and 0·79. We found slightly higher correlations for macronutrients and fatty acids, but somewhat lower correlations for micronutrients. Correlations for food groups were generally higher, except for cheese, fats/oils/savoury sauces and pastry/cake/biscuits. Goldbohm *et al.* validated a 150-item FFQ against three 3-d dietary records in a representative subsample of the Netherlands Cohort Study on diet and cancer. For most nutrients, correlations between 0·60 and 0·80 were observed[25], which were generally higher compared with the present validation study. Moreover, in a reproducibility study of the FFQ, correlations were found within the range of 0·42–0·80[26]. Furthermore, Ocké *et al.* validated the FFQ used in the Dutch European Prospective Investigation into Cancer and Nutrition (EPIC) with respect to nutrients[27] and food groups[28] against the average of 12 monthly 24hR. For nutrients, the median Pearson's correlation coefficient was 0·59 in men and 0·58 in women[27]; median Spearman's correlation coefficients for food groups were 0·60–0·64 for men and 0·52–0·58 for women[28]. De-attenuated correlation between protein intake and urinary N was 0·43 in men and 0·50 in women[27]. For the FFQ-NL 1.0, we found lower correlations for both nutrients and food groups, which might be explained by the lower number of repeated 24hR – that is, 2·7/person on average.

Freedman *et al.*[29] pooled five large US validation studies, comprising data of 2265 participants. Compared with 24-h urinary N, the FFQ under-reported protein intake by approximately 10–29 %. Furthermore, compared with 24-h K excretion, the FFQ under-reported K intake by 5–6 %[30]. Estimation of protein and K intakes in the present study was in line with the findings from these five large US studies. Attenuation factors for reported intake by FFQ were on average 0·17 for protein and 0·25–0·30 for K[29,30]. Our study showed attenuation factors of 0·46 for protein and 0·44 for K, indicating substantially lower de-attenuation of relative risks.

Plasma carotenoids are considered as biomarkers of the intake of fruits and vegetables during the previous weeks or months[31]. Al-Delaimy *et al.* investigated the correlation between fruit and vegetable intakes from an FFQ and plasma carotenoids within the EPIC study. The Spearman's correlation coefficient between reported fruit and vegetable intakes and total carotenoids was 0·38[31]. Burrows *et al.*[32] found a correlation between vegetable intake by FFQ and plasma *β*-carotene of 0·42, between fruit intake and *β*-cryptoxanthin of 0·52 and a correlation of 0·30 and 0·26 between vegetable intake and lutein and zeaxanthin, respectively. For fruit and vegetable intakes by FFQ and plasma carotenoids, the present study showed correlation coefficients in the same range.

Although no accurate biomarker for total fat intake exists, EPA and DHA may serve as concentration biomarkers to evaluate fish intake[33]. Within 3009 participants from EPIC, Saadatian-Elahi *et al.*[33] showed a correlation coefficient of 0·29 between fatty fish intake and *n*-3 fatty acids at the individual level. In EPIC-Norfolk, Welch *et al.*[34] evaluated an FFQ against *n*-3 fatty acids in blood plasma and found for reported fish intake a correlation coefficient of 0·17 and for fatty fish intake a correlation of 0·19 in women and 0·23 in men. With correlation coefficients of 0·43 for fish and 0·47 for fatty fish, values in the current study are higher than those found these two studies.

Dietary intake from multiple 24hR was assumed to best approximate true intake. However, correlated errors exist between FFQ and 24hR, including the use of the same food composition table, and they both rely on memory and may be subject to socially desirable answers. As such, the 24hR may be considered an alloyed gold standard reference method. However, it is generally considered the best reference method if no recovery biomarkers are available[4]. Using 24hR may not remove all measurement errors of FFQ, but its use in addition

Table 6. Reproducibility measures of food group intakes between FFQ-NL 1.0 and the replicate FFQ-NL 1.0 in 278 adults*
(Medians and percentiles 25th–75th (P25–P75); group-level bias, Pearson's correlation coefficient and 95 % confidence intervals)

	Intake (g)									
	FFQ-NL 1.0		Replicate FFQ						Cross-classification (%)	
	Median	P25–P75	Median	P25–P75	Group-level bias (%)	95 % CI	Pearson's correlation coefficient	95 % CI	Same or adjacent *Q*	Extreme *Q*
Potatoes	75	39–107	70	36–107	3·5	2·4, 4·6	0·70	0·63, 0·75	84	0
Non-alcoholic beverages	1692	1332–2059	1672	1305–1990	1·2	−1·0, 3·5	0·78	0·73, 0·83	89	1
Bread and bread products	120	80–170	118	76–167	3·0	2·0, 4·0	0·84	0·80, 0·87	93	0
Eggs	14	7–29	14	7–29	−0·6	−1·3, 0·1	0·72	0·66, 0·77	82	0
Fruits	206	102–238	214	100–250	−4·0	−5·6, −2·5	0·76	0·70, 0·80	88	1
Cake and cookies	23	13–40	22	11–42	−5·4	−6·1, −4·6	0·63	0·56, 0·70	86	1
Cereals	52	29–106	52	28–101	−1·8	−3·0, −0·6	0·61	0·53, 0·68	82	0
Vegetables	138	90–188	127	81–194	−0·8	−1·0, 0·5	0·67	0·59, 0·73	78	3
Savoury sandwich fillings	0	0–4	0	0–6	−18·2	−18·7, −17·6	0·63	0·55, 0·69	92	0
Cheese	10	5–21	11	5–21	9·4	8·7, 10·1	0·55	0·46, 0·63	75	1
Milk and milk products	344	200–511	328	194–482	3·9	1·9, 5·9	0·75	0·70, 0·80	89	0
Nuts, seeds and snacks	16	7–33	17	6–35	−7·3	−8·0, −6·6	0·64	0·56, 0·70	85	1
Legumes	16	4–22	16	4–26	−13·0	−14·0, −12·0	0·43	0·33, 0·52	82	2
Composite dishes	5	0–19	3	0–19	0·3	−0·5, 1·0	0·71	0·46, 0·76	87	0
Soups	30	8–48	29	10–48	5·8	4·1, 7·5	0·76	0·71, 0·81	84	1
Soya and vegetarian products	0	0–11	0	0–8	8·4	6·4, 10·4	0·85	0·81, 0·88	89	0
Sugar, honey, jams, candy	21	9–37	23	12–36	−4·1	−4·7, −3·4	0·69	0·62, 0·74	84	1
Fats, oils and sauces	34	22–53	33	21–52	1·1	0·4, 1·7	0·60	0·51, 0·67	75	1
Fish	18	9–34	18	9–43	−6·7	−7·6, −5·7	0·71	0·65, 0·77	88	0
Meat	93	47–137	85	50–137	−0·6	−1·8, 0·6	0·76	0·70, 0·80	86	0

* % Group-level bias = (mean intake FFQ-NL 1.0/mean intake replicate FFQ-NL 1.0) × 100 − 100.

to an FFQ will improve diet–disease associations[4,35]. Furthermore, the use of multiple 24hR is recommended above a single recall[29,30]. Compared with the 24hR, the FFQ-NL 1.0 seemed to under-report the intakes of fat and high-fat foods, particularly SFA, *trans*-fatty acids, cake and cookies, and cheese. The current study population comprised more women and highly educated persons than the general population. As a result, total variation in fat intake might be lower, corresponding with lower validity measures. Furthermore, subjects over-reported their intakes of legumes, soya and vegetarian products, alcohol and most micronutrients in the FFQ-NL 1.0 compared with the 24hR. Subjects also tended to under-report the intake of composite dishes, which may be due to coding differences. In the FFQ-NL 1.0, the covered variance in intake was <80 % for EPA, DHA, *trans*-fatty acids and vitamins B_1, B_2, B_6, C, D, E and folate equivalents, which is likely reflected in the lower validity measures found for these nutrients. To increase the covered variance of particularly B vitamins, a new version of the FFQ-NL 1.0 is now being developed including a few additional food items. Hence, the validity of the improved FFQ is expected to be similar or higher.

Age and BMI may contribute to intake-related bias in the FFQ as well as correlated errors between FFQ and 24hR[35]. Freedman *et al.* observed that a higher BMI was associated with a larger degree of under-reporting; having a lower educational level was also associated with more under-reporting. Furthermore, age above 59 years was associated with less under-reporting[29,30]. Indeed, the current study showed that attenuation factors were generally higher among older subjects and subjects with normal BMI, as well as among men and subjects with higher education.

The NQplus study population comprises a sample of highly educated and committed participants, who have become familiar with dietary assessment methods and with blood and urine collections. Hence, the participants may have been more diligent and accurate in recording their intakes and collecting their urine samples than the general population. However, the study benefitted from the multiple reference methods to which the FFQ could be validated: urinary recovery biomarkers, blood concentration markers and multiple 24hR, as well as the advanced statistical methods, which were used to assess validity.

To provide a reliable and correct measure of dietary intake in free-living populations is the largest challenge of nutritional epidemiology. Measurement errors in FFQ cannot be prevented, but they can be quantified and accounted for. Therefore, it is always recommended to use objective biological markers of dietary intake or 24hR complementary to an FFQ. Furthermore, an external validation study such as the present one is also essential in identifying and quantifying measurement errors and how diet–disease associations are affected. Attenuation directly affects the observed relative risk as well as the necessary sample size to detect these diet–disease relationships[36]. Thus, future epidemiological studies using the FFQ-NL 1.0 can apply the attenuation factors presented here to calculate the sample size needed for desired statistical power and to adjust for observed relative risks.

Validity coefficients or de-attenuated correlation coefficients may also be used to quantify the impact of measurement error on diet–disease relationships[35], and were estimated as the correlation coefficients between the FFQ-NL 1.0 and the reference instrument divided by the square root of the ICC of replicates of the reference method. It is assumed that if the time between replicate urine collections and the 24hR is not too close, the errors in replicates are independent and they provide a measure of within-person variation within the biomarker[37]. However, within-person variation of the 24hR, characterised by a low ICC, was high, which may have led to an overestimation of the de-attenuated correlation coefficient. This may be because of the correlated errors between FFQ and 24hR.

In conclusion, the overall validity of the newly developed FFQ-NL 1.0 was acceptable to good, and the FFQ was able to adequately rank subjects according to their dietary intake. Therefore, the FFQ-NL 1.0 is well suited for future use within Dutch cohort studies among adults. As a future application, the FFQ-NL 1.0 can be used to improve the pooling of results from individual studies using the FFQ.

Acknowledgements

This study was financially supported by the Dutch Biobanking and Biomolecular Research Infrastructure project (BBMRI-NL), a Research Infrastructure financed by the Dutch Government (NWO 184·021·007).

M. C. O., E. J. M. F. and P. C. D. designed the study. A. G., J. H. M. d. V. and E. J. M. F. acquired the data. D. S. carried out the analysis, interpreted the data and drafted the article. All the authors interpreted the data, critically reviewed the article for important intellectual content and gave final approval of the version to be published.

All authors declare no conflicts of interest.

Supplementary material

For supplementary material/s referred to in this article, please visit http://dx.doi.org/doi:10.1017/S0007114516002749

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