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Micronutrient intakes and the role of nutritional supplements in the diet of school-aged children (5-12y) in Ireland

THESIS

Presented by

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Do not be discouraged by the doubt in your mind

but be inspired by the ***vision*** *in your heart*

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"ár saol, ár dturas"

This is to certify that the work I am submitting is my own and has not been submitted for another degree, either at University College Cork or elsewhere. All external references and sources are clearly acknowledged and identified within the contents. I have read and understood the regulations of University College Cork concerning plagiarism.

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Stephanie O'Regan

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Personal contribution

This thesis was based on data from the National Children's Food Survey II (NCFS II) (*n* 600). This survey was carried out between April 2017 and May 2018 by the nutrition units in University College Cork (UCC) and University College Dublin (UCD), which form part of the Irish Universities Nutrition Alliance (IUNA).

Contribution to the research group

During the timeframe of this PhD thesis, I worked with the Dietary Surveys Research Team in UCC as a fieldworker on the NCFS II. During the data collection period, I collected data from 86 participants in the study including dietary, health & lifestyle, eating behaviour, anthropometric data and the collection of spot urine samples from the participants and their parents/guardians. Following data collection, I entered the dietary intake data into Nutritics® and the questionnaire data into DaSurvey®. I was involved in the batch processing of urine samples. I led the structuring, restructuring and updating of the NCFS II dietary supplement database and contributed to the quality control of the dietary intake database. I also played a role in training and mentoring new team members.

All database manipulation and analyses in this thesis were performed by me. The attached work is entirely my own original work.

Stephanie O'Regan

Abbreviations

ABS	Australian Bureau of Statistics
AI	Adequate intake
BMR	Basal metabolic rate
DFE	Dietary folate equivalents
DNA	Deoxyribonucleic acid
DOH	Department of Health
DRV	Dietary reference value
DVFA	Danish Veterinary and Food Administration,
EAR	Estimated average requirement
EC	European Commission
EFSA	European Food Safety Authority
EU	European Union
EVM	Expert Group on Vitamins and Minerals
FSAI	Food Safety Authority Ireland
IFCD	Irish Food Composition Database
IOM	Institute of Medicine
IQR	Inter quartile range
IUNA	Irish Universities Nutrition Alliance
LRNI	Lower reference nutrient intake
MDI	Mean daily intake
NANS	National Adult Nutrition Survey
NCFS	National Children's Food Survey
NCFS II	National Children's Food Survey II
NDNS	National Diet and Nutrition Survey
NE	Niacin equivalent

NNR	Nordic Nutrition Recommendations
NRV	Nutrient reference value
PRI	Population reference intake
RBC	Red blood cell
RDA	Recommended daily allowance
RNA	Ribonucleic acid
RTEBC	Ready-to-eat breakfast cereal
SACN	Scientific Advisory Committee on Nutrition
SD	Standard deviation
UCD	University College Dublin
UK	United Kingdom
UL	Tolerable upper level of intake
UR	Under reporter
US	United States

Abstract

Background: Childhood is an important stage of life due to the rapid growth, acquisition of bone and cognitive development that takes place. Adequate intakes of micronutrients are important during this life phase to prevent nutrient deficiencies and to ensure optimal growth and development.

Objective: The aim of this thesis was to estimate current micronutrient intakes, adequacy and risk of excess in school-aged children in Ireland and to determine the role of nutritional supplements in the diet of this population group.

Methods: The analyses for this thesis are based on data from the National Children's Food Survey II (NCFS II) which was a nationally representative cross-sectional study that collected food and beverage intake data from 600 children aged 5-12 years in the Republic of Ireland between 2017 and 2018 (www.iuna.net).

Food, beverage and nutritional supplement intake data were collected at brand level using a 4-day weighed food diary. For foods that were not weighed, weights provided on product labels, photographic atlases of food portion sizes, standard portion sizes and household measures were used to quantify the amount consumed. Micronutrient intakes were estimated using food composition data from McCance & Widdowson's The Composition of Foods 7th edition (and 6th edition for a small number of foods). Modifications were made to this food consumption database to include recipes of composite dishes, fortified foods, nutritional supplements, generic Irish foods and new foods on the market. Usual micronutrient intakes (mean, standard deviation, median, inter-quartile range) were estimated using the validated National Cancer Institute (NCI)-Method using SAS Enterprise Guide© version 6.1. The prevalence of inadequate intakes was estimated using estimated average requirements (EARs) as cut-off points and the risk of excessive intake of micronutrients was evaluated using tolerable upper intake levels (ULs). As under-reporting of food consumption can result in an overestimate of the prevalence of inadequacy in a population group, under-reporters were identified and excluded

from analysis when assessing nutrient adequacy. In the total population 19.5% (n=117) were identified as under-reporters.

The key sources and dietary determinants of vitamin D and folate intakes were investigated to complement similar research carried out on calcium and iron intakes using the same datasets (Walsh, 2019). The percent contribution of each food group to the mean daily intake (MDI) (µg/d) of vitamin D and dietary folate equivalents (DFE) were calculated by the mean proportion method. Dietary determinants of vitamin D and DFE intake were investigated using tertile analysis by splitting the population into low, medium and high intake groups and examining the food groups which contributed to the difference in intakes between the high and low intake groups and examining the patterns of consumption of these foods.

The NCFS II Dietary Supplement Database (2017-18) was manually constructed in Microsoft Excel and was facilitated using product labels of the dietary supplements used by the participants during the recording period. The database contains detailed information on the types, potencies, combinations and forms of the 102 dietary supplements recorded.

For the purposes of determining the role of nutritional supplements on micronutrient intakes, nutritional supplements were defined as any supplement that contained a single micronutrient or a combination of micronutrients. Nutritional supplement 'users' were defined as children who consumed a nutritional supplement at any time over the 4-day recording period.

Results: A large proportion of children were found to have inadequate intakes of vitamin D (94%) and calcium (37%) and significant proportions had inadequate intakes of zinc (29%), iron (20%), vitamin C (19%), magnesium (18%) and folate (13%). In terms of risk assessment, this study showed no risk of excessive intakes for micronutrients with established ULs (retinol, vitamin D, vitamin E, vitamin C, preformed niacin, vitamin B6, folic acid, calcium, iron and magnesium salts) with only negligible proportions of children (<2%) having zinc intakes exceeding the UL.

The key sources of vitamin D included natural sources such as ‘meat & meat products’ (20%), ‘eggs & egg dishes’ (9%) and ‘fish & fish dishes’ (7%), fortified foods such as ‘ready-to-eat breakfast cereals’ (RTEBCs) (22%) and ‘vitamin D fortified milks & yogurts’ (12%) and nutritional supplements (10%). Nutritional supplements, ‘RTEBCs’ and ‘fortified milks’ were identified as the key dietary determinants of vitamin D intakes. For those with higher vitamin D intakes there was a higher proportion of consumers of ‘RTEBCs’ and ‘vitamin D fortified milks’, they consumed these foods more frequently over the recording period and in greater amounts for ‘vitamin D fortified milks’ (but not for ‘RTEBCs’). Those with higher vitamin D intakes were also more likely to use vitamin D containing supplements and to obtain more vitamin D from these supplements.

For DFE, the key sources included fortified foods such as ‘RTEBCs’ (28%) and natural sources such as ‘bread & rolls’ (12%), ‘milks’ (10%) ‘fruit & fruit juices’ (8%) and ‘meat & meat products’ (8%). ‘RTEBCs’, ‘folic acid fortified milks’ and nutritional supplements were identified as the key dietary determinants of DFE intakes. For those with higher DFE intakes there was a higher proportion of consumers of ‘RTEBCs’ and ‘folic acid fortified milks’, they consumed these foods more frequently over the recording period and in greater amounts. Those with higher DFE intakes were also more likely to use folic acid containing supplements and to obtain more folic acid from these supplements.

The NCFS II Dietary Supplement Database (2017-18) includes detailed information on the types, potencies, combinations and forms of the 102 dietary supplements used by school-aged children. Multivitamin and/or minerals supplements were the most frequent type of supplement recorded followed by single vitamin D and C supplements. In the database, 14% of the supplements included were recommended for adults or adolescents over the age of 12 years or did not specify the population group they were intended for highlighting possible misuse of supplements among children. For most nutrients, the P75 of micronutrient content was at or below the nutrient reference value (NRV). For vitamin D however, the conservative NRV of 5µg together with the inclusion of two supplements that were not marketed for children resulted in a P75 of 200% NRV. Overall, investigation of this database suggests that if supplements were taken as per label instructions there would be no cause for concern.

This study showed that 22% of school-aged children in Ireland used a nutritional supplement with vitamin D being the most commonly obtained micronutrient from nutritional supplements followed by vitamins A, E, C, B6 and B12. When micronutrient intakes and adequacy were examined from 'food sources only' (excluding nutritional supplements), the food component of the diets of nutritional supplement users were not found to be any more or less nutrient-dense than the diets of non-users with the exception of iron. A higher proportion of nutritional supplement users had iron intakes below the EAR compared to non-users from 'food sources only' (users: 30%, non-users: 22%).

For nutritional supplement users, nutritional supplements were shown to increase intakes of all vitamins examined in addition to iron and zinc but made no difference to intakes of calcium and magnesium due to their limited presence in the nutritional supplements being used. For nutrients previously identified as inadequate in this population group (vitamin D, folate, calcium and iron), a small proportion of nutritional supplement users (7%) had intakes of folate below the EAR but a significant proportion had intakes of vitamin D (77%), calcium (33%) and iron (19%) below the respective EARs. Nutritional supplements were not shown to increase the risk of excessive micronutrient intakes in this population group.

Conclusions: Overall, this thesis has shown that school-aged children in Ireland have low intakes of vitamin D, folate, calcium and iron and these intakes need to be improved to avoid negative effects on childhood growth and development. Fortified foods and nutritional supplements were shown to make important contributions to vitamin D and folate intakes and were key dietary determinants between the high and low intake groups. Although the use of nutritional supplements was shown to increase intakes of some micronutrients (mainly vitamins) among those who used them, under current practices it is unlikely they will eliminate the low intakes observed in children. Dietary strategies aiming to increase micronutrient intakes in this population group may require a combination of approaches specific to each nutrient such as increasing natural dietary sources, increased compliance with the food based dietary guidelines, food fortification and nutritional supplement recommendations. The data presented in this study may be useful for research related to nutrition, public health and food safety, and support the work of agencies that are responsible for food and nutrition policy and regulation in Ireland and the EU. These data will also inform the industry with regard to current practices of nutritional supplement use in the diets of Irish children.

Chapter 1

Literature review

Introduction

Children have increased requirements for many nutrients (including micronutrients) due to the growth and development that takes place during this important life stage (Serra-Majem *et al*., 2006). For example, sufficient intakes of vitamin D, calcium and magnesium are required for the formation and maintenance of bone and help to increase bone density and optimise peak bone mass (IOM, 1997). Iron is required for the transport of oxygen around the body while B vitamins including thiamin, riboflavin, niacin and vitamin B6 are involved in metabolic pathways for energy production, and vitamin B12 and folate are involved in the formation of red blood cells and DNA synthesis (IOM, 1998, Halterman *et al*., 2001). Other micronutrients such as vitamins A, C, E and zinc are required for cell growth, the immune response and the development of the nervous system (IOM, 2000, IOM, 2001).

To optimise micronutrient intakes, it is recommended to consume a wide variety of foods in line with the food based dietary guidelines (Flynn *et al*., 2012). However, this is not always achievable and so it may be necessary for certain subgroups of the population to use additional means to increase micronutrient intakes (American Dietetic Association, 2005, EFSA, 2016). Potential strategies to increase micronutrient intakes include increasing the consumption of nutrient rich foods and/or fortified foods and/or the use of nutritional supplements. For example, natural food sources such as dairy products are important sources of calcium, magnesium and zinc and fortified foods such as ready-to-eat breakfast cereals (RTEBCs), milks and margarines are important sources of nutrients such as vitamin D and B vitamins (Barr *et al*., 2014, Fayet-Moore *et al*., 2016, Coulthard *et al*., 2017). With regard to nutritional supplements, they can be used according to national policies or recommendations or based on an individual's own choice and have been shown to help improve nutrient intakes in children (Bailey *et al*., 2012). Of note, when evaluating the role of fortified foods or nutritional supplements in a population group, it is important to consider the balance between the benefit of addressing nutrient imbalances with the risk of excessive intakes above the tolerable upper level of intake (UL) (Flynn *et al*., 2009).

The first section of this literature review aims to investigate micronutrient intakes, adequacy and risk of excess in school-aged children using data from national nutritional surveys across Europe, the United States (US), Canada, Australia and New Zealand. For nutrients identified as being low compared to recommendations, the key sources of the nutrient and dietary determinants of higher intakes will also be discussed. The second section of this review aims to examine the prevalence of nutritional supplement use, the types of supplements used and the impact of nutritional supplements on micronutrient intakes, adequacy and risk of excess in school-aged children.

Section One

Inclusion criteria

This section of the review includes data from nationally representative nutrition surveys of school-aged children (2-14y) across Europe, the US, Canada, Australia and New Zealand. For inclusion in this review, the studies were conducted post 2000 and dietary intake data were collected at an individual level via food records, 24hr recalls or diet histories. Furthermore, the studies included in this review were publicly available in reports or scientific papers and published in or translated to English.

Table 1 presents an overview of the methodologies used in the nineteen nationally representative nutrition surveys that met the criteria for inclusion in this review. This overview includes the study year, age range of participants and dietary assessment method used. The most frequent type of dietary assessment method used across the surveys was a food record. Food records were used by twelve of the nineteen countries and the recording period ranged from two to seven days. They are considered the "gold standard" of individual quantitative dietary assessment methods (Carlsen et al., 2010). The next most frequent type of dietary assessment method used was a 24hr recall which was used by eight countries. Of note, there are different strengths and weaknesses to different dietary assessment methods for example the weighed food record offers a high degree of accuracy in assessing food and nutrient intake relative to the 24hr recall however they can be intrusive and time-consuming and require significant participant training to minimize errors in data collection (Ortega et al., 2015). The 24hr recall has been reported as preferred by the respondent compared to food records (Holmes and Nelson, 2009). When comparing micronutrient intakes across studies, it is important to note that micronutrient intakes may be underestimated if contributions from fortified foods and nutritional supplements are not accounted for (Doets *et al*., 2008).

Compliance with dietary reference values

In this review, mean micronutrient intakes in children were compared to the most recent dietary reference values (DRV) available from the European Food Safety Authority (EFSA) or the US Institute of Medicine (IOM) (IOM, 2011, EFSA, 2015). Mean intakes as reported in the national nutrition studies were compared with population reference intakes (PRI), recommended daily allowances (RDA) or adequate intakes (AI) as appropriate. The PRI and RDA refer to the level of nutrient intake that is adequate for virtually all people in a population group and is assumed to meet the requirements of 97-98% of the individuals in the population (IOM, 2011, EFSA, 2015). The AI is the value estimated when a PRI/RDA cannot be established and is the average observed nutrient intake by a population group of apparently healthy people that is assumed to be adequate (EFSA, 2015). Some studies have investigated the prevalence of inadequate intakes and this review includes these where available. Different methods were applied across different studies to estimate the adequacy of micronutrient intake for example some studies used estimated average requirements (EARs) set by EFSA or the IOM or lower reference nutrient intakes (LRNI) (United Kingdom (UK) only) which led to different prevalence estimates of micronutrient inadequacy. The EAR is the amount of a nutrient that is estimated to meet the needs of 50% of a particular population (EFSA, 2015). Unlike the PRI, RDA and AI, the method of estimating the proportion of individuals with intakes below the EAR has been shown to be effective in obtaining a realistic estimate of the prevalence of dietary inadequacy (Carriquiry, 1999). The LRNI is the amount of a nutrient that is enough for only a small proportion of a population who have low requirements (2.5%) (Salmon and Britain, 1991). Nutrient adequacy can be evaluated by comparing the dietary reference values including those listed above and the intake of the nutrient of interest (Appendix I). As nutritional status biomarkers are objective measures of nutrient intake and are often used in combination with other dietary assessment methods to investigate the nutritional status of a population group, where nationally representative data were available, biomarker status was included for reference.

Micronutrient intakes, adequacy, risk of excess and dietary sources

Table 2 presents mean micronutrient intakes from national nutrition surveys of school-aged children (2-14y) across Europe, the US, Australia, and New Zealand. When mean intakes of vitamin A were compared with the EFSA PRI (4-6y: 300µg/d, 7-10y: 400µg/d and 11-14y: 600µg/d) mean intakes in all countries were found to be sufficient with the exception of Australia (498µg/d) where intakes were low compared to recommendations for older children (11-14y). Of note, fortified foods and nutritional supplements were not accounted for in estimates for Australia and hence these intakes are likely to be underestimated. Mean vitamin E intakes were shown to be below the AI (9-13mg/d) in all countries except for Italy (10.4mg/d), Norway (11mg/d) and the Netherlands (13mg/d). Mean vitamin C intakes were above the PRI (4-6y: 30mg/d, 7-10y: 45mg/d and 11-14y: 70mg/d) in all countries except for Norway (66mg/d) where intakes were below recommendations for older children (11-14y). For B vitamins, mean intakes of thiamin, riboflavin and niacin were above the respective PRIs across all countries except for mean intakes of riboflavin in Belgium (1.3mg/d) and Estonia (1.0mg/d) which were below recommendations for older children (11-14y: 1.4mg/d). Intakes of vitamin B6 in Denmark (1.2mg/d), Estonia (1.2mg/d), France (1.2mg/d), Norway (1.2mg/d) and Australia (1.1mg/d) were also below recommendations for older children (11-14y: 1.4mg/d) while vitamin B12 intakes were above the AI (1.5-3.5µg/d) in all countries. Mean intakes of magnesium were below the PRI (3-9y: 230mg/d, 10-14y: 300mg/d) in Ireland (196mg/d), France (206mg/d), Norway (225mg/d), Portugal (213mg/d), Sweden (208mg/d) and the UK (192mg/d) while intakes in all other countries were below recommendations for older children (11-14y). Whilst these findings may suggest low intakes of some nutrients particularly in older children, intakes between the AI and PRI may still be adequate (EFSA, 2015) and as these studies have not suggested any clinical outcomes it is unlikely that there are any public health issues regarding intakes of these nutrients in school-aged children. However, a high proportion of children were shown to have inadequate intakes and status (where relevant) of vitamin D, folate, calcium, iron and zinc and so are discussed in more detail below.

Vitamin D

During childhood, vitamin D promotes the growth of healthy bones by facilitating the absorption of calcium and phosphorus (SACN, 2016). Based on requirements for bone health, the EFSA have set an AI for vitamin D and the US IOM have set an RDA of 15µg/d for all ages (>1y) (IOM, 2011, EFSA, 2015). **Table 2** presents the mean intakes of vitamin D from national nutrition surveys of school-aged children (2-14y) across Europe, the US, Australia, and New Zealand. Mean intakes from 'food sources only' (excluding nutritional supplements) ranged from 1.0µg in Turkey to 6.0µg in France and mean intakes from all sources (including nutritional supplements) ranged from 3.0µg in the Netherlands to 7.7µg in Norway. When mean intakes were compared with the appropriate DRVs, intakes across all studies were shown to be below the 15µg/d recommendations. Studies investigated the prevalence of inadequate vitamin D intakes using EARs set by the IOM or Nordic Council of Ministers (IOM, 2011, Nordic Council of Ministers, 2014). The Nordic countries (Denmark, Finland and Norway) reported vitamin D intake in children to be low compared to the Nordic Nutrition Recommendation of 10µg/d (Nordic Council of Ministers, 2012). In studies that reported the prevalence of inadequate intakes (%<EAR) at population level such as in Ireland, Spain, Sweden, the UK and Canada almost all children (90-100%) were reported to have vitamin D intakes below the IOM EAR of 10µg/d (Barbieri *et al*., 2006, Hannon, 2006, Shakur *et al*., 2012, Bates *et al*., 2014, Lopez-Sobaler *et al*., 2017). These low intakes may increase the risk of inefficient absorption of calcium which can impact on bone health (SACN, 2016). In order to account for vitamin D produced in the body by exposure to sunlight containing ultraviolet B, vitamin D status was measured using serum 25-hydroxyvitamin D (25(OH)D) in some studies. The UK Scientific Advisory Committee on Nutrition (SACN) define vitamin D deficiency as serum 25(OH)D <25nmol/L while the US IOM define deficiency as serum 25(OH)D <30nmol/L, inadequacy between 30-50nmol/L and sufficiency as >50nmol/L (SACN, 2007, IOM, 2011). Nationally representative data on vitamin D status in children has shown that 6% of 4-10 year old children in the UK, 5.4% of 6-79 year olds in Canada and less than 2% of children aged 6-11 years in the US had levels considered to be deficient (Whiting *et al*., 2011, Bates *et al*., 2014). Furthermore, 12.3% of 6-11 year olds in the US and 25.7% of 6-79 year olds in Canada were considered to be at risk of vitamin D inadequacy (Whiting *et al*., 2011, Herrick *et al*., 2019).

Among countries that reported sources of vitamin D intake in children (Belgium, Ireland, Italy, Spain, the Netherlands and the UK), the key sources of vitamin D were 'meat & meat products' (20-37%), 'fats & oils' (14-36%), 'eggs' (12-25%), 'fish & seafood' (7-26%), 'milk & milk products' (10-23%), 'cereal products' (10-30%) and nutritional supplements (6-26%) (Van Rossum *et al*., 2011, Sette *et al*., 2013, Black *et al*., 2014, Olza *et al*., 2017, Bel and De Ridder, 2018, Roberts *et al*., 2018).

Folate

During childhood, folate is an important contributor to growth processes such as DNA synthesis and cell division (Mcnulty and Pentieva, 2004). The EFSA have set a PRI of 140µg/d for 4-6 year olds, 200µg/d for 7-10 year olds and 270µg/d for 11-14 year olds (EFSA, 2015). **Table 2** presents the mean intakes of folate from national nutrition surveys of school-aged children (2-14y) across Europe, the US, Australia, and New Zealand. Mean intakes from 'food sources only' (excluding nutritional supplements) ranged from 160µg/d in Austria to 280µg/d in Denmark and mean intakes from all sources (including nutritional supplements) ranged from 168µg/d in Sweden to 249µg/d in the US and New Zealand. For all studies included in this review, mean folate intakes were above the PRI of 140µg/d for younger children (4-6y) but below the PRI of 270µg/d for older children (11-14y). For children aged 7-10 years, mean intakes in Austria, Belgium, Estonia, Norway, Portugal and Sweden were below the recommendation (200µg/d) while mean intakes were above this recommendation in Denmark, France, Ireland, Spain, the Netherlands, the UK, Turkey, the US, Australia and New Zealand. Some studies reported the prevalence of inadequate intakes at population level for example in Ireland 14% of children had folate intakes below the EAR for folate of 110µg for 5-6 year olds, 160µg for 7-10y and 210µg for 11-12 year olds which was extrapolated from RDAs from the Food Safety Authority of Ireland (FSAI) (Hannon, 2006). In the UK 28% of children were reported to have intakes below the LRNI of 75µg/d for 4-10 year olds (Bates *et al*., 2014). These studies suggest that folate intakes may need to be improved to avoid negative impacts on growth (EFSA, 2014). In the UK nationally representative data on folate status in children has shown that less than 3% of 4-10 year old children had a serum total folate <10nmol/L indicating possible deficiency, and less than 4% had RBC folate <340nmol/L indicating risk of anaemia (Bates *et al*., 2014).

Among countries that reported sources of folate intake in children (Belgium, Ireland, Italy, the Netherlands and the UK), the key sources of folate were cereal products (22-39%), 'vegetables & potatoes' (14-26%), 'milk & milk products' (8-11%) and nutritional supplements (4-37%) (Hannon, 2006, Van Rossum *et al*., 2011, Sette *et al*., 2013, Bel and De Ridder, 2018, Roberts *et al*., 2018).

Calcium

During childhood, calcium is essential for the formation and maintenance of bone and plays an integral part in the growth process by increasing bone density and optimising peak bone mass (Zemel *et al*., 2010). Based on requirements for bone health, EFSA have set a PRI for calcium of 450mg/d for 4-6 year olds, 800mg/d for 7-10 year olds and 1150mg/d for 11-14 year olds (EFSA, 2015). **Table 2** presents the mean intakes of calcium from national nutrition surveys of school-aged children (2-14y) across Europe, the US, Australia, and New Zealand. Mean intakes from 'food sources only' (excluding nutritional supplements) ranged from 535mg/d in Turkey to 1010mg/d in Denmark and mean intakes from all sources (including nutritional supplements) ranged from 716mg/d in Belgium to 1082mg/d in the US. Mean calcium intakes across all studies were above the PRI of 450mg/d for younger children (4-6y) but below the PRI of 800-1150mg/d for older children (7-14y) in Austria, Belgium, Estonia, Italy, Norway, Turkey, Australia and New Zealand. Some studies reported the prevalence of inadequate intakes at population level for example in Ireland 25% of children had calcium intakes below the EAR of 680mg/d for 4-10 year olds and 960mg/d for 11-14 year olds extrapolated from FSAI RDAs (Hannon, 2006) while in the UK 25% of children had calcium intakes below the LRNI of 325mg/d (Bates *et al*., 2014). In Spain 21% of 4-8 year olds and 74% of 9-13 year olds had calcium intakes below the IOM EAR of 800mg/d and 1100mg/d, respectively (Lopez-Sobaler *et al*., 2017). In Canada 17% of 4-8 year olds and 46% of 9-13 year olds had intakes below the same IOM EAR (Shakur *et al*., 2012). In Belgium 45% of 6-9 year olds and 69% of 10-13 year olds had calcium intakes below the EFSA EAR of 680mg/d for 4-10 year olds and 960mg/d for 11-13 year olds (Bel and De Ridder, 2018). Overall, these findings suggest that children especially older children (>8y) may be at risk of low calcium intakes which may have negative effects on bone health (Zemel *et al*., 2010).

Among countries that reported sources of calcium intake in children (Ireland, Italy, Spain, the Netherlands and the UK), the key sources of calcium were 'milk & milk products' (34-63%), 'cereal products' (9-39%) and 'beverages' (3-10%) (Hannon, 2006, Sette *et al*., 2013, Van Rossum *et al*., 2011, Olza *et al*., 2017, Roberts *et al*., 2018).

Iron

Iron is required for oxygen transport and short-term oxygen storage. It is also important for growth and cognitive development in children as it plays a role in essential activities such as electron transfer, oxidase activities and energy and substrate metabolism (Halterman *et al*., 2001). The EFSA have set a PRI for iron of 7mg/d for 5-6 year olds and 11mg/d for 7-14 year olds (EFSA, 2015). **Table 2** presents the mean intakes of iron from national nutrition surveys of school-aged children (2-14y) across Europe, the US, Australia, and New Zealand. Mean intakes of iron from 'food sources only' (excluding nutritional supplements) ranged from 7.2mg/d in Turkey to 11.6mg/d in Spain and mean intakes from all sources (including nutritional supplements) ranged from 7.0mg/d in Norway to 14.8mg/d in the US. Iron intakes across all studies were above the PRI of 7mg/d for younger children (4-6y) but were below the PRI of 11mg/d for older children (7-14y) in

Austria, Belgium, Denmark, Estonia, France, Ireland, Italy, Norway, Portugal, Sweden, the Netherlands, the UK, Turkey and Australia. Some studies reported the prevalence of inadequate intakes at population level for example in Ireland 16% of boys and 43% of girls had iron intakes below the EAR extrapolated from FSAI recommendations (5-6y: 6.9mg, 7-10y: 7.7mg, boys 11-12y: 10mg, girls 11-12y: 10.8mg) (Hannon *et al*., 2006). In Spain 16% of children had intakes below the IOM EAR (4-8y: 4.1mg/d, 9-13y boys: 5.9mg/d, 9-13y girls: 5.7mg/d) while in Belgium, 44% of children had iron intakes below the EFSA EAR (5-6y: 5mg/d, 7-11y: 8mg, 12y boys: 8mg/d and 12y girls: 7mg/d) (Lopez-Sobaler *et al*., 2017, Bel and De Ridder, 2018). In the UK nationally representative data on iron status in children has shown that 3% of children had a haemoglobin concentration indicative of anaemia and 9% had plasma ferritin concentration indicative of low iron stores with 1% of children having evidence of iron deficiency anaemia (Bates *et al*., 2014). Overall, these findings suggest that a proportion of children may be at risk of low iron intakes which can lead to iron deficiency anaemia and health implications such as poor cognitive and behavioural performance (Halterman *et al*., 2001).

Among countries that reported sources of iron intake in children (Ireland, Italy, Spain, the Netherlands and the UK), the key sources of iron were 'cereal products' (26-55%), 'meat and meat products' (14-31%) and 'vegetables' (9-14%) (Hannon, 2006, Van Rossum *et al*., 2011, Sette *et al*., 2013, Samaniego-Vaesken *et al*., 2017, Roberts *et al*., 2018).

Zinc

Zinc plays a central role in cellular growth, specifically in the production of enzymes that are necessary for the synthesis of RNA and DNA and is an important mineral for cognitive development during childhood (IOM, 2001). EFSA have set a PRI for zinc of 5.5mg/d for 4-6 year olds, 7.4mg/d for 7-10 year olds and 10.7mg/d for 11-14 year olds (EFSA, 2015). **Table 2** includes mean zinc intakes from national nutrition surveys of school-aged children (2-14y) across Europe, the US, Australia, and New Zealand. Mean intakes from 'food sources only' (excluding nutritional supplements) ranged from 6.2mg/d in Turkey to 9.9mg/d in France and mean intakes from all sources (including nutritional supplements) ranged from 6.6mg/d in the UK to 10.5mg/d in the US. Mean zinc intakes were above the 5.5mg/d recommendation for younger children (4-6y) but below the 10.7mg/d recommendation for older children (11-14y) across all studies. For children aged 7-10 years, mean zinc intakes were below the 7.4mg/d recommendation in Estonia, Ireland, the UK and Turkey. Some studies reported the prevalence of inadequate intakes at population level for example in Ireland, 15% of boys and 26% of girls had intakes below the EAR of 4.6 mg for 5-6 year olds, 5.4mg for 7-10 year olds and 7mg for 11-12 year olds extrapolated from FSAI recommendations (Hannon, 2006). In the UK, 11% of children had intakes below the LNRI of 4mg for 4-10 year olds and 5.3mg for 11-14 year olds (Bates *et al*., 2014). In the Netherlands 1-2% of 4-8 year olds and 15-29% of 9-13 year olds had intakes below the IOM EAR (4-8y: 4mg/d, 9-13y: 7mg/d) (Van Rossum *et al*., 2011). In Spain 9% of 9-13 year olds had zinc intakes below the same IOM EAR (Lopez-Sobaler *et al*., 2017) while in the US up to 19% of 9-13 year olds had intakes below the IOM recommendation (Bailey *et al*., 2012).

Among countries that reported sources of zinc intake in children (Ireland, Italy, the Netherlands and the UK), the key sources of zinc were ‘meat and meat products’ (24-34%), ‘cereal products’ (20-31%) and ‘milk & milk products’ (20-29%) (Hannon, 2006, Sette *et al*., 2013, Van Rossum *et al*., 2011, Roberts *et al*., 2018).

The risk of excessive micronutrient intakes

When evaluating micronutrient intakes, it is important to consider the balance between the benefit of addressing low intakes with the risk of intakes above the UL. The UL is defined as the maximum level of total chronic daily intake of a nutrient (from all sources) judged to be unlikely to pose a risk of adverse health effects to individuals (EFSA, 2006). This review includes studies which assessed micronutrient intakes in children with regard to established ULs from Belgium, Denmark, Ireland, Spain, the Netherlands, the UK, the US and Canada (Hannon, 2006, Van Rossum *et al*., 2011, Bailey *et al*., 2012, Shakur *et al*., 2012, Bates *et al*., 2014, Pedersen *et al*., 2015, Lopez-Sobaler *et al*., 2017, Bel and De Ridder, 2018). This review found that for the most part that there was little or no risk of adverse effects from excess intakes for most micronutrients examined (vitamins A, D, E and C, niacin, vitamin B6, calcium, iron and magnesium). However, for zinc a relatively small proportion of children in the Netherlands (2%) had intakes above the EFSA UL of 10mg/d for 4-6 year olds, 13 mg/d for 7-10 year olds and 18mg/d for 11-14 year olds and a higher proportion of children in the US (5-13%) had intakes exceeding the IOM UL of 12mg/d for 4-8 year olds and 23mg/d for 9-13 year olds (Van Rossum *et al*., 2011, Bailey *et al*., 2012). Furthermore, 5% of children in the US had folic acid intakes above the IOM UL of 400 µg/d for 4-8 year olds and 600µg/d for 9-13 year olds (Bailey *et al*., 2012).

For zinc, it has previously been noted that the established UL is low relative to observed intakes in several European countries and while intakes exceeding the UL for zinc are not without some risk, the probability of individuals suffering adverse effects is low as ULs are established using uncertainty factors to ensure that the risk of adverse effects is negligible for even the most sensitive of individuals in a population (Flynn *et al*., 2009). For folic acid, it should be noted that the UL for folic acid is extrapolated from that of adults (set in relation to masking of pernicious anaemia in older adults) and because there is no clinical evidence that the consumption of high amounts of folic acid in children has caused any adverse effects, it may not be a risk for children (IOM, 1998).

Dietary patterns associated with higher micronutrient intakes in children

Findings from this review have highlighted low intakes of vitamin D, folate, calcium, iron and zinc in children across Europe, the US, Canada, Australia and New Zealand, particularly for older children (9-14y). Identifying the dietary patterns associated with higher intakes of these nutrients may help inform dietary strategies to improve intakes. If those with low intakes can adopt the dietary patterns of children with higher intakes it may help to increase intakes within the overall population (Gibney and Sandström, 2001). Across studies that examined dietary patterns, consumption of dairy products and 'RTEBCs' have been shown to be associated with improved micronutrient intakes in children (Barr *et al*., 2014, Dror and Allen, 2014, Fayet-Moore *et al*., 2016, Gaal *et al*., 2018). Additionally, for some micronutrients nutritional supplements were also shown to increase intakes.

Dairy consumption

Dairy products are an important source of micronutrients such as vitamin D, calcium and zinc and can play an important role in helping to meet nutrient intake recommendations (Nicklas *et al*., 2009). A review that examined dairy product intake in children and adolescents in developed countries found that dairy foods made significant contributions to calcium (50-73%) and zinc (16-39%) intakes in France, the Netherlands and the US (Dror and Allen, 2014). Furthermore, longitudinal data collected in the US throughout childhood showed that consuming at least two cups of milk per day (473ml) was associated with significantly higher mean calcium intake (Moore *et al*., 2008). More recently, a nationally representative study of school-aged children in Ireland has reported that the key determinants of higher intakes of calcium were milk, cheese and 'cereals made up with milk' (Walsh, 2019). In some countries, dairy products including milk are fortified with vitamin D and have been shown to significantly contribute to higher vitamin D intakes in these countries. For example, in Finland there is a national policy for vitamin D fortification of fat spreads and fluid milk products, in Sweden all fluid milk products are mandatorily fortified with vitamin D (0.38–0.50μg/100g) and in Canada milk is also mandatorily fortified with vitamin D (0.825–1.125μg/100g) while in Norway and the US milk is routinely fortified with vitamin D (0.4-1.0μg/100g) (Health Canada, 1985, Calvo *et al*., 2004, Itkonen *et al*., 2018). The inclusion of vitamin D fortified milk in the diet has been shown to increase vitamin D intakes and status in children and adolescents aged 2-18 years across the UK, Belgium, Denmark, the US, Canada and New Zealand (Graham *et al*., 2009, Madsen *et al*., 2013, Moyersoen *et al*., 2017, Gaal *et al*., 2018). Furthermore, 'milk and milk products' have been reported as a key dietary source of zinc in children, accounting for 16, 25, and 39% of total zinc intake in the US, France and the Netherlands, respectively (Coudray, 2011, Drewnowski, 2011, Vissers *et al*., 2011).

'Ready-to eat breakfast cereal' consumption

'RTEBCs' are commonly fortified with vitamins and iron and have been shown to increase intakes of vitamin D, thiamin, riboflavin, niacin, vitamin B6, vitamin B12, folate, calcium and iron intakes in children across Europe (Van den Boom *et al*., 2006). A recent study in Ireland reported that higher intakes of iron in school-aged children were largely determined by the consumption of fortified 'RTEBCs' (Walsh, 2019). Similarly, in Spain and the UK fortified breakfast cereal consumption has been associated with higher dietary intakes of vitamin D, B vitamins and iron (Van den Boom *et al*., 2006, Gaal *et al*., 2018). A recent modelling study in the UK based on data from the National Diet and Nutrition Survey (NDNS) (2008-12) has indicated that the daily consumption of 30g of vitamin D fortified 'RTEBCs' would increase vitamin D status in children (4-10y) (Calame *et al*., 2020). In the US, Canada and Australia 'RTEBCs' have also been reported to be associated with higher intakes of vitamin D, calcium, iron, and zinc in children (Barr *et al*., 2014, Fulgoni and Buckley, 2015, Fayet-Moore *et al*., 2016).

Section Two

In addition to natural dietary sources of micronutrients and fortified foods, the use of nutritional supplements has also been shown to improve micronutrient intakes among population groups (Walsh *et al*., 2006, Bailey *et al*., 2012, Shakur *et al*., 2012, Bates *et al*., 2014, Rangan *et al*., 2015, Walsh, 2019).

A second aim of this review was to examine the prevalence of nutritional supplement use, the types of supplements used and the impact of nutritional supplements on micronutrient intakes, adequacy and risk of excess in school-aged children. Among the national nutrition surveys included in this review, fourteen countries included data on nutritional supplement use in school-aged children between the years 2002 to 2016 **(Table 3)**.

Nutritional Supplement types

Nutritional supplements are concentrated sources of nutrients (such as vitamins and minerals) or other substances with a nutritional or physiological effect that are marketed in ‘dose’ form (e.g., pills, tablets, capsules, liquids in measured doses) (EFSA, 2016). **Table 3** includes data on the prevalence of nutritional supplement use and the types of nutritional supplements used in school-aged children (2-14y) across Europe, the US, Canada, Australia, and New Zealand. This review found that nutritional supplement use was low (<10%) among children in Italy, Portugal, Spain and New Zealand. In France, the UK and Australia 3-16% of children reported using nutritional supplements. In Ireland 25% of children reported using a nutritional supplement while 36-38% of children in Belgium and the US reported nutritional supplement use. A higher proportion of children were reported as nutritional supplement users in Canada (41%), the Netherlands (43%) and Norway (63%). This review demonstrates a significant variation in the proportion of children who use nutritional supplements (from as low as 2% in Italy to as high as 63% in Norway). The reasons as to why children use nutritional supplements were not reported in these studies, however other studies have suggested that nutritional supplements are primarily used to help improve or maintain health (Bailey *et al*., 2013) and it has also been reported that children whose parents use supplements are more likely to use them (Dwyer *et al*., 2013). Another reason for the differences in nutritional supplement use across countries may be due to some countries having nutritional supplement recommendations in place for certain nutrients. For example, many European countries particularly those at latitudes above 40°N including Ireland, Denmark, Finland, Iceland, Norway, Sweden and the UK recommend that children take 5-10µg vitamin D supplements daily especially during the winter period when the capacity for UVB sunlight-induced dermal synthesis of vitamin D is much reduced or even absent (Nordic Council of Ministers, 2014, SACN, 2016, FSAI, 2017).

This review found that the most common types of nutritional supplements used were multivitamin and/or minerals supplements. Single vitamin supplements such as single vitamin C and vitamin D were also reported for children in Belgium, Ireland, Norway, Portugal, Spain, the Netherlands, the US, Canada, Australia and New Zealand (New Zealand Ministry of Health, 2003, Walsh *et al*., 2006, Van Rossum *et al*., 2011, Bailey *et al*., 2012, Shakur *et al*., 2012, ABS, 2014, Hansen *et* *al*., 2016, Lopez-Sobaler *et al*., 2017, Bel and De Ridder, 2018, Lopes *et al*., 2018). Calcium supplements were reported to be used by a small proportion of children in Spain, the US and Australia while fish or cod liver oils were used by children in Ireland, Norway, the Netherlands and the UK (Walsh *et al*., 2006, Van Rossum *et al*., 2011, Bailey *et al*., 2012, ABS, 2014, Bates *et al*., 2014, Hansen *et al*., 2016, Lopez-Sobaler *et al*., 2017).

The contribution of nutritional supplements to micronutrient intakes

Figure 1 presents the percent contribution of nutritional supplements to micronutrient intakes in school-aged children across countries that reported micronutrient intakes from 'food sources only' (excluding nutritional supplements) and all sources (including nutritional supplements). These countries included Belgium, Ireland, Norway, the Netherlands, the UK, the US and New Zealand (New Zealand Ministry of Health, 2003, Hannon, 2006, Van Rossum *et al*., 2011, Bates *et al*., 2014, Rhodes *et al*., 2015, Hansen *et al*., 2016, Bel and De Ridder, 2018, Roberts *et al*., 2018). This review showed that nutritional supplements contributed to 10-22% of vitamin A intakes, 1-36% of vitamin E intakes and 3-15% of vitamin C intakes. For vitamin D, nutritional supplements contributed to 17-29% of intakes in the UK, the Netherlands and the US and to 52-56% of intakes in Ireland, Belgium, and Norway. Nutritional supplements contributed to 2-25% of B vitamin intakes across all studies. Nutritional supplements made a small contribution to iron and zinc intakes (3-6%) and little or no contribution to calcium and magnesium intakes (1-2%) across all studies. These findings indicate that for children, nutritional supplements make an important contribution to intakes of a number of key vitamins (in particular vitamin D) but make little contribution to mineral intakes except for a small impact on iron and zinc intakes.

Micronutrient intakes from 'food sources only'

It has been suggested that children who may benefit from the use of nutritional supplements (i.e., those with a less nutrient-dense diet and low micronutrient intakes) are not the ones using them (Bailey *et al*., 2012). This review includes studies that examined micronutrient intakes from 'food sources only' (excluding nutritional supplements) in supplement users and non-users.

Data from the National Children's Food Survey (2003-04) in Ireland showed that when the prevalence of inadequate micronutrient intakes from 'food sources only' was compared across nutritional supplement users and non-users, a smaller proportion of nutritional supplement users had inadequate intakes of vitamin A (users: 23%, non-users: 28%), vitamin C (users: 7%, non-users: 11%), folate (users: 17%, non-users: 31%), calcium (users: 29%, non-users: 33%), iron (users: 33%, non-users: 44%) and zinc (users: 30%, non-users: 34%) (Walsh *et al*., 2006). Among children and adolescents (2-18y) in the US, from 'food sources only' a smaller proportion of nutritional supplement users compared to non-users had inadequate intakes of vitamin A (users: 17%, non-users: 31%), vitamin C (users: 13%, non-users: 21%), calcium (users: 38%, non-users: 50%) and magnesium (users: 29%, non-users: 37%) (Bailey *et al*., 2012). In the UK, from 'food sources only' a similar proportion of nutritional supplement users and non-users had intakes of vitamin A, C, D and B vitamins, calcium, iron, magnesium and zinc below the respective LRNIs (Bates *et al*., 2014). In Canadian children, from 'food sources only', a similar proportion of nutritional supplement users and non-users had inadequate intakes of vitamin A, C, D, B6, B12, folate, calcium, magnesium and zinc (Shakur *et al*., 2012).

The impact of nutritional supplements on micronutrient intakes

This review also aimed to assess the impact of nutritional supplements on micronutrient intakes in school-aged children among those who used nutritional supplements. **Table 4** presents mean micronutrient intakes in nutritional supplement users from 'food sources only' (excluding nutritional supplements) and from 'all sources' (including nutritional supplements) in children (2-14y) from national nutrition surveys in Belgium, Ireland, the Netherlands, Norway, the UK, the US and New Zealand. Overall, nutritional supplements were shown to increase mean intakes of vitamin A (by up to 181μg), vitamin D (by up to 4.3mg), vitamin C (by up to 25mg), thiamin (by up to 0.3mg), riboflavin (by up to 0.2mg), niacin (by 0.4mg), vitamin B6 (by up to 0.4mg) and vitamin B12 (by up to 0.8µg), however nutritional supplements made little impact on intakes of calcium (up to 14mg), iron (up to 0.6mg), magnesium (up to 8mg) and zinc (up to 0.6mg). The micronutrients for which low intakes were previously identified in children (vitamin D, folate, calcium, iron and zinc) are reviewed below in more detail to determine whether nutritional supplements could play a potential role in improving low intakes of these nutrients in this population group.

For vitamin D, mean intakes from 'all sources' ranged from 2.8-7.7µg/d and were higher than mean intakes from 'food sources only' that ranged from 1.5-3.4µg/d across all studies reviewed (New Zealand Ministry of Health, 2003, Hannon, 2006, Van Rossum *et al*., 2011, Bates *et al*., 2014, Rhodes *et al*., 2015, Hansen *et al*., 2016, Bel and De Ridder, 2018, Roberts *et al*., 2018). However, when vitamin D intakes from 'all sources' were compared to recommendations, intakes remained below established DRVs proposed by EFSA and the US IOM for children aged 2-14 years old (IOM, 2011, EFSA, 2015). Studies that reported the prevalence of inadequate intakes at population level such as in Ireland, the UK, the US and Canada found that the use of nutritional supplements reduced the prevalence of inadequate intakes of vitamin D in school-aged children (Walsh *et al*., 2006, Bailey *et al*., 2012, Shakur *et al*., 2012, Bates *et al*., 2014).

For folate, mean intakes from 'all sources' ranged from 174-249µg/d and were higher than mean intakes from 'food sources only' that ranged from 163-216µg/d across all studies (New Zealand Ministry of Health, 2003, Hannon, 2006, Van Rossum *et al*., 2011, Bates *et al*., 2014, Rhodes *et al*., 2015, Hansen *et al*., 2016, Bel and De Ridder, 2018, Roberts *et al*., 2018). Studies that reported the prevalence of inadequate intakes at population level such as in Ireland and the UK found that the use of nutritional supplements had little impact on the proportion of school-aged children with inadequate intakes of folate (Walsh *et al*., 2006, Barr *et al*., 2014).

For calcium, mean intakes from 'all sources' ranged from 716-1082mg/d and were similar to mean intakes from 'food sources only' that ranged from 716-1074mg/d across all studies (New Zealand Ministry of Health, 2003, Hannon, 2006, Van

Rossum *et al*., 2011, Bates *et al*., 2014, Rhodes *et al*., 2015, Hansen *et al*., 2016, Bel and De Ridder, 2018, Roberts *et al*., 2018). Studies that reported the prevalence of inadequate intakes at population level such as in Ireland, the UK, the US and Canada found that the use of nutritional supplements had little impact on the proportion of school-aged children with inadequate intakes of calcium (Walsh *et al*., 2006, Bailey *et al*., 2012, Shakur *et al*., 2012, Bates *et al*., 2014).

For iron, mean intakes from 'all sources' ranged from 7.0-14.8mg/d and were similar to mean intakes from 'food sources only' that ranged from 7.0-14.3mg/d across all studies (New Zealand Ministry of Health, 2003, Hannon, 2006, Van Rossum *et al*., 2011, Bates *et al*., 2014, Rhodes *et al*., 2015, Hansen *et al*., 2016, Bel and De Ridder, 2018, Roberts *et al*., 2018). Studies that reported the prevalence of inadequate intakes at population level such as in Ireland and the UK found that the use of nutritional supplements had little impact on the proportion of school-aged children with inadequate intakes of iron (Walsh *et al*., 2006, Bates *et al*., 2014).

For zinc mean intakes from 'all sources' ranged from 6.2-9.9mg/d and were similar to mean intakes from 'food sources only' 6.2-10.5mg/d across all studies (New Zealand Ministry of Health, 2003, Hannon, 2006, Van Rossum *et al*., 2011, Bates *et al*., 2014, Rhodes *et al*., 2015, Hansen *et al*., 2016, Bel and De Ridder, 2018, Roberts *et al*., 2018). Studies that reported the prevalence of inadequate intakes at population level such as in Ireland, the UK and Australia found that the use of nutritional supplements had little impact on the proportion of school-aged children with inadequate intakes of zinc (Walsh *et al*., 2006, Bates *et al*., 2014, Rangan *et al*., 2015).

These findings suggest that based on current practices, nutritional supplements may increase intakes and reduce the prevalence of inadequacy of vitamin D in school-aged children but would need to be used in combination with other dietary strategies to make any meaningful impact. In contrast, nutritional supplements had very little if any impact on the adequacy of folate, calcium, iron and zinc in school-aged children.

The impact of nutritional supplements on the risk of excessive micronutrient intakes

This review previously showed little risk of school-aged children having micronutrient intakes exceeding the UL, however, it is important to consider whether the use of nutritional supplements could impact on this. Overall, this review found that children across Europe were not reported to be at an additional risk of exceeding the UL for the micronutrients examined (vitamins A, D, E, C, niacin, vitamin B6, folic acid, calcium, iron, magnesium and zinc) as a result of nutritional supplement use (Hannon, 2006, Van Rossum *et al*., 2011, Bates *et al*., 2014, Hansen *et al*., 2016, Lopez-Sobaler *et al*., 2017, Bel and De Ridder, 2018). However, in Canada nutritional supplements were shown to increase the risk of excess vitamin A, niacin and zinc intakes in children aged 1-13 years and, in the US,, nutritional supplement use was shown to increase the risk of excess vitamin A, folic acid, iron and zinc intakes in children aged 2-18 years (Bailey *et al*., 2012, Shakur *et al*., 2012).

Conclusion

This review used data from national nutrition surveys of school-aged children across Europe, the US, Canada, Australia and New Zealand and found that intakes of vitamin D, folate, calcium, iron and zinc were low compared to recommendations. Across studies that examined dietary patterns, compliance with recommendations for dairy consumption was associated with higher calcium and zinc intakes while the consumption of fortified milks increased intakes and biochemical status of vitamin D. The consumption of 'RTEBCs' was associated with increased vitamin D, thiamin, riboflavin, niacin, vitamin B6, vitamin B12, folate, calcium and iron intakes. For most micronutrients (vitamins A, D, E, C, niacin, vitamin B6, calcium, iron and magnesium) intakes were below respective ULs with the exception of a small proportion of children in the Netherlands and the US with intakes of folic acid and zinc above the UL.

The use of nutritional supplements among children varied significantly across studies (from as low as 2% in Italy to as high as 63% in Norway) with multivitamin and/or mineral preparations being the most common types of nutritional supplements used followed by single vitamin D and C supplements. When examining micronutrient intakes from ‘food sources only’, the diet of nutritional supplement users was not any more or less nutrient-dense than that of non-users. Among nutritional supplement users, the inclusion of nutritional supplements in the diet increased intakes of vitamin A, D, E, C and B vitamins but had very little impact on mineral intakes. Furthermore, nutritional supplements did not significantly reduce the prevalence of inadequate intakes for any micronutrient examined with the exception of vitamin D. Nutritional supplements were not shown to increase the risk of excessive intakes of micronutrients in children across Europe, however nutritional supplements did increase the risk of intakes above the UL for some micronutrients in Canada and the US.

Overall, this review has found that based on current dietary practices nutritional supplements did not significantly reduce the prevalence of inadequate micronutrient intakes in school-aged children and did not significantly increase the risk of excess intakes. However, for vitamin D nutritional supplements increased intakes and made some reductions to the prevalence of inadequate intakes but would need to be used in combination with other dietary strategies to make any meaningful impact on intakes in school-aged children.

Table 1. Overview of the national nutrition surveys included in this review by the study year, age groups of participants and dietary assessment methodology

Country	Study name	Study year(s)	Age group	*n*	Dietary assessment methodology
Austria [a]	Austrian Nutrition Report	2010-12	7-14y	387	3-day food record
Belgium [b]	Belgium National Food Consumption Survey	2014-15	3-64y	3146	2 x 24hr recall
Cyprus [c]	Dietary Intake of Cypriot Children and Adolescents	2009-10	6-18y	1414	3-day food record
Denmark [d]	Danish National Survey of Diet	2011-13	4-75y	3946	7-day food record
Estonia [e]	Estonian National Dietary Survey	2013-14	0-74y	4906	24hr recall/food record
France [f]	Individual National Food Consumption Survey	2014-15	0-79y	5855	3-day food record
Ireland [g]	National Children's Food Survey	2004-05	5-12y	594	7-day food record
Italy [h]	Third Italian National Food Consumption Survey	2005-06	0-97y	3323	3-day food record
Norway [i]	UNGKOST 3	2015-16	4-13y	1721	4-day food record and FFQ
Portugal [j]	National Food and Physical Activity Survey	2015-16	0-84y	4221	2-day food record
Spain [k]	ANIBES Study	2013	9-75y	2285	3-day food record, 24hr recall
Sweden [l]	Riksmaten Barn	2003	4y, 8-12y	2495	4-day food record
The Netherlands [m]	Dutch National Food Consumption Survey	2012-16	7-69y	4313	Diet history
The UK [n]	National Diet and Nutrition Survey	2008-16	4-10y	500	4-day food record
Turkey [o]	Turkey Nutrition and Health Survey 2010	2010	0-100y	14248	24hr recall, FFQ and diet history
US [p]	National Health and Nutrition Examination Survey	2013-14	0-19y	8245	24hr recall
Canada [q]	Canadian Community Health Survey 2.0	2015	1+y	-	24hr recall
Australia [r]	The Australian Health Survey	2011-12	4-13y	-	24hr recall
New Zealand [s]	The National Children's Nutrition Survey	2002	5-14y	3275	24hr recall

[a] (Elmadfa *et al*., 2012) [b] (Bel and De Ridder, 2018) [c] (Tornaritis *et al*., 2014) [d] (Pedersen *et al*., 2015) [e] (Nurk *et al*., 2017) [f] (Dubuisson *et al*., 2019) [g] (Sette *et al*., 2013) [h] (Hannon, 2006) [i] (Hansen *et al*., 2016) [j] (Lopes *et al*., 2018) [k] (Barbieri *et al*., 2006) [l] (Lopez-Sobaler *et al*., 2017) [m] (Van Rossum *et al*., 2011) [n] (Roberts *et al*., 2018) [o] (Güler *et al*., 2014) [p] (Rhodes *et al*., 2015) [q] (Shakur *et al*., 2012) [r] (ABS, 2014) [s] (New Zealand Ministry of Health, 2003)
'-' Data not available

Table 2. Mean micronutrient intakes from national nutrition surveys of school-aged children (2-14y) across Europe, the US, Australia and New Zealand

Country	Dietary Source	Vitamin A µg	Vitamin D µg	Vitamin E mg	Vitamin C mg	Thiamin mg	Riboflavin mg	Niacin mg	Vitamin B6 mg	Vitamin B12 µg	Folate µg	Calcium mg	Iron mg	Magnesium mg	Zinc mg
Austria [a]	Food only	-	1.7	-	-	-	-	-	-	3.7	160	758	9.6	-	8.7
Cyprus [b]	Food only	923	-	-	91.8	1.4	1.9	-	1.8	-	-	923	11.1	-	-
Denmark [c]	Food only	1212	2.7	7.4	104	1.2	1.6	-	1.2	5.3	280	1010	8.9	287	9.3
Estonia [d]	Food only	837	3.0	7.5	82.5	0.9	1.0	22.5	1.2	5.1	166	795	10.5	249	8.0
France [e]	Food only	-	6.0	8.2	75.5	1.0	1.5	11.4	1.2	3.6	235	830	8.2	206	6.8
Italy [f]	Food only	740	2.0	10.4	107	0.9	1.4	-	1.7	5.7	-	749	9.4	230	9.9
Spain [g]	Food only	890	2.5	8.7	100	1.3	1.8	-	1.9	4.6	236	960	11.6	253	8.8
Turkey [h]	Food only	-	1.0	-	-	-	-	-	-	2.3	203	535	7.2	-	6.2
Australia [i]	Food only	498	-	8.3	90.3	1.7	1.9	-	1.1	3.7	238	798	9.6	247	8.8
Belgium [j]	All sources	-	7.6	-	80.3	0.9	1.3	-	1.4	4.1	190	716	7.8	-	-
Ireland [k]	All sources	830	3.1	7.3	101	1.7	2.0	-	2.2	4.6	235	871	9.7	196	6.7
Norway [l]	All sources	752	7.7	11.0	66.0	1.1	1.4	-	1.2	4.8	192	726	7.0	225	-
Portugal [m]	All sources	828	6.5	8.7	97.3	1.3	1.7	27.7	1.7	3.6	179	847	9.3	213	8.5
Sweden [n]	All sources	752	6.6	6.0	89.0	1.1	1.5	-	1.5	4.5	168	855	8	208	7.5
The Netherlands*	All sources	670	3.0	13.0	99.9	1.2	1.7	-	2.0	4.4	227°	948	9.6	276	9.4
The United Kingdom [p]	All sources	722	2.7	8.2	92.4	1.3	1.5	26.5	1.8	4.0	201	804	8.9	192	6.6
The United States [q]	All sources	-	7.4	-	89.9	1.7	2.2	-	2.1	5.5	249	1082	14.8	233	10.5
New Zealand [r]	All sources	655	-	8.1	115	1.6	1.9	-	1.4	3.6	249	767	11.3	241	9.9

[a] (Elmadfa *et al*., 2012) [b] (Tornaritis *et al*., 2014) [c] (Pedersen *et al*., 2015) [d] (Nurk *et al*., 2017) [e] (Dubuisson *et al*., 2019) [f] (Sette *et al*., 2013) [g] (Lopez-Sobaler *et al*., 2017) [h] (Güler *et al*., 2014) [i] (ABS, 2014) [j] (Bel and De Ridder, 2018) [k] (Hannon, 2006) [l] (Hansen *et al*., 2016) [m] (Lopes *et al*., 2018) [n] (Barbieri *et al*., 2006) [o] (Van Rossum *et al*., 2011) [p] (Bates *et al*., 2014) [q] (Rhodes *et al*., 2015) [r] (New Zealand Ministry of Health, 2003)

* Median intake °Dietary folate equivalents '-' Data not available

Table 3. Percentage (%) of nutritional supplement users and the types of supplements used from national nutrition surveys of children aged 2-14y across Europe, the US, Canada, Australia and New Zealand

Country	Age	%	Types
Belgium [a]	3-13y	38	Multivitamin/mineral (50%), vitamin D (18%), vitamin C (5%)
France [b]	3-14y	14	Unreported
Ireland [c]	5-12y	25	Multivitamins/minerals (44%), multivitamins (19%), fish/cod liver oils (14%), vitamin C (12%)
Italy [d]	3-9y	2	Multivitamin/minerals
Norway [e]	4-13y	63	Multivitamins/minerals (42%), cod liver oil (28%), single vitamin/mineral (9%), omega 3 (8%)
Portugal [f]	3-12y	6	Multivitamin (40%), vitamin (33%), mineral (7%)
Spain [g]	4-13y	4	Multivitamins/minerals, multivitamins, vitamin D, vitamin C, vitamin B-complex, iron, calcium
Sweden [h]	4y, 8-12y	34	Multivitamin preparations
The Netherlands [i]	7-13y	43	Multivitamins/minerals, vitamin C, vitamin D and fish oils
The United Kingdom [j]	4-10y	16	Multivitamins/minerals, fish oils (with cod liver oil)
The United States [k]	2-11y	36	Multivitamin, vitamin C, calcium
Canada [l]	4-13y	41	Multivitamin/minerals, multivitamins, single vitamin D and fish oils
Australia [m]	4-13y	13	Multivitamin/minerals (58%), vitamin C (27%), calcium (7%)
New Zealand [n]	5-14y	5	Multivitamin/minerals (40%), vitamin C (40%)

[a] (Bel and De Ridder, 2018) [b] (Dubuisson *et al*., 2019) [c] (Walsh *et al*., 2006) [d] (Sette *et al*., 2013) [e] (Hansen *et al*., 2016) [f] (Lopes *et al*., 2018) [g] (Lopez-Sobaler *et al*., 2017) [h] (Barbieri *et al*., 2006) [i] (Van Rossum *et al*., 2016) [j] (Bates *et al*., 2014) [k] (Bailey *et al*., 2012) [l] (Shakur *et al*., 2012) [m] (ABS, 2014) [n] (New Zealand Ministry of Health, 2003)

Table 4. Mean micronutrient intakes from national nutrition surveys of children aged 2-14y that reported intakes from 'food sources only' and 'all sources' across Europe, the US and New Zealand

	Belgium [a]		**Ireland** [b]		**Norway** [c]		**The Netherlands**[*] [d]		**The United Kingdom** [e]		**The United States** [f]		**New Zealand** [g]	
	Food	All	Food	All	Food	All	Food	All	Food	All	Food	All	Food	All
Vitamin A (μg)	-	-	649	830	633	752	556	670	651	722	649	-	-	655
Vitamin D (μg)	3.4	7.6	1.5	3.1	3.4	7.7	2.5	3.0	2.0	2.8	5.5	7.4	-	-
Vitamin E (mg)	-	-	5.7	7.3	7.0	11.0	12.1	13.0	7.1	8.2	7.8	-	8.0	8.1
Vitamin C (mg)	78.0	80.3	75.8	101	50.0	66.0	88.5	99.9	85.9	92.4	74.5	89.9	104	115
Thiamin (mg)	0.9	0.9	1.4	1.7	0.9	1.1	1.2	1.2	1.3	1.3	1.6	1.7	1.4	1.6
Riboflavin (mg)	1.3	1.3	1.8	2.0	1.3	1.4	1.5	1.7	1.5	1.5	2.0	2.2	1.7	1.9
Niacin (mg)	-	-	-	-	-	-	-	-	26.1	26.5	-	-	-	-
Vitamin B6 (mg)	1.3	1.4	1.9	2.2	0.9	1.2	1.8	2.0	1.7	1.8	1.7	2.1	1.2	1.4
Vitamin B12 (μg)	3.9	4.1	4.3	4.6	4.6	4.8	3.7	4.4	3.9	4.0	4.7	5.5	3.3	3.6
Total Folate (μg)	180	190	216	235	163	192	203	227	170	174	214	249	-	249
Calcium (mg)	716	716	857	871	721	726	941	948	803	804	1074	1082	767	767
Iron (mg)	7.6	7.8	9.1	9.7	7.0	7.0	9.0	9.6	8.7	8.9	14.3	14.8	11.3	11.3
Magnesium (mg)	-	-	194	196	225	233	272	276	192	192	233	233	241	241
Zinc (mg)	-	-	6.5	6.7	-	-	9.0	9.4	6.2	6.6	9.9	10.5	9.9	9.9

[a] (Bel and De Ridder, 2018) [b] (Hannon, 2006) [c] (Hansen *et al.*, 2016) [d] (Van Rossum *et al.*, 2016) [e] (Bates *et al.*, 2014, Roberts *et al.*, 2018) [f] (Rhodes *et al.*, 2015) [g] (Ministry of Health, 2003)
[*] Median intake '-' Data not available

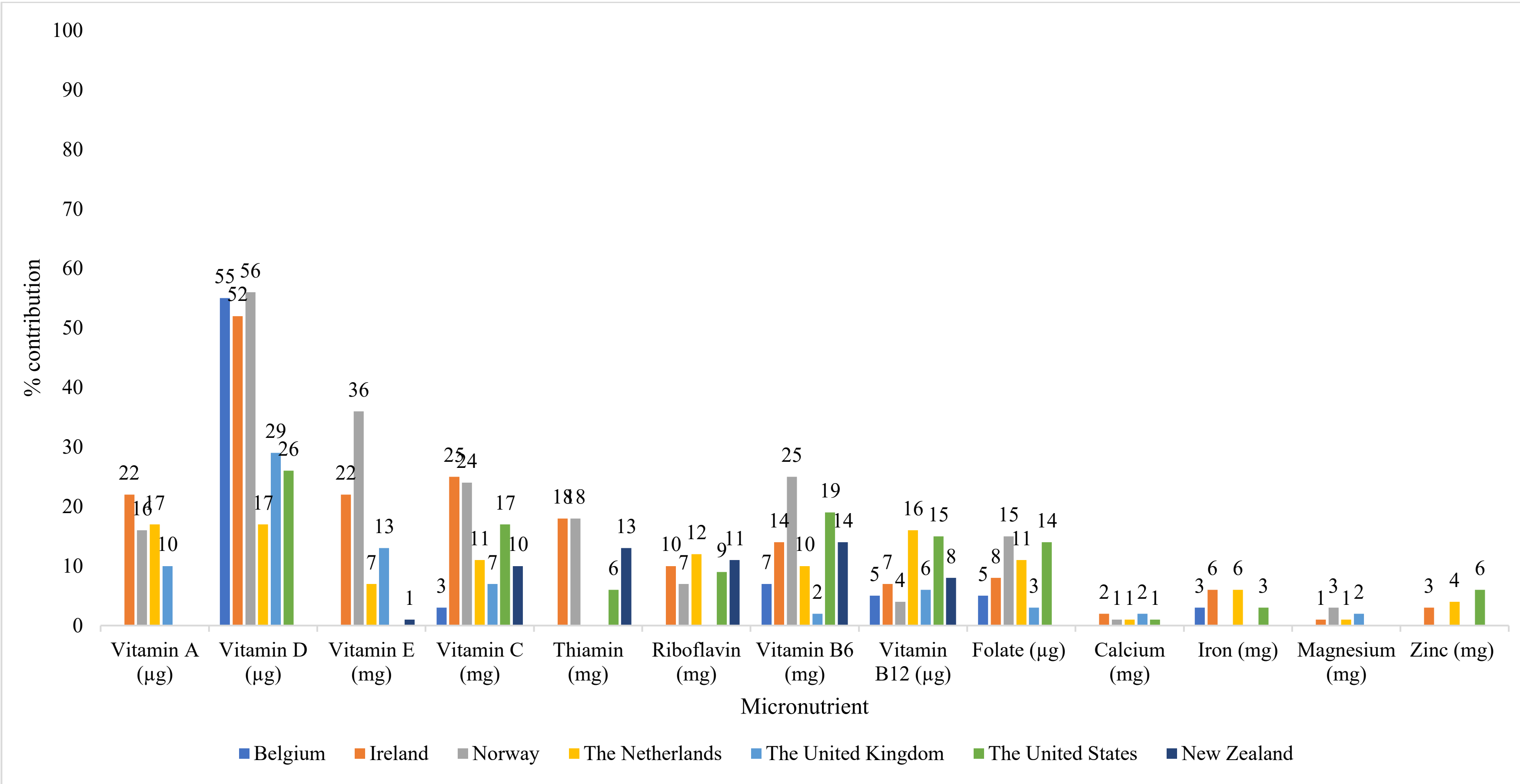

Figure 1. Percent (%) contribution of nutritional supplements to mean micronutrient intakes in the total population from national nutrition surveys of children aged 2-14years across Europe, the US, Australia and New Zealand

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Aims & objectives

The overall aim of this thesis was to examine micronutrient intakes, adequacy and risk of excess intakes in school-aged children (5-12y) in Ireland and also to determine the role of nutritional supplements in the diet of this population group. This research used data from the National Children's Food Survey II (NCFS II) (2017-18), a nationally representative dietary survey of school-aged children (5-12y) (*n* 600) in Ireland carried out by the Irish Universities Nutrition Alliance (www.iuna.net).

Objectives:

1. To estimate usual micronutrient intakes, the prevalence of inadequate intakes and the risk of excessive intakes in school-aged children in Ireland.
2. To identify the key sources and dietary determinants of vitamin D and folate intakes in school-aged children in Ireland.
3. To develop a database of the dietary supplements currently being used by school-aged children in Ireland (NCFS II Dietary Supplement Database 2017-18).
4. To investigate nutritional supplement use and to examine the impact of nutritional supplements on micronutrient intakes, adequacy and risk of excessive intakes in school-aged children in Ireland.

Chapter 2

Methodology of the National Children's Food Survey II (2017-18)

Methodology

Analyses for the present study were based on data from the National Children's Food Survey II (NCFS II) (2017-18). The NCFS II (2017-18) was a nationally representative cross-sectional study that collected food and beverage consumption data in 600 school-aged children (5-12y) in the Republic of Ireland between April 2017 and May 2018. This study was carried out by the Irish Universities Nutrition Alliance (IUNA) research teams in University College Cork, Cork Institute of Technology, University College Dublin (UCD) and Technological University Dublin. The methods relevant to this thesis are outlined below with further information available on www.iuna.net.

Ethical approval

The NCFS II (2017-18) was conducted according to the guidelines laid down in the Declaration of Helsinki. Ethical approval was obtained from the Clinical Research Ethics Committee of the Cork Teaching Hospitals and the Humans Ethics Research Committee of UCD (Ref: ECM 4 (aa) 07/02/17). Written informed consent was obtained from all participants and parents/guardians prior to participation in the survey.

Sampling and recruitment

Eligible participants were children aged between 5 and 12 years, inclusive. A total sample of 600 participants (300 boys and 300 girls) were selected from primary schools in the Republic of Ireland using a database provided by the Department of Education and Skills. This database included a total of 3124 schools which were categorised according to:

a) size of the school ('large' >500 pupils, 'medium' = 200-499 pupils or 'small' <200 pupils)

b) sex attending the school ('all boys', 'all girls' or 'mixed')

c) whether disadvantaged or not disadvantaged

d) location (urban or rural)

Participating schools were randomly selected so that the final sample of children surveyed was representative of school-aged children in Ireland with respect to the proportion of children attending these categories of schools according to the database. This survey sample size follows the European Food Safety Authority (EFSA) guidance of a minimum of 160 children per sub-group (EFSA, 2014) and was deemed enough to describe frequency distribution of outcomes and to compare means for subgroups (e.g., based on age, sex etc).

An introductory letter with information about the survey was sent to the principal of selected schools followed by a phone call from the survey's recruitment coordinator with 80% of schools contacted agreeing to take part. If the principal agreed to the participation of their school, a suitable date and time was arranged for a researcher to visit the school. Upon the researcher's visit, information packs about the survey were provided to the school principal as well as instructions on how to distribute them to randomly selected children using the school roll. The randomly selected children were given an information pack consisting of an introductory letter, information brochure and a reply slip to bring home to their parents/guardians. If the selected children and their parents/guardians were interested in participating in the survey or finding out more information about participating in the survey, they were instructed to fill out the reply slip and return it to the school where it was collected by a researcher.

Children who returned a reply slip were excluded if they were not between the ages of 5 and 12 years, if they belonged to an age-group, sex or urban/rural location for which the appropriate number of children had already been recruited, or if another member of their household had already been recruited for participation in the survey. A researcher contacted the parents/guardians of all eligible children who returned a reply slip and if they agreed to participate in the survey, a suitable date and time for a researcher to visit their home was arranged. During this visit, the researcher explained the survey in more detail and obtained written consent from both parents/guardians and the child. All researchers were qualified nutritionists. The overall response rate for the survey was 65%. Demographic analysis of the sample has shown it to be representative of children in Ireland with respect to age-group, sex and urban/rural location when compared to Census 2016 data (CSO, 2017). However, the final sample contained a higher proportion of children of professional workers and a lower proportion of children of semi-skilled and unskilled workers than the national population. To account for this all nutrient intake, adequacy and risk of excess data, nutritional supplement use, dietary sources and dietary determinants data in this thesis have been weighted.

Food intake data collection

Food, beverage and nutritional supplement intake data were collected using a 4-day weighed food record. For all participants, the study period included at least one weekend day. Participants were provided with a food diary and a digital food scales and asked to record detailed information regarding the amount, type and brand of all foods, beverages and nutritional supplements consumed, as well as the amount of any leftovers. The cooking method, the packaging size and type, and recipe details were also recorded. Additionally, data were collected on the time of each eating or drinking occasion, the participant's definition of each eating or drinking occasion (e.g., morning snack, lunch) and the location of preparation of the meal or snack (e.g. home, school, childminder). Participants were also provided with a packaging bag and asked to keep any packaging and labelling information of any foods, beverages or nutritional supplements consumed. This packaging was photographed and stored to facilitate the updating of the Irish food composition databases. Researchers made three visits to the participant's home over the survey period: an initial training visit to demonstrate how to complete the food diary and use the weighing scales; a second visit 24-36 hours into the recording period to review the diary and clarify details regarding specific food descriptors and quantities; and a final visit one or two days after the recording period had ended to review the last days and collect the food diary.

Quantification

A quantification protocol that had been established by the IUNA for the North/South Ireland Food Consumption Survey (Harrington *et al*., 2001) and is available at www.iuna.net was adapted for the NCFS II (2017-18). It is summarised as follows:

(1) Weighed (by participant/manufacturer's weights) - A portable food scales (Tanita KD400, Japan) were provided to each participant. Researchers provided detailed instructions (including a demonstration) on how to use the scales. This method was used to quantify 76% of foods and drinks consumed. A further 11% of foods were quantified using manufacturer's weights. To facilitate collection of such data, participants were provided with a storage bag and asked to retain packaging from food and beverages consumed throughout the recording period.

(2) Food atlas - An age appropriate photographic food atlas (Foster *et al*., 2010) was used to quantify 7% of foods and beverages consumed.

(3) Food portion sizes – 'The Irish Food Portion Sizes Database' (Lyons and Giltinan, 2013) and 'Food Portion Sizes' (Ministry of Agriculture Fisheries and Food, 1997) were used to quantify 3% of foods and beverages consumed.

(4) Household measures – Household measures (e.g., teaspoon, tablespoon, pint) were used to quantify 1% of foods and beverages consumed.

(5) Estimated - Food quantities were defined as estimated when the researcher made an estimate of the amount likely to have been consumed based on their knowledge of the participant's eating habits as observed during the recording period. This quantification method was used for 2% of foods and beverages consumed.

Nutrient composition of foods

Nutritics© software was used to estimate nutrient intakes from food intakes using data from McCance and Widdowson's The Composition of Foods, 7th edition and 6th edition (for a small number of foods) (FSA, 2002, FSA, 2015). During the survey, modifications were made to include recipes of composite dishes, nutritional supplements, fortified foods and generic Irish foods that were commonly consumed.

Quality control

Quality procedures were put in place to minimise error and ensure consistency throughout the collection and manipulation of the data. Researchers received training that included role-play workshops prior to commencing fieldwork, where they were trained to take a natural and friendly approach to fieldwork and to avoid prompting foods. It was important that researchers did not prompt or show bias towards any foods to avoid influencing the participant's diet and every day eating habits in any way. For example, researchers were trained to ask, 'did you have any snacks' rather than 'did you have fruit for as a snack?' and 'did you have anything to eat or drink before school?' rather than 'did you have any breakfast?'. Researchers also used the participant's household foods to carry out training demonstrations or asked the participant to provide an example to avoid suggesting foods. This was carried out to make participants feel at ease and so to ensure that the most reliable data possible could be obtained. It was stressed to participants that they should not try to change or 'improve' their diet during the recording period. At the end of the recording period, participants and their parents/guardians were asked whether the child's food intake had been the same as usual, less than usual or more than usual during the recording period and to explain why this might have been. They were also asked if there were any items consumed during the 4-day recording period which had not yet been written down. If so, details on such items were then recorded by the researcher in the food diary. Each researcher was primarily responsible for the collection, quantification, coding and data entry of their own participants' food diaries. The researcher quantified their diaries using the IUNA quantification protocol as outlined above and coded them in line with the project's standard operating procedures before entering the food and drink consumption data into Nutritics using the corresponding food code and brand code. The researcher checked and checked again that all data were entered correctly. Once all food diaries were quantified, coded and entered into Nutritics, a different researcher was assigned a proportion of another researcher's food diaries (10%) to check for accuracy and completeness. These measures helped to avoid any individual variation among researchers. Researchers were also asked to rate each participants food diary as 'accurate and complete', 'inaccurate and complete', 'accurate and incomplete' and 'inaccurate and incomplete' so that data quality could be considered during certain analyses.

Defining under-reporters of energy (food) intake

Energy under reporters (19.5%) were identified by evaluating reported energy intake (as a ratio of energy intake to basal metabolic rate (EI:BMR)) against presumed age-specific energy cut offs calculated on the basis of reported levels of physical activity (Goldberg, 1991, Black, 2000). Mean energy intake to basal metabolic rate (BMR) ratio was determined for each child and age specific cut offs were calculated based on different categories of physical activity. Age specific PAL values for low, moderate, active, very active and highly active physical activity (EFSA Panel on Dietetic Products Nutrition and Allergies, 2013) were applied to the equations to establish misreporting of EI for individuals. Basal metabolic rate (BMR) was predicted for each participant from the Schofield equations using body weight and height measurements (Schofield, 1985). Physical activity was self-reported with the international physical activity questionnaire (CPAQ/YPAQ). Energy under reporting was taken into account for certain analyses (e.g., in estimating the prevalence of inadequate micronutrient intakes).

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Chapter 3

Micronutrient intakes, adequacy, and risk of excess in school-aged (5-12y) children in Ireland

Introduction:

Childhood is a period of rapid growth, acquisition of bone mass and cognitive and behavioural development (Serra-Majem *et al*., 2006). Micronutrients play an important role in achieving optimal health across all life stages including childhood by contributing to a wide range of critical functions in the body. Low intakes of micronutrients such as vitamin D, calcium and magnesium in children can increase the risk of rickets and abnormal growth and may lead to osteoporosis and fractures in later life (IOM, 1997). Low intakes of iron may lead to iron deficiency anaemia and health implications such as poor cognitive and behavioural performance (Halterman *et al*., 2001). In addition, vitamins A and C are required for growth, the integrity of cells and the repair of body tissues (IOM, 2000, IOM, 2001) and low intakes of B vitamins such as vitamin B12 and folate can compromise growth as a result of impaired DNA synthesis and cell division (IOM, 1998).

A review of the literature has highlighted low intakes of some key micronutrients (vitamin D, folate, calcium, iron and zinc) in children across Europe, the United States (US), Canada, Australia and New Zealand (Chapter 1). Inadequate micronutrient intakes, as indicated by the proportion of children with intakes below established cut-points were observed for vitamin D (90-100% of children in Ireland, Spain, Sweden, the United Kingdom (UK) and Canada), folate (14% in Ireland and 28% in the UK), calcium (17-74% of children in Belgium, Ireland, Spain, the UK and Canada), iron (16-44% of children in Belgium, Ireland and Spain) and zinc (15-29% of children in Ireland, Spain, the Netherlands, the UK and the US) (Barbieri *et al*., 2006, Hannon *et al*., 2006, Van Rossum *et al*., 2011, Bailey *et al*., 2012, Shakur *et al*., 2012, Bates *et al*., 2014, Lopez-Sobaler *et al*., 2017, Bel and De Ridder, 2018). Nationally representative data on vitamin D status in children has shown that, 6% of 4-10 year old children in the UK, 5.4% of 6-79 year olds in Canada and less than 2% of children aged 6-11 years in the US had levels considered to be deficient (Whiting *et al*., 2011, Bates *et al*., 2014, Herrick *et al*., 2019). Furthermore, 12% of 6-11 year olds in the US and 26% of 6-79 year olds in Canada were considered to be at risk of vitamin D inadequacy (Whiting *et al*., 2011, Herrick *et al*., 2019). In the UK nationally representative data on folate status in children has shown that less than 3% of 4-10 year old children had a serum total folate <10nmol/L indicating possible deficiency, and less than 4% had RBC folate <340nmol/L indicating risk of anaemia (Bates *et al*., 2014). For iron, data from the UK has also shown that 3% of children had a haemoglobin concentration indicative of anaemia and 9% had plasma ferritin concentration indicative of low iron stores with 1% of children having evidence of iron deficiency anaemia (Bates *et al*., 2014).

While ensuring optimal intakes of micronutrients in children is important, it is also important to consider that nutrients may have adverse effects if consumed in excessive amounts i.e., above the tolerable upper level of intake (UL) (Flynn *et al*., 2009). The UL is defined as the maximum level of total chronic daily intake of a nutrient (from all sources) judged to be unlikely to pose a risk of adverse health effects to individuals (EFSA, 2006). Although few studies across Europe and internationally reported on the proportion of children with micronutrient intakes greater than the UL, where data were available there was no risk of adverse effects from excess intakes of most micronutrients (Hannon, 2006, Shakur *et al*., 2012, Bates *et al*., 2014, Pedersen *et al*., 2015, Lopez-Sobaler *et al*., 2017, Bel and De Ridder, 2018). However, a small proportion (<5%) of children had intakes of zinc (the Netherlands and the US) and folic acid (US) greater than the UL (Van Rossum *et al*., 2011, Bailey *et al*., 2012).

New data on dietary intakes in school-aged (5-12y) children in Ireland have recently become available from the National Children's Food Survey II (NCFS II) (2017-18). The aim of this chapter is to estimate micronutrient intakes, the prevalence of inadequate intakes and the risk of excessive intakes in school-aged children in Ireland.

Methodology

The analyses for this chapter are based on data from the NCFS II (2017-18). A detailed survey methodology for NCFS II including sampling and recruitment, data collection, food quantification and nutrient composition is described in Chapter 2. The methods relating to this chapter are outlined below.

Food intake data collection

Food, beverage and nutritional supplement intake data were collected using a 4-day weighed food record. For all participants, the study period included at least one weekend day. A trained researcher visited each participant in their home three times over the recording period to demonstrate how to keep the food diary, use the portable food scales that were provided, and review the diary to check for completeness. Participants were asked to record detailed information regarding the amount, type and brand of all foods, beverages and nutritional supplements consumed, as well as the amount of any leftovers. The cooking method, the packaging size and type, and recipe details were also recorded. To facilitate the collection of such data, the participants were asked to provide nutrition labels from foods, beverages and nutritional supplements consumed over the recording period. If the nutrition labels were not available, the researcher recorded the full name of the product (at brand level) and found the product in the relevant retail outlet (supermarket/pharmacy) and photographed the details from there.

Estimation of micronutrient intakes

Micronutrient intakes from food and beverages were estimated using data from McCance and Widdowson's The Composition of Foods, 7th edition and 6th edition (for a small number of foods) (FSA, 2002, FSA, 2015) and the Irish Food Composition Database (IFCD) (2018) (Black *et al*., 2011). The IFCD (2018) supplements the UK food composition data used and includes recipes of composite dishes, fortified foods, generic Irish foods and new foods on the market.

Additionally, the food composition database has been updated with values for vitamin D as the Composition of Foods does not contain vitamin D values for some potentially important sources such as milk, fish, meat and mushrooms; hence, vitamin D values from other food composition databases were included. Data from the US Department of Agriculture National Nutrient Database for Standard Reference – Release 28 (USDA, 2009) and the Danish Frida Food Data composition database version 4 (2019) were used to update these values (Technical University of Denmark, 2007).

Vitamin A was calculated as retinol equivalents i.e., retinol plus (carotene/6). Total folate intake was estimated using the methods described above. To estimate folic acid intake, fortified foods and nutritional supplements containing folic acid were identified using the ingredients list on the label at the time of the survey. The folic acid composition of fortified foods and nutritional supplements was established from the food packaging labels or obtained directly from the manufacturer. To account for the lower bioavailability of natural food folates compared to synthetic folic acid, dietary folate equivalents (DFE) were estimated using the following equation: 1µg DFE = 1µg food folate + (1.7*Folic Acid).

Micronutrient intakes (mean, SD, median, IQR) were estimated via the validated National Cancer Institute (NCI)-Method (Tooze *et al*., 2010) using SAS Enterprise Guide© version 6.1 (SAS Institute Inc., Cary, NC, USA). The NCI-Method has been implemented in SAS macros (version 2.1) which were downloaded from the website www.riskfactor.gov/diet/usualintakes/macro.html (date of download: July 2015). Using these macros, distributions of usual intakes were estimated for micronutrients for the total population and stratified by sex and age groups (5-8y and 9-12y).

Adequacy of micronutrient intakes

The prevalence of inadequate micronutrient intakes was estimated using estimated average requirements (EARs) as cut-off points. This method has been shown to be effective in obtaining a realistic estimate of the prevalence of dietary inadequacy (Carriquiry, 1999). EARs as established by the European Food Safety Authority (EFSA) (EFSA, 2017) were used as cut-offs for assessing the prevalence of inadequate intakes for vitamin A, vitamin C, riboflavin, total niacin equivalents (preformed niacin and potential niacin), vitamin B6, DFE, calcium, iron and zinc. The UK Department of Health (DOH) EARs were used as cut-offs for vitamin B12 and magnesium (UK DOH, 1991) and the US Institute of Medicine (IOM) EAR was used as a cut-off for vitamin D (IOM, 2011).

As under-reporting of food consumption can result in an overestimate of the prevalence of inadequacy in a population group (Carriquiry, 1999), under-reporters were identified and excluded from analysis when assessing nutrient adequacy. Under-reporting was investigated using Goldberg's cut-off 2 criterion (Goldberg, 1991) updated by Black (Black, 2000). In the total population 19.5% (n=117) were identified as under-reporters.

Risk of excessive intakes of micronutrients

The risk of excessive intake of micronutrients was evaluated using the tolerable upper intake level (UL) as a reference value. ULs are defined as the maximum level of total chronic daily intake of a nutrient (from all sources) judged to be unlikely to pose a risk of adverse health effects in humans (EFSA, 2006). For nutrients with established ULs, the proportion of children with usual intakes exceeding the UL was calculated. ULs have been derived by EFSA/EU Scientific Committee for vitamin A (retinol), vitamin D, vitamin E, pre-formed niacin, vitamin B6, folic acid, calcium and zinc (EFSA, 2017) and by the US IOM Food and Nutrition Board for vitamin C and iron (IOM, 2000, IOM, 2001). The UL established for magnesium applies to magnesium salts (e.g., chloride, sulphate, aspartate and lactate) and compounds often found in nutritional supplements and does not include magnesium naturally present in foods and beverages.

Statistical analyses

Statistical analyses were carried out using SPSS© for windows™ Version 26.0 (SPSS, Inc., IBM, Chicago, IL, USA). Differences in micronutrient intakes between sex and age-groups were assessed using independent sample T-tests regardless of normality (due to the large sample size). As sample size increases so does the robustness of t-tests to identify deviations from normality, thus parametric tests are recommended for large samples (Fagerland, 2012). To minimise type 1 errors (as a result of multiple testing), the Bonferoni adjustment was used by dividing the alpha level (0.05) by the number of comparisons. Therefore, intakes were considered significantly different from each other if $P<0.01$. Also due to the large sample in this study, even a small difference between group means was highly statistically significant. Thus, greater emphasis was placed on a descriptive, rather than a formal statistical analysis of the data. The difference in the prevalence of inadequate intakes and the risk of excessive intakes across sex and age-groups (5-8y and 9-12y) were assessed using a Chi-square test.

Results:

Vitamin A

The mean intake of vitamin A was 666µg/d with significantly higher intakes in boys compared to girls (boys: 702µg/d, girls: 632µg/d) **(Table 1)**. Vitamin A intakes were similar in children aged 9-12y (673µg/d) and children aged 5-8y (659µg/d) **(Table 2)**. The mean intakes of retinol and carotene were 292µg/d and 2397µg/d, respectively. The proportion of children with intakes below the EAR for vitamin A was 9% (boys: 8%, girls: 10%) **(Table 5)**. The proportion of children with retinol intakes greater than the UL was 0% **(Table 7)**.

Vitamin D

The mean intake of vitamin D was 4.2µg/d with similar intakes in boys and girls (boys: 4.4µg/d, girls: 4.1µg/d) **(Table 1)**. Vitamin D intakes were similar in children aged 9-12y (4.4µg/d) and children aged 5-8y (4.1µg/d) **(Table 2)**. The proportion of children with intakes below the EAR for vitamin D was 94% (boys: 94%, girls: 94%) **(Table 5)**. The proportion of children with intakes greater than the UL for vitamin D was 0% **(Table 7)**.

Vitamin E

The mean intake of vitamin E was 6.9mg/d with significantly higher intakes in boys compared to girls (boys: 7.3mg/d, girls: 6.5mg/d) **(Table 1)**. Vitamin E intakes were significantly higher in children aged 9-12y (7.2mg/d) compared to children aged 5-8y (6.7mg/d) **(Table 2)**. Mean intakes were compared to the adequate intake (AI) set by EFSA for vitamin E (5-9y: 9mg/d, 10-12y girls: 11mg/d and 10-12y boys: 13mg/d) and found to be above the AI for all groups examined. The proportion of children with intakes greater than the UL was 0% **(Table 7)**.

Vitamin C

The mean intake of vitamin C was 73.1mg/d with similar intakes in boys and girls (boys: 74.0mg/d, girls: 72.3mg/d) **(Table 1)**. Vitamin C intakes were similar in children aged 9-12y (73.6mg/d) and children aged 5-8y (72.7mg/d) **(Table 2)**. The proportion of children with intakes below the EAR was 19% (boys: 19%, girls:

19%) **(Table 5)**. The proportion of children with intakes greater than the UL was 0% **(Table 7)**.

Thiamin

The mean intake of thiamin was 1.4mg/d with significantly higher intakes in boys compared to girls (boys: 1.5mg/d, girls: 1.3mg/d) **(Table 1)**. Thiamin intakes were significantly higher in children aged 9-12y (1.5mg/d) compared to children aged 5-8y (1.3mg/d) **(Table 2)**. The proportion of children with intakes below the EAR was 0% **(Table 5)**.

Riboflavin

The mean intake of riboflavin was 1.6mg/d with significantly higher intakes in boys compared to girls (boys: 1.8mg/d, girls: 1.4mg/d) **(Table 1)**. Riboflavin intakes were similar in children aged 9-12y (1.6mg/d) and children aged 5-8y (1.6mg/d) **(Table 2)**. The proportion of children with intakes below the EAR was 5% (boys: 2%, girls: 8%) **(Table 5)**.

Niacin

The mean intakes of total niacin equivalents (NE) (pre-formed niacin and potential niacin) were 28.8mg/d with significantly higher intakes in boys compared to girls (boys: 31.6mg/d, girls: 26.3mg/d) **(Table 1)**. Total niacin intakes were significantly higher in children aged 9-12y (30.9mg/d) compared to children aged 5-8y (26.9mg/d) **(Table 2)**. The mean intake of preformed niacin and potential niacin was 17.2mg/d and 11.7mg/d, respectively. The proportion of children with intakes below the EAR was 0% **(Table 5)**. The proportion of children with preformed niacin intakes greater than the UL was 0% **(Table 7)**.

Vitamin B6

The mean intake of vitamin B6 was 1.5mg/d with significantly higher intakes in boys compared to girls (boys: 1.7mg/d, girls: 1.4mg/d) **(Table 1)**. Vitamin B6 intakes were similar in children aged 9-12y (1.6mg/d) and children aged 5-8y (1.5mg/d) **(Table 2)**. The proportion of children with intakes below the EAR was 8% (boys: 4%, girls: 12%) **(Table 5)**. The proportion of children with intakes greater than the UL was 0% **(Table 7)**.

Vitamin B12

The mean intake of vitamin B12 was 4.6µg/d with significantly higher intakes in boys compared to girls (boys: 5.1µg/d, girls 4.2µg/d) **(Table 1)**. Vitamin B12 intakes were similar in children aged 9-12y (4.7µg/d) and children aged 5-8y (4.6µg/d) **(Table 2)**. The proportion of children with intakes below the EAR was 0% **(Table 5)**.

Folate

The mean intake of total folate was 211µg/d with significantly higher intakes in boys compared to girls (boys: 229µg/d, girls: 194µg/d) **(Table 1)**. Folate intakes were significantly higher in children aged 9-12y (216µg/d) compared to children aged 5-8y (205µg/d) **(Table 2)**. The mean intake of dietary folate equivalents (DFE) was 248µg/d with 66µg/d coming from folic acid **(Table 1)**. The proportion of children with DFE intakes below the EAR was 13% (boys: 8%, girls: 17%) **(Table 5)**. The proportion of children with folic acid intakes greater than the UL was 0% **(Table 7)**.

Calcium

The mean intake of calcium was 791mg/d with significantly higher intakes in boys compared to girls (boys: 871mg/d, girls: 717mg/d) **(Table 3)**. Calcium intakes were significantly higher in children aged 9-12y (804mg/d) compared to children aged 5-8y (778mg/d) **(Table 4)**. The proportion of children with intakes below the EAR was 37% (boys: 25%, girls: 49%) **(Table 6)**. The proportion of children with intakes greater than the UL was 0% **(Table 8)**.

Iron

The mean intake of iron was 9.0mg/d with significantly higher intakes in boys compared to girls (boys: 9.7mg/d, girls: 8.3mg/d) **(Table 3)**. Iron intakes were significantly higher in children aged 9-12y (9.5mg/d) compared to children aged 5-8y (8.5mg/d) **(Table 4)**. The proportion of children with intakes below the EAR was 20% (boys: 13%, girls: 26%) **(Table 6)**. The proportion of children with intakes greater than the UL was 0% **(Table 8)**.

Magnesium

The mean intake of magnesium was 194mg/d with significantly higher intakes in boys compared to girls (boys: 211mg/d, girls: 178mg/d) **(Table 3)**. Magnesium intakes were significantly higher in children aged 9-12y (206mg/d) compared to children aged 5-8y (180mg/d) **(Table 4)**. The proportion of children with intakes below the EAR was 18% (boys: 12%, girls: 24%) **(Table 6)**. The proportion of children with intakes greater than the UL was 0% **(Table 8)**.

Zinc

The mean intake of zinc was 7.3mg/d with significantly higher intakes reported in boys compared to girls (boys: 8.0mg/d, girls: 6.7mg/d) **(Table 3)**. Zinc intakes were significantly higher in children aged 9-12y (7.7mg/d) compared to children aged 5-8y (7.0mg/d) **(Table 4)**. The proportion of children with intakes below the EAR was 29% (boys: 18%, girls: 38%) **(Table 6)**. The proportion of children with intakes greater than the UL was 2% **(Table 8)**.

Energy adjusted intakes

When intakes were adjusted for energy (per 10MJ), the nutrient density of the diet was similar between sex and age-group indicating that higher intakes were due to boys consuming more food and beverages than girls (boys: 1583±280kcal, girls: 1398±238kcal) and older (9-12y) children consuming more food and beverages than younger (5-8y) children (9-12y: 1600±270kcal, 5-8y: 1380±234kcal).

Table 1. Usual intakes of selected vitamins in school-aged (5-12y) children in Ireland (*n* 600) by sex

	All (*n* 600)		Boys (*n* 300)		Girls (*n* 300)	
	Mean ± SD	Median (IQR)	Mean ± SD	Median (IQR)	Mean ± SD	Median (IQR)
Vitamin A (µg)	666 ± 307	613 (445-825)	702 ± 319	649 (473-871)	632 ± 291†	582 (426-782)
Retinol (µg)	292 ± 146	268 (186-371)	317 ± 152	294 (206-401)	269 ± 136†	246 (171-341)
Carotene (µg)	2397 ± 1828	1920 (1199-3022)	2405 ± 1837	1926 (1196-3045)	2390 ± 1820	1913 (1203-3007)
Vitamin D (µg)	4.2 ± 3.1	3.5 (2.1-5.5)	4.4 ± 3.1	3.7 (2.2-5.8)	4.1 ± 3.0†	3.3 (2.0-5.3)
Vitamin E (mg)	6.9 ± 2.9	6.5 (4.8-8.5)	7.3 ± 3.1	6.9 (5.1-9.0)	6.5 ± 2.7†	6.1 (4.6-8.0)
Vitamin C (mg)	73.1 ± 42.3	64.8 (42.6-93.8)	74.0 ± 42.7	65.7 (43.0-95.1)	72.3 ± 41.8	63.8 (42.4-92.5)
Thiamin (mg)	1.4 ± 0.4	1.4 (1.1-1.7)	1.5 ± 0.4	1.5 (1.2-1.8)	1.3 ± 0.4†	1.3 (1.0-1.5)
Riboflavin (mg)	1.6 ± 0.6	1.5 (1.2-1.9)	1.8 ± 0.6	1.7 (1.4-2.1)	1.4 ± 0.5†	1.4 (1.1-1.7)
Total Niacin (mg)	28.8 ± 7.5	28.0 (23.5-33.3)	31.6 ± 7.8	30.8 (25.9-36.4)	26.3 ± 6.1†	25.8 (22.0-30.0)
Preformed Niacin equivalents (mg)	17.2 ± 5.1	16.5 (13.4-20.2)	18.8 ± 5.4	18.2 (14.9-22.0)	15.7 ± 4.4†	15.2 (12.5-18.2)
Potential Niacin (mg)	11.7 ± 2.9	11.4 (9.6-13.4)	12.8 ± 3.1	12.5 (10.5-14.7)	10.7 ± 2.4†	10.5 (9.0-12.2)
Vitamin B6 (mg)	1.5 ± 0.5	1.4 (1.1-1.8)	1.7 ± 0.6	1.6 (1.3-2.0)	1.4 ± 0.5†	1.3 (1.0-1.6)
Vitamin B12 (µg)	4.6 ± 1.8	4.4 (3.3-5.7)	5.1 ± 1.9	4.9 (3.8-6.3)	4.2 ± 1.6†	4.0 (3.0-5.1)
Total Folate (µg)	210 ± 65.3	203 (164-250)	229 ± 67.1	222 (181-269)	194 ± 58.9†	188 (152-229)
Dietary Folate Equivalents (µg)	253 ± 96.6	238 (183-306)	276 ± 101	263 (203-333)	231 ± 87.0†	219 (169-280)
Folic Acid (µg)	60.1 ± 64.5	44.4 (14.4-82.4)	64.0 ± 68.5	49.9 (15.6-88.2)	56.0 ± 59.8†	41.5 (13.4-74.0)

† Statistically different (P<0.01) from that of boys within the rows via independent sample T-tests and adjusted for multiple testing

Table 2. Usual intakes of selected vitamins in school-aged (5-12y) children in Ireland (*n* 600) by age-group

	5-8y (*n* 300)		9-12y (*n* 300)	
	Mean ± SD	Median (IQR)	Mean ± SD	Median (IQR)
Vitamin A (µg)	659 ± 303	607 (439-819)	673 ± 310	619 (453-831)
Retinol (µg)	291 ± 144	268 (185-370)	292 ± 148	267 (186-371)
Carotene (µg)	2317 ± 1754	1852 (1146-2939)	2482 ± 1900[†]	1993 (1258-3117)
Vitamin D (µg)	4.4 ± 3.1	3.7 (2.2-5.8)	4.1 ± 3.0[†]	3.3 (2.0-5.3)
Vitamin E (mg)	6.7 ± 2.8	6.3 (4.7-8.2)	7.2 ± 3.0[†]	6.7 (5.0-8.8)
Vitamin C (mg)	72.7 ± 42.2	64.2 (41.9-93.6)	73.6 ± 42.3	65.2 (43.5-94.0)
Thiamin (mg)	1.3 ± 0.4	1.3 (1.1-1.6)	1.5 ± 0.4[†]	1.4 (1.2-1.7)
Riboflavin (mg)	1.6 ± 0.6	1.5 (1.2-1.9)	1.6 ± 0.6[†]	1.6 (1.2-2.0)
Total Niacin (mg)	26.9 ± 6.4	26.3 (22.3-30.9)	30.9 ± 8.0[†]	30.0 (25.1-35.8)
Preformed Niacin equivalents (mg)	16.2 ± 4.6	15.7 (12.9-19.0)	18.1 ± 5.5[†]	17.5 (14.2-21.4)
Potential Niacin (mg)	10.7 ± 2.4	10.5 (9.0-12.2)	12.7 ± 3.1[†]	12.4 (10.5-14.7)
Vitamin B6 (mg)	1.5 ± 0.5	1.4 (1.1-1.8)	1.6 ± 0.6[†]	1.5 (1.2-1.9)
Vitamin B12 (µg)	4.6 ± 1.8	4.4 (3.3-5.6)	4.7 ± 1.9[†]	4.4 (3.3-5.8)
Total Folate (µg)	205 ± 63.4	199 (160-244)	216 ± 66.9[†]	208 (169-256)
Dietary Folate Equivalents (µg)	248 ± 94.0	234 (179-301)	258 ± 99.0[†]	243 (187-312)
Folic Acid (µg)	58.2 ± 65.9	41.1 (13.3-78.4)	61.9 ± 63.1[†]	47.3 (16.3-85.9)

[†] Statistically different ($P<0.01$) from that of 5-8y within the rows via independent sample T-tests and adjusted for multiple testing

Table 3. Usual intakes of selected minerals in school-aged (5-12y) children in Ireland (*n* 600) by sex

	All (*n* 600)		Boys (*n* 300)		Girls (*n* 300)	
	Mean ± SD	Median (IQR)	Mean ± SD	Median (IQR)	Mean ± SD	Median (IQR)
Calcium (mg)	791 ± 241	768 (618-939)	871 ± 243	853 (699-1022)	717 ± 213[†]	699 (566-846)
Iron (mg)	9.0 ± 2.4	8.7 (7.2-10.4)	9.7 ± 2.5	9.5 (7.9-11.3)	8.3 ± 2.1[†]	8.1 (6.8-9.6)
Magnesium (mg)	194 ± 47.2	190 (161-223)	211 ± 48.0	208 (177-242)	178 ± 40.3[†]	176 (150-203)
Zinc (mg)	7.3 ± 2.1	7.1 (5.9-8.5)	8.0 ± 21.0	7.8 (6.5-9.3)	6.7 ± 1.7[†]	6.5 (5.4-7.7)

[†] Statistically different (P<0.01) from that of boys within the rows via independent sample T-tests and adjusted for multiple testing

Table 4. Usual intakes of selected minerals in school-aged (5-12y) children in Ireland (*n* 600) by age-group

	5-8y (*n* 300)		9-12y (*n* 300)	
	Mean ± SD	Median (IQR)	Mean ± SD	Median (IQR)
Calcium (mg)	778 ± 235	757 (608-925)	804 ± 245[†]	779 (630-954)
Iron (mg)	8.5 ± 2.2	8.3 (6.9-9.9)	9.5 ± 2.6[†]	9.2 (7.6-11.0)
Magnesium (mg)	183 ± 42.5	180 (153-210)	206 ± 49.1[†]	201 (171-237)
Zinc (mg)	7.0 ± 1.9	6.8 (5.6-8.1)	7.7 ± 2.2[†]	7.4 (6.1-9.0)

[†] Statistically different (P<0.01) from that of 5-8y within the rows via independent sample T-tests and adjusted for multiple testing

Table 5. Proportion (%) of school-aged (5-12y) children in Ireland (*n* 600) with selected vitamin intakes below the Estimated Average Requirement (EAR) (excluding under-reporters) by sex & age-group

	EAR	All (*n* 483)	Boys (*n* 242)	Girls (*n* 241)	5-8y (*n* 265)	9-12y (*n* 218)
Vitamin A [a]	245µg RE (4-6y)					
	320µg RE (7-10y)	9	8	10	6	13
	480µg RE (11-12y)					
Vitamin D [b]	10µg (4-12y)	94	94	94	94	94
Vitamin C [a]	20mg (4-6y)					
	30mg (7-10y)	19	19	19	14	26*
	45mg (11-12y)					
Thiamin [a]	0.072mg/MJ (4-12y)	0	0	0	0	0
Riboflavin [a]	0.6mg (4-6y)					
	0.8mg (7-10y)	5	2	8	3	8
	1.1mg (11-12y)					
Total Niacin equivalents [a]	1.3mg NE/MJ** (4-12y)	0	0	0	0	0
Vitamin B6 [a]	0.6mg (4-6y)					
	0.9mg (7-10y)	8	4	12†	5	12*
	1.2mg (11-12y)					
Vitamin B12 [c]	0.7µg (4-6y)					
	0.8µg (7-10y)	0	0	0	0	0
	1.0µg (11-12y)					
Dietary Folate Equivalents [a]	110µg (4-6y)					
	160µg (7-10y)	13	8	17†	9	18*
	210µg (11-12y)					

[a] (EFSA, 2017) [b] (IOM, 2011) [c] (UK DOH, 1991)

† Statistically different (P<0.01) from that of boys within the rows via Chi-Square Test and adjusted for multiple testing

* Statistically different (P<0.01) from that of 5-8y within the rows via Chi-Square Test and adjusted for multiple testing

**NE/MJ = Niacin requirement is related to energy requirement and therefore expressed in mg NE/MJ. NE: niacin equivalent (1 NE = 1 mg niacin)

Table 6. Proportion (%) of school-aged (5-12y) children in Ireland (*n* 600) with selected mineral intakes below the Estimated Average Requirement (EAR) (excluding under-reporters) by sex & age-group

	EAR	All (*n* 483)	Boys (*n* 242)	Girls (*n* 241)	5-8y (*n* 265)	9-12y (*n* 218)
Calcium [a]	680mg (5-10y) 960mg (11-12y)	37	25	49†	33	43*
Iron [a]	5mg (5-6y) 8mg (7-11y) 8mg (boys, 12y) 7mg (girls, 12y)	20	13	26†	21	18
Magnesium [b]	90mg (4-6y) 150mg (5-10y) 230mg (11-12y)	18	12	24†	9	30*
Zinc [a]	4.6mg (5-6y) 6.2mg (7-10y) 8.9mg (11-12y)	29	18	38†	20	40*

[a] (EFSA, 2017) [b] (UK DOH, 1991)

† Statistically different (P<0.01) from that of boys within the rows via Chi-Square Test and adjusted for multiple testing

* Statistically different (P<0.01) from that of 5-8y within the rows via Chi-Square Test and adjusted for multiple testing

Table 7. Proportion (%) of the school-aged (5-12y) children in Ireland (*n* 600) with selected vitamin intakes above the Tolerable Upper Intake Level (UL) by sex & age-group

	UL	All (*n* 483)	Boys (*n* 242)	Girls (*n* 241)	5-8y (*n* 265)	9-12y (*n* 218)
Retinol [a]	1100µg (4-6y) 1500µg (7-10y) 2000µg (11-12y)	0	0	0	0	0
Vitamin D [a]	50µg (4-10y) 100µg (11-12y)	0	0	0	0	0
Vitamin E [a]	120mg (4-6y) 160mg (7-10y) 220mg (11-12y)	0	0	0	0	0
Vitamin C [b]	650mg (4-8y) 1200mg (9-12y)	0	0	0	0	0
Preformed Niacin [a]	3mg (4-6y) 4mg (7-10y) 6mg (11-12y)	0	0	0	0	0
Vitamin B6 [a]	7mg (4-6y) 10mg (7-10y) 15mg (11-12y)	0	0	0	0	0
Folic acid [a]	300µg (4-6y) 400µg (7-10y) 600µg (11-12y)	0	0	0	0	0

[a] (EFSA, 2017) [b] (IOM, 2000)
No statistical differences were noted between sex or age-group

Table 8. Proportion (%) of school-aged (5-12y) children in Ireland (*n* 600) with selected mineral intakes above the Tolerable Upper Intake Level (UL) by sex & age-group

	UL	All (*n* 483)	Boys (*n* 242)	Girls (*n* 241)	5-8y (*n* 265)	9-12y (*n* 218)
Calcium [a]	2500mg/d (5-8y) 3000mg/d (9-12y)	0	0	0	0	0
Iron [b]	40mg (5-12y)	0	0	0	0	0
Magnesium [a]	250mg (5-12y)	0	0	0	0	0
Zinc [a]	10mg (5-6y) 13mg (7-10y) 18mg (11-12y)	2	4	1	4	2

[a] (EFSA, 2017) [b] (IOM, 2001)

No statistical differences were noted between sex or age-group

Discussion

This study provides up to date information on micronutrient intakes in school-aged children in Ireland and provides an estimate of the prevalence of inadequate intakes and the risk of excess in this population group. In line with findings from other countries, intakes of most vitamins are adequate in children in Ireland as indicated by the low proportion of children with intakes below the EAR. However, there were some notable exceptions. This study showed that a large proportion of children in Ireland have inadequate intakes of vitamin D (94%) and calcium (37%) and significant proportions of children have inadequate intakes of zinc (29%), iron (20%), vitamin C (19%), magnesium (18%) and folate (13%). It also showed that there is no risk of excessive micronutrient intakes in children in Ireland as only negligible proportions (<2%) of children have zinc intakes exceeding the UL.

The micronutrients for which low intakes were identified in children in Ireland are discussed in more detail below in context with the literature and potential health implications. When comparing micronutrient intakes across studies, it is important to note that some studies may underestimate intakes if they do not account for nutritional supplement use or collect detailed information on the consumption of fortified foods. The variation in cut-points and dietary reference values used to assess adequacy can also make it difficult to compare studies as this can lead to a difference in estimates of the prevalence of inadequate intakes (Doets et al., 2008). For example, some studies have investigated the prevalence of inadequate intakes using estimated average requirements (EARs) set by EFSA and the IOM or lower reference nutrient intakes (LRNI) (United Kingdom (UK) only) and this review includes these where available. The EAR is the amount of a nutrient that is estimated to meet the needs of 50% of a particular population (EFSA, 2015). The method of estimating the proportion of individuals with intakes below the EAR has been shown to be effective in obtaining a realistic estimate of the prevalence of dietary inadequacy (Carriquiry, 1999). The LRNI is the amount of a nutrient that is enough for only a small proportion of a population who have low requirements (2.5%) (Salmon and Britain, 1991).

Bone health

Calcium absorption in the body is dependent on vitamin D and magnesium and therefore sufficient intakes of all three nutrients during childhood are important for the formation and maintenance of bone (Zemel *et al*., 2010).

The mean intake of vitamin D in school-aged children in Ireland was 4.4µg/d which is higher than intakes observed in children in Denmark, Greece, Italy, Spain, the Netherlands and the UK (1.6µg/d - 3.0µg/d) (Van Rossum *et al*., 2011, Sette *et al*., 2013, Bates *et al*., 2014, Manios *et al*., 2015, Pedersen *et al*., 2015, Lopez-Sobaler *et al*., 2017). Children in Ireland have lower intakes than children in Belgium, Norway, Sweden and the US (6.1µg/d - 7.7µg/d) which may be due to the widespread vitamin D fortification of milk and margarine in these countries or the traditionally higher consumption of oily fish and fish liver in Norway and Sweden (Welch *et al*., 2002, Barbieri *et al*., 2006, Rhodes *et al*., 2015, Hansen *et al*., 2016, Bel and De Ridder, 2018). The proportion of children in Ireland with vitamin D intakes below the EAR was 94% which is similar to the 90-100% of children with vitamin D intakes below the EAR in Spain, Sweden, the UK and Canada (Barbieri *et al*., 2006, Shakur *et al*., 2012, Bates *et al*., 2014, Lopez-Sobaler *et al*., 2017). The UK Scientific Advisory Committee on Nutrition (SACN) define vitamin D deficiency as serum 25(OH)D <25nmol/L while the US IOM define deficiency as serum 25(OH)D <30nmol/L, inadequacy between 30-50nmol/L and sufficiency as >50nmol/L (SACN, 2007, IOM, 2011). Nationally representative data on vitamin D status in children has shown that 6% of 4-10 year old children in the UK, 5.4% of 6-79 year olds in Canada and less than 2% of children aged 6-11 years in the US had levels considered to be deficient (Whiting *et al*., 2011, Bates *et al*., 2014). Furthermore, 12% of 6-11 year olds in the US and 26% of 6-79 year olds in Canada were considered to be at risk of vitamin D inadequacy (Whiting *et al*., 2011, Herrick *et al*., 2019).

The mean intake of calcium in school-aged children in Ireland was 791mg/d which is higher than intakes observed in children in Italy, Norway, Sweden, the UK, Australia and New Zealand (726mg/d - 855mg/d) (New Zealand Ministry of Health, 2003, Sette *et al*., 2013, ABS, 2014, Bates *et al*., 2014, Hansen *et al*., 2016). Children in Ireland have lower intakes than children in Denmark, Greece, Spain, the Netherlands and the US (948mg/d - 1010mg/d) (Van Rossum *et al*., 2011, Manios *et al*., 2015, Pedersen *et al*., 2015, Rhodes *et al*., 2015, Lopez-Sobaler *et al*., 2017). The proportion of children in Ireland with calcium intakes below the EAR was 37% which is in line with findings from Canada (32%) (Shakur *et al*., 2012). In the UK, 25% of children had intakes below the sex appropriate lower reference nutrient intake (LRNI) (4-6y: 275mg/d, 7-10y: 325mg/d) (Bates *et al*., 2014). The prevalence of inadequate intakes of calcium was higher in children in Spain (48%), Greece (50%) and Belgium (57%) compared to children in Ireland which may be due to different cut-off points being used to assess adequacy of calcium intakes (EFSA: 680mg (5-10y) or 960mg (11-12y), IOM: 1100mg/d) (Manios *et al*., 2015, Lopez-Sobaler *et al*., 2017, Bel and De Ridder, 2018).

The mean intake of magnesium in school-aged children in Ireland was 194mg/d with similar intakes observed in children in the UK (192mg/d) (Bates *et al*., 2014). Children in Ireland have lower intakes than children in Belgium, Denmark, Greece, Italy, Norway, Spain, Sweden, the Netherlands, the US, Australia and New Zealand (208mg/d - 287mg/d) (New Zealand Ministry of Health, 2003, Barbieri *et al*., 2006, Van Rossum *et al*., 2011, Sette *et al*., 2013, ABS, 2014, Pedersen *et al*., 2015, Rhodes *et al*., 2015, Hansen *et al*., 2016, Lopez-Sobaler *et al*., 2017, Bel and De Ridder, 2018). The proportion of children in Ireland with magnesium intakes below the EAR was 18% which is similar to the 15% of children with magnesium intakes below the EAR in the Netherlands (Van Rossum *et al*., 2011). In the UK, 5% of children had intakes below the sex appropriate LRNI (4-6y: 70mg/d, 7-10y: 115mg/d) (Bates *et al*., 2014).

These findings highlight the need to improve intakes of vitamin D, calcium and magnesium in children in Ireland to optimise bone growth and reduce the risk of low intakes negatively impacting on bone health and the development of osteoporosis and fractures in later life.

Cognitive development

During childhood, iron is particularly important for growth and cognitive and behavioural development as it is required in the body for the transport of oxygen, electron transport, respiration and hormone synthesis (Halterman *et al*., 2001). Zinc also plays a vital role in cognitive and behavioural development in children (IOM, 2001).

The mean intake of iron in school-aged children in Ireland was 9.0mg/d with similar intakes observed in children in Denmark and the UK (8.9mg/d) (Bates *et al*., 2014, Pedersen *et al*., 2015). Children in Ireland have higher intakes than children in Belgium, Norway and Sweden (7.0mg/d to 8.0mg/d) (Barbieri *et al*., 2006, Hansen *et al*., 2016, Bel and De Ridder, 2018) and lower intakes than children in Greece, Italy, Spain, the Netherlands, the US, Australia and New Zealand (9.4g/d - 14.8mg/d) (New Zealand Ministry of Health, 2003, Van Rossum *et al*., 2011, Sette *et al*., 2013, ABS, 2014, Manios *et al*., 2015, Rhodes *et al*., 2015, Lopez-Sobaler *et al*., 2017) which may be due to the variation in consumption of iron rich cereals and meat and meat products in these countries (Welch *et al*., 2009). The proportion of children in Ireland with iron intakes below the EAR was 20% which is similar to the 16% of children with iron intakes below the IOM EAR in Belgium and Greece (Manios *et al*., 2015, Bel and De Ridder, 2018). In Spain and Sweden, 30% and 40% of children had inadequate intakes compared to the same IOM EAR (4-8y: 4.1mg/d, 9-13y girls: 5.7mg/d and 9-13y boys: 5.9mg/d) respectively. (Barbieri *et al*., 2006, Lopez-Sobaler *et al*., 2017). Although, few studies reported data on iron status in children, data from the nationally representative National Diet and Nutrition Survey (NDNS) in the UK reported that 9% of children (4-10y) had low iron stores with 1% showing evidence of anaemia (Bates *et al*., 2014).

The mean intake of zinc in school-aged children in Ireland was 7.3mg/d with similar intakes observed in children in Sweden and the UK (6.6mg/d – 7.5mg/d) (Barbieri *et al*., 2006, Bates *et al*., 2014). Children in Ireland have lower intakes than children in Denmark, Greece, Norway, Spain, the Netherlands, the US, Australia and New Zealand (8.8mg/d - 10.5mg/d) (New Zealand Ministry of Health, 2003, Van

Rossum *et al*., 2011, ABS, 2014, Manios *et al*., 2015, Pedersen *et al*., 2015, Rhodes *et al*., 2015, Hansen *et al*., 2016, Lopez-Sobaler *et al*., 2017). The proportion of children in Ireland with zinc intakes below the EAR was 29%. In the UK, 11% of children had intakes below the LNRI of 4mg for 4-10 year olds and 5.3mg for 11-14 year olds (Bates *et al*., 2014). In the Netherlands 1-2% of 4-8 year olds and 15-29% of 9-13 year olds had intakes below the IOM EAR (4-8y: 4mg/d, 9-13y: 7mg/d) (Van Rossum *et al*., 2011). In Spain 9% of 9-13 year olds had zinc intakes below the same IOM EAR (Lopez-Sobaler *et al*., 2017) while in the US up to 19% of 9-13 year olds had intakes below the IOM recommendation (Bailey *et al*., 2012).

These findings in children in Ireland highlight the need to improve intakes of iron and zinc to optimise cognitive and behavioural development during childhood. Adequate intakes of iron are especially important to help prevent iron deficiency anaemia, the clinical manifestation of low iron intake and status which may lead to a number of health implications in children including retarded growth and poor cognitive development (Halterman *et al*., 2001). This is of particular importance for girls due to the onset of menstruation, which leads to increased iron requirements due to additional iron losses and can elevate the risk of low iron stores and iron deficiency anaemia (Moschonis *et al*., 2013).

General growth and development

Vitamin C is an important antioxidant which is required during childhood due to its involvement in the regulation of different cell types, cell development, function and maintenance in the body (IOM, 2000). The mean intake of vitamin C in school-aged children in Ireland was 73.1mg/d with similar intakes observed in children in Norway (66.0mg/d) (Hansen *et al*., 2016). Children in Ireland have lower intakes than children in Belgium, Denmark, Greece, Italy, Spain, Sweden, the Netherlands, the UK, the US, Australia and New Zealand (80.3mg/d - 107mg/d) (New Zealand Ministry of Health, 2003, Barbieri *et al*., 2006, Van Rossum *et al*., 2011, ABS, 2014, Bates *et al*., 2014, Manios *et al*., 2015, Pedersen *et al*., 2015, Rhodes *et al*., 2015, Lopez-Sobaler *et al*., 2017, Bel and De Ridder, 2018). The proportion of children in Ireland with vitamin C intakes below the EAR was 19%. Vitamin C intakes were not reported to be below recommendations in any other studies (Chapter 1). This may be partially explained by the different cut-offs used to assess adequacy where most countries used the IOM reference values and this study used the recently published EFSA value (IOM, 2000, EFSA, 2015).

During childhood, folate is required for integral stages of the growth process such as DNA synthesis and cell division (Mcnulty and Pentieva, 2004). The mean intake of total folate in school-aged children in Ireland was 210µg/d with similar intakes observed in children in Belgium (190µg/d) and Norway (192µg/d) (Hansen *et al.*, 2016, Bel and De Ridder, 2018). Children in Ireland have higher intakes than children in Sweden (168µg/d) and the UK (174µg/d) (Barbieri *et al.*, 2006, Bates *et al.*, 2014) but lower intakes than children across other European countries (Denmark, Greece, Spain and the Netherlands), the US, Australia and New Zealand (227µg/d - 249µg/d) which may be due to folic acid fortification practices being in place in these countries (New Zealand Ministry of Health, 2003, Van Rossum *et al.*, 2011, ABS, 2014, Manios *et al.*, 2015, Pedersen *et al.*, 2015, Rhodes *et al.*, 2015, Lopez-Sobaler *et al.*, 2017). The proportion of children in Ireland with DFE intakes below the EAR was 13%. In the UK 28% of children were reported to have folate intakes below the LRNI of 75µg/d for 4-10 year olds (Bates *et al.*, 2014). Additionally, in the UK nationally representative data on folate status in children has shown that less than 3% of 4-10 year old children had a serum total folate <10nmol/L indicating possible deficiency, and less than 4% had RBC folate <340nmol/L indicating risk of anaemia (Bates *et al.*, 2014).

Whilst these findings may suggest low intakes of vitamin C in school-aged children in Ireland, there is currently no evidence of any clinical outcomes and so it is unlikely that there are any public health issues regarding vitamin C intakes in this population group. However, it is important to continuously monitor all nutrient intakes and dietary patterns as vitamin C deficiencies can lead to conditions such as scurvy, bone pain and impaired wound healing and low intakes. Folate intakes may need to be improved to help prevent impaired DNA synthesis and cell division.

Risk of excessive micronutrient intakes

For certain micronutrients where a UL is established, it is important to monitor higher intakes of the nutrient. In the current study, there was no risk of excessive intakes of micronutrients in children in Ireland with negligible proportions (<2%) of the population having intakes of zinc greater than the UL. While few data are available from other countries, 5% of children in the Netherlands and the US have been reported to have zinc intakes greater than the UL (Van Rossum *et al*., 2011, Bailey *et al*., 2012). However, it has previously been noted that the UL established for zinc is low relative to the observed intakes in several European countries and while intakes exceeding the UL for zinc are not without some risk, the probability of individuals suffering adverse effects is low as ULs are established using uncertainty factors to ensure that the risk of adverse effects is negligible for even the most sensitive of individuals in a population (Flynn *et al*., 2009). Furthermore, while 5% of children in the US were reported to have excessive folic acid intakes, it should be noted that the UL for folic acid is extrapolated from that of adults (set in relation to masking of pernicious anaemia in older adults) and may not be a risk for children (IOM, 1998). On-going monitoring of micronutrient intakes at both the lower and upper ends of distribution is important due to continued changes in formulation of both dietary supplements and fortified foods.

Strengths and limitations

The key strengths of this study are the nationally representative sample of school-aged children in Ireland included in the study and the detailed dietary intake data collected at brand level with the ability to account for nutrient intakes from naturally occurring sources, added nutrients and nutritional supplements. Another important strength is the use of statistical modelling to estimate the ‘usual intakes’ of nutrients, resulting in a better estimate of the true distribution of usual intakes with shorter tails at the upper and lower ends therefore improving the estimates of the proportions of the population with intakes above or below a particular reference value (e.g., EAR or UL) which would otherwise be overestimated. Misreporting or under reporting of energy intake, is a known limitation with all dietary assessment including a 4-day weighed food record. A weighed food diary can also involve a high level of participant and interviewer time and burden. Under reporting was minimised by a high-level of researcher-participant interaction (three-visits over the 4-day period) by trained nutritionists. We also accounted for this issue by identifying under-reporters of energy intake (19.5%) and excluding them from the analysis on adequacy of micronutrient intake.

Conclusion

This study showed that a large proportion of children in Ireland have inadequate intakes of vitamin D (94%) and calcium (37%) and significant proportions have inadequate intakes of zinc (29%), iron (20%), vitamin C (19%), magnesium (18%) and folate (13%). Although, there is currently no evidence of clinical manifestations for low vitamin C, magnesium and zinc intakes in EU populations (Mensink *et al*., 2013), there is a need for further research to identify dietary patterns associated with imbalance of key micronutrients and to assess the best strategies for ensuring nutrient adequacy. Low intakes of vitamin D, folate, calcium and iron can lead to negative effects on growth, bone health and behavioural and cognitive development during childhood and possible dietary strategies need to be identified to help improve intakes. In addition, there was no risk of excessive intakes for micronutrients with established ULs (retinol, vitamin D, vitamin E, vitamin C, preformed niacin, vitamin B6, folic acid, calcium, iron and magnesium salts) in children in Ireland as only negligible proportions (<2%) have zinc intakes exceeding the UL. Overall, these findings will be useful for research related to nutrition, public health and food safety, and support the work of agencies that are responsible for food and nutrition policy and regulation in Ireland and the EU.

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Chapter 4

The key sources and dietary determinants of vitamin D and folate intakes in school-aged children (5-12y) in Ireland

Introduction

For school-aged children in Ireland intakes of vitamin D, folate, calcium and iron have been identified as being low compared to recommendations (Chapter 3). Due to the fundamental role that these micronutrients play in bone growth and cognitive development, there is a need to develop dietary strategies to increase intakes of these nutrients. One approach that can be used to develop strategies to improve nutrient intakes in specific population groups is to identify a proportion of the population with adequate or sufficient intakes and to identify the foods and consumption patterns that contribute to the difference in intakes between those with higher intakes and those with lower intakes (Gibney and Sandström, 2001). If those with low intakes can adopt the dietary patterns of those with higher intakes, it may assist in improving intakes within the overall population. A recent study used this approach to identify the key dietary determinants of calcium and iron in school-aged children in Ireland using data from the most recent National Children's Food Survey II (NCFS II) (2017-18) (Walsh, 2019), hence this study will focus on identifying the dietary determinants of vitamin D and folate.

National nutrition surveys across Europe have shown the key sources of vitamin D in children to be 'meat & meat products' (20-37%), 'fats & oils' (14-36%), 'cereal products' (10-30%), 'milk & milk products' (10-23%), 'eggs' (12-25%), 'fish & seafood' (7-26%) and nutritional supplements (6-9%) (Sette *et al.*, 2013, Van Rossum *et al.*, 2016, Olza *et al.*, 2017, Bel and De Ridder, 2018, Roberts *et al.*, 2018). In Ireland, in the previous National Children's Food Survey (NCFS) (2003-04), the key sources of vitamin D were nutritional supplements (26%), 'meat & meat products' (17%), 'ready-to-eat breakfast cereals' (RTEBCs) (15%), 'milks & yogurt' (13%), 'fish & fish dishes' (7%) and 'eggs & egg dishes' (5%) (Black *et al.*, 2014).

While dietary sources can help us to determine important sources of a nutrient for individuals within the food supply, investigating the dietary determinants of higher intakes can help us to determine the foods and specifically the patterns of consumption that contribute to higher intakes, which can help to inform targeted dietary strategies to increase intakes of these nutrients. In Ireland, data from the previous NCFS (2003-04) in Ireland showed ‘nutritional supplements’, ‘RTEBCs’ and ‘milks’ were the key dietary determinants of higher vitamin D intakes in children (Cronin, 2007). Similarly, studies from the United Kingdom (UK), the United States (US), Canada and Australia also found a positive association between the consumption of ‘RTEBCs’ and higher intakes of vitamin D in children and adolescents aged 2-18 years (Barr *et al*., 2014, Fulgoni and Buckley, 2015, Fayet-Moore *et al*., 2016, Gaal *et al*., 2018). A recent modelling study in the UK based on data from the National Diet and Nutrition Survey (NDNS) (2008-2012) has suggested that the daily consumption of 30g of ‘RTEBCs’ can increase vitamin D status in children (4-10y) (Calame *et al*., 2020). Milk consumption has also been found to make significant contributions to vitamin D intakes in children in France, the Netherlands and the US (Dror and Allen, 2014) while in Belgium, Denmark, the UK, the US, Canada and New Zealand the consumption of fortified milks has been shown to increase vitamin D intakes and status in children and adolescents aged 2-18 years (Prentice, 2008, Houghton *et al*., 2011, Madsen *et al*., 2013, Moyersoen *et al*., 2017, Gaal *et al*., 2018). Nutritional supplements were shown to increase intakes of vitamin D in children in the UK, the US and Canada (Bailey *et al*., 2012, Shakur *et al*., 2012, Barr *et al*., 2014).

For folate, national nutrition surveys across Europe have shown the key sources of folate in children to be ‘cereal products’ (22-39%), ‘vegetables & potatoes’ (14-26%), ‘milk & milk products’ (8-11%) and nutritional supplements (4-37%) (Sette *et al*., 2013, Van Rossum *et al*., 2016, Olza *et al*., 2017, Bel and De Ridder, 2018, Roberts *et al*., 2018). In Ireland in the previous NCFS (2003-04), the key sources of folate were ‘RTEBCs’ (25%), ‘milks & yogurt’ (14%), ‘bread & rolls’ (12%), ‘fruit & fruit juices’ (8%) and ‘meat & meat products’ (5%) (Hannon, 2006).

Data from the previous NCFS (2003-04) in Ireland showed ‘RTEBCs’, ‘milks & yogurt’, and nutritional supplements were the key determinants of higher folate intakes in children (Cronin, 2007). Similarly, the consumption of ‘RTEBCs’ was shown to positively contribute to folate intakes in children in the US, Canada and

Australia (Barr *et al*., 2014, Fulgoni and Buckley, 2015, Fayet-Moore *et al*., 2016). Studies from the UK, the US and Canada have shown that children who used nutritional supplements had higher intakes of folate compared to children who did not (Bailey *et al*., 2012, Shakur *et al*., 2012, Barr *et al*., 2014).

New data on dietary intakes in school-aged children (5-12y) in Ireland have recently become available from the NCFS II (2017-18). The aim of this chapter is to use these data to identify the current sources and dietary determinants of vitamin D and folate intakes in school-aged children in Ireland.

Methodology

The analyses for this chapter are based on data from the NCFS II (2017-18). A detailed survey methodology for NCFS II including sampling and recruitment, data collection, food quantification and nutrient composition is described in Chapter 2. The methods relating to this chapter are outlined below.

Nutrient composition of foods and estimation of nutrient intake

Food and beverage intake data were collected at brand level using a 4-day weighed food record. Micronutrient intakes were estimated using data from McCance and Widdowson's The Composition of Foods, 7th edition and the 6th edition (for a small number of foods) (FSA, 2002, FSA, 2015) using Nutritics© software. The Irish food composition database was used to supplement these food composition data for recipes of composite dishes, nutritional supplements, fortified foods, generic Irish foods and new foods on the market. The micronutrient contents of all fortified foods and nutritional supplements were recorded using brand level information from product labels. Folate intakes were estimated as dietary folate equivalents (DFE) and calculated using the following equation: 1µg DFE = 1µg food folate + (1.7 × folic acid) to account for the lower bioavailability of natural food folates compared to synthetic folic acid (EFSA, 2014).

Contribution of food groups to intakes of vitamin D and dietary folate equivalents

A database was created with one line of data (including full nutrient composition) for each food and drink item consumed. All 2048 foods and drinks codes were categorised into one of the nineteen previously established IUNA food groups **(Appendix II)**. The percent contribution of each food group to the mean daily intake (MDI) (µg/d) of vitamin D and DFE were calculated using the mean proportion method and the key contributors to each nutrient were established in order of importance (Krebs-Smith *et al.*, 1989). The mean proportion method provides information about the sources that are contributing to the nutrient intake 'per person' and is the preferred method when determining important food sources of a nutrient for individuals in the population group as opposed to investigating the sources of a nutrient within the food supply.

Dietary determinants of vitamin D and dietary folate equivalents intakes

The dietary determinants of vitamin D and DFE intakes were investigated using tertile analysis. For each nutrient, participants were split into three groups based on their MDI, stratified by sex and age group (5-8y and 9-12y). This provided low, medium and high vitamin D and DFE intake groups. The MDI of each nutrient in the low, medium, and high intake groups was determined and the difference in intake between the high and low intake groups was examined. The proportion of the population in the low, medium and high intake group with intakes below the estimated average requirement (EAR) for vitamin D (10µg/d) and DFE (5-6y: 110µg/d, 7-10y: 160µg/d and 11-12y: 210µg/d) were determined excluding under-reporters (19.5%) as described in detail in Chapter 3 (IOM, 2011, EFSA, 2015).

The food groups accounting for the greatest difference in intakes between the high and low intake groups were identified as determinants of vitamin D and DFE intakes. The MDI of the food groups identified as dietary determinants were reported for the total population and for consumers only. The patterns of consumption of these food groups were further investigated to understand the dietary patterns of those with higher intakes compared to those with lower intakes. For each food group, the percentage of consumers, the MDI, the frequency of intake (over the four-day recording period) and the mean intake (g) at each eating occasion were compared between consumers in the high and low intake groups. A consumer of a food group was defined as a participant who consumed this food at least once over the 4-day recording period. The frequency of intake of a food group was determined by identifying each eating occasion at which the participant consumed this food group over the recording period. The mean intake per eating occasion was determined by calculating the total intake (g) of this food group divided by the frequency of consumption for each participant.

Statistical analyses

Statistical analyses were carried out using SPSS© for Windows™ Version 26.0 (SPSS, Inc., IBM, Chicago, IL, USA). Differences in the MDI of food groups, the frequency of intake of food groups and the mean intake (g) per eating occasion between low and high intake groups for both vitamin D and DFE were assessed using independent sample t-tests regardless of normality (due to the large sample size). As sample size increases so does the robustness of t-tests to identify deviations from normality, thus parametric tests are recommended for large samples (Fagerland, 2012). The difference in the percentage of consumers between low and high intake groups was assessed using the Chi-Square test for independence. To minimise type 1 errors (as a result of multiple testing), the Bonferoni adjustment was used by dividing the alpha level (0.05) by the number of comparisons. Therefore, values were considered significantly different from each other if $P<0.01$. Due to the large sample in this study even a small difference between group means was statistically significant thus greater emphasis was placed on a descriptive, rather than a formal statistical analysis of the data.

Results:

Vitamin D

Table 1 presents the contribution (µg, %) of food groups to vitamin D intakes in school-aged children in Ireland. The key food groups contributing to vitamin D intakes were ‘breakfast cereals’ (23%) including ‘RTEBCs’ (22%), ‘meat & meat products’ (20%), ‘milks & yogurt’ (17%) including ‘vitamin D fortified milks’ (6%) and ‘vitamin D fortfied yogurt’ (7%), ‘nutritional supplements’ (10%), ‘eggs & egg dishes’ (9%) and ‘fish & fish dishes’ (7%),.

Table 2 presents the MDI of vitamin D (µg/d) in the low, medium and high vitamin D intake groups and the difference in intakes between the high and low intake groups. The MDI of vitamin D was 1.4, 3.2 and 8.8µg/d in the low, medium and high intake groups, respectively. The MDI of vitamin D was significantly higher among children in the high intake group compared to those in the low intake group with a difference of 7.4µg/d between the groups. All children (100%) in the low and medium intake groups had vitamin D intakes below the EAR compared to 82% of children in the high intake group.

Table 3 presents the contribution of food groups to the difference in vitamin D intake between high and low vitamin D intake groups. Vitamin D containing supplements contributed to 43% of the difference in vitamin D intake between the high and low intake group. ‘Breakfast cereals’ contributed to 23% of the difference in vitamin D intakes of which ‘RTEBCs’ contributed to 21% of the difference between high and low intake groups. ‘Milks & yogurt’ contributed to a further 19% of the difference of which ‘vitamin D fortified milk’ contributed 14%. ‘Fish & fish dishes’ contributed to 9% of the difference in intakes between those in the high and low intake groups.

Tables 4 and 5 present the patterns of consumption of ‘RTEBCs’, ‘vitamin D fortified milks’, and ‘vitamin D containing supplements’ in the low and high vitamin D intake groups. The MDI of ‘RTEBCs’ in consumers was significantly higher among those in the high intake group compared to the low intake group (37 vs 29g/d, respectively). The proportion of consumers of 'RTEBCs' was significantly higher in the high intake group compared to the low intake group (92 vs 76%, respectively). Among consumers, those in the high intake group consumed 'RTEBCs' significantly more times over the four days compared to those in the low intake group (3.6 vs 2.9 times) with no difference in the amount of 'RTEBCs' consumed at each eating occasion (42 vs 41g).

The MDI of 'vitamin D fortified milks' in consumers was significantly higher among those in the high intake group compared to the low intake group (183 vs 32g/d, respectively). The proportion of consumers of 'vitamin D fortified milks' was significantly higher in the high intake group compared to the low intake group (34 vs 4%, respectively). Among consumers, those in the high intake group consumed 'vitamin D fortified milks' significantly more times over the four days compared to those in the low intake group (4.4 vs 1.5 times) and the high intake group consumed significantly higher portions of 'vitamin D fortified milks' at each eating occasion compared to the low intake group (163 vs 100g).

The MDI of vitamin D from 'vitamin D containing supplements' in consumers was significantly higher among those in the high intake group compared to the low intake group (7.2 vs 1.1µg/d, respectively) with a significantly higher proportion of consumers in the high intake group compared to the low intake group (45 vs 2%, respectively)**.**

Dietary folate equivalents

Table 6 presents the contribution (µg, %) of food groups to folate intakes (expressed as DFE) in school-aged children in Ireland. The key food groups contributing to DFE intakes were 'breakfast cereals' (30%) inlcuding 'RTEBCs' (28%), 'bread & rolls' (12%), 'milks' (10%) including 'folic acid fortified milks' (3%), 'fruit & fruit juices' (8%) and 'meat & meat products' (8%).

Table 7 presents the MDI of DFE (µg/d) in the low, medium and high DFE intake groups and the difference in intakes between the high and low intake groups. The MDI of DFE was 144, 231 and 379µg/d in the low, medium and high intake groups, respectively. DFE intake was significantly higher among children in the high intake group compared to those in the low intake group with a difference of 234µg/d between the groups. The proportion of children with intakes below the EAR was 61% in the low DFE intake group, 9% in the medium DFE intake group and 0% in the high DFE intake group.

Table 8 presents the contribution of food groups to the difference in DFE intake between high and low DFE intake groups. 'Breakfast cereals' contributed to 50% of the difference in DFE intakes between the high and low intake groups, of which 'RTEBCs' contributed to 48% of the difference. 'Milks' contributed to 18% of the difference in intakes between the high and low intake groups of which 'folic acid fortified milks' contributed to 15% of the difference. 'Folic acid containing supplements' contributed to 17% of the difference in intakes between those in the high and low intake groups.

Tables 9 and 10 present the patterns of consumption of 'RTEBCs', 'folic acid fortified milks', and 'folic acid containing supplements' in the low and high DFE intake groups. The MDI of 'RTEBCs' in consumers was significantly higher among those in the high intake group compared to the low intake group (48 vs 19g/d, respectively). The proportion of consumers of 'RTEBCs' was significantly higher in the high intake group compared to the low intake group (97 vs 68%, respectively). Among consumers, those in the high intake group consumed 'RTEBCs' significantly more times over the four days compared to those in the low intake group (4.1 vs 2.4 times) and also consumed significantly higher portions of 'RTEBCs' at each eating occasion compared to those in the low intake group (47 vs 34g).

The MDI of 'folic acid fortified milks' in consumers was significantly higher among those in the high intake group compared to the low intake group (206 vs 37g/d, respectively). The proportion of consumers of 'folic acid fortified milks' was significantly higher in the high intake group compared to the low intake group (27 vs 4%, respectively). Among consumers, those in the high intake group consumed 'folic acid fortified milks' significantly more times over the four days compared to those in the low intake group (4.7 vs 1.9 times) and consumed significantly higher portions of 'folic acid fortified milks' at each eating occasion compared to those in the low intake group (173 vs 82g).

The MDI of DFE from 'folic acid containing supplements' in consumers was significantly higher among those in the high intake group compared to the low intake group (196 vs 47µg/d, respectively) with a significantly higher proportion of consumers in the high intake group compared to the low intake group (20 vs 2%, respectively).

Table 1. The percentage contribution (µg, %) of food groups to vitamin D intake in school-aged children (5-12y) in Ireland (*n* 600)

	µg	**%**
Breakfast cereals	1.01	23
Ready-to-eat breakfast cereals	*0.93*	*22*
Other breakfast cereals	*0.08*	*1.8*
Meat & meat products	0.48	20
Milks & yogurt	0.77	17
Vitamin D fortified yogurts	*0.24*	*6.5*
Vitamin D fortified milks	*0.41*	*5.7*
Non vitamin D fortified milks and yogurts	*0.12*	*5.1*
Nutritional supplements	1.12	9.8
Eggs & egg dishes	0.29	8.5
Fish & fish dishes	0.33	7.0
Butter, spreading fats & oils	0.10	3.1
Grains, rice, pasta & savouries	0.06	2.3
Creams, ice-creams & chilled desserts	0.06	2.2
Biscuits, cakes & pastries	0.06	1.9
Cheese	0.06	1.8
Sugars, confectionery, preserves & savoury snacks	0.03	1.2
Breads & rolls	0.04	1.0
Beverages	0.02	0.6
Soups, sauces & miscellaneous foods	0.01	0.3
Potatoes & potato products	0.01	0.2
Vegetable & vegetable dishes	0.00	0.1
Fruit & fruit juices	0.00	0.0
Nuts, seeds, herbs & spices	0.00	0.0
Total	**4.44**	**100**

Table 2. Mean daily intake of vitamin D (μg/d) and the proportion (%) of school-aged children (5-12y) in Ireland (*n* 600) with intakes below the estimated average requirement (EAR) in low, medium and high vitamin D intake groups and the difference between the high and low intake group

	Low (*n* 196)	Medium (*n* 208)	High (*n* 196)	Difference
Vitamin D (μg/d)	1.4[a]	3.2[b]	8.8[c]	7.3
% < EAR*	100	100	82	

Statistically significant differences (P<0.01) between intake groups are denoted by different superscript lowercase letters

*EAR= Estimated average requirement: 10μg (5-12 years) for vitamin D (Institute of Medicine, 2011) (excluding energy under-reporters (19.5%) (low: *n* 148; medium *n* 161; high: *n* 174)).

Table 3. Contribution of food groups to the difference in vitamin D intakes between the high and low vitamin D intake group in school-aged children (5-12y) in Ireland (*n* 600)

	Low (*n* 196) µg/d	High (*n* 196) µg/d	Difference µg/d	%
Nutritional supplements	0.02	3.22	3.21	43
Breakfast cereals	0.20	1.90	1.71	23
Ready-to-eat breakfast cereals	*0.18*	*1.72*	*1.54*	*21*
Other breakfast cereals	*0.02*	*0.19*	*0.17*	*2.3*
Milk and yogurt	0.24	1.63	1.39	19
Vitamin D fortified milks	*0.02*	*1.09*	*1.07*	*14*
Vitamin D fortified yogurts	*0.11*	*0.37*	*0.26*	*3.5*
Non vitamin D fortified milks and yogurt	*0.11*	*0.17*	*0.06*	*0.9*
Fish & fish dishes	0.08	0.68	0.60	8.1
Eggs & egg dishes	0.13	0.31	0.18	2.4
Butter, spreading fats & oils	0.06	0.15	0.09	1.2
Cheese	0.03	0.10	0.07	1.0
Biscuits, cakes & pastries	0.04	0.08	0.04	0.5
Breads & rolls	0.02	0.06	0.04	0.5
Meat & meat products	*0.46*	*0.49*	0.03	0.4
Creams, ice-creams & chilled desserts	0.05	0.08	0.03	0.3
Grains, rice, pasta & savouries	0.05	0.07	0.02	0.3
Beverages	0.01	0.01	0.00	0.1
Potatoes & potato products	0.00	0.01	0.00	0.1
Fruit & fruit juices	0.00	0.00	0.00	0.0
Soups, sauces & miscellaneous foods	0.01	0.01	0.00	0.0
Nuts, seeds, herbs & spices	0.00	0.00	0.00	0.0
Vegetable & vegetable dishes	0.00	0.00	0.00	0.0
Sugars, confectionery, preserves & savoury snacks	0.03	0.03	0.00	0.0
Total	**1.4**	**8.8**	**7.4**	**100**

Table 4. Consumption patterns of the food groups making the greatest contribution to the difference between the high and low vitamin D intake group in school-aged children (5-12y) in Ireland (*n* 600)

	Ready-to-eat breakfast cereals		Vitamin D fortified milks	
	Low *n* 196	High *n* 196	Low *n* 196	High *n* 196
MDI in the total population (g)	22.1	33.8†	1.30	61.8†
% Consumers	76	92*	4	34*
MDI in consumers (g)	29.2	36.6†	32.1	183†
Frequency/4 days	2.9	3.6†	1.5	4.4†
Mean per eating occasion (g)	40.9	42.0	100	163†

†Statistically different (P<0.01) from that in the low intake group via independent sample T-tests and adjusted for multiple testing
*Statistically different (P<0.01) from that in the low intake group via Chi Square test for independence

Table 5. Consumption patterns of vitamin D containing supplements between the high and low vitamin D intake group in school-aged children (5-12y) in Ireland (*n* 600)

	Low *n* 196	High *n* 196
MDI of vitamin D from nutritional supplements in the total population (μg)	0.2	3.2†
% Consumers of vitamin D containing supplements	2	45*
MDI (μg) from vitamin D containing supplements in consumers	1.1	7.2†

† Statistically different ($P<0.01$) from that in the low intake group via independent sample T-tests and adjusted for multiple testing
* Statistically different ($P<0.01$) from that in the low intake group via Chi-Square test

Table 6. The percent contribution (µg, %) of food groups to dietary folate equivalent intakes in school-aged children (5-12y) in Ireland (*n* 600)

	µg	**%**
Breakfast cereals	83.5	30
Ready-to-eat breakfast cereals	*78.5*	*28*
Other breakfast cereals	*5.01*	*2.1*
Breads & rolls	27.3	12
Non folic acid fortified breads	*25.2*	*12*
Folic acid fortified breads	*2.03*	*0.6*
Milks	27.7	9.6
Non folic acid fortified milks	*14.7*	*6.4*
Folic acid fortified milks	*12.9*	*3.2*
Fruit & fruit juices	18.0	7.9
Meat & meat products	16.5	7.8
Vegetable & vegetable dishes	13.4	6.2
Potatoes & potato products	11.6	5.4
Nutritional supplements	13.7	3.2
Grains, rice, pasta & savouries	6.47	3.1
Sugars, confectionery, preserves & savoury snacks	5.56	2.6
Biscuits, cakes & pastries	5.33	2.5
Yogurt	3.82	1.8
Eggs & egg dishes	3.35	1.6
Cheese	3.03	1.4
Beverages	2.10	1.0
Creams, ice-creams & chilled desserts	1.95	1.0
Soups, sauces & miscellaneous foods	1.84	0.8
Fish & fish dishes	1.58	0.7
Butter, spreading fats & oils	1.54	0.6
Nuts, seeds, herbs & spices	0.32	0.1
Total	**248**	**100**

Table 7. Mean daily intake of dietary folate equivalents (µg/d) and the proportion (%) of school-aged children (5-12y) in Ireland (*n* 600) with intakes below the estimated average requirement (EAR) in low, medium and high DFE intake groups and the difference between the high and low intake group

	Low (*n* 207)	Medium (*n* 202)	High (*n* 191)	Difference
DFE (µg/d)	144^{a}	231^{b}	379^{c}	235
% < EAR*	61	9	0	

Statistically significant differences (P<0.01) between intake groups are denoted by different superscript lowercase numbers

*EAR= Estimated average requirement: 110µg (5-6 y), 160µg (7-10y) and 210µg (11-12y) for dietary folate equivalents (EFSA, 2017) (excluding energy under-reporters (19.5%) (low: *n* 141; medium *n* 167; high: *n* 175)).

Table 8. Contribution of food groups to the difference in dietary folate equivalents intake between the high and low intake group in school-aged children (5-12y) in Ireland (*n* 600)

	Low *n* 207	High *n* 191	Difference	
	µg/d	µg/d	µg/d	% Total
Breakfast cereals	28.4	146	118	50
Ready-to-eat breakfast cereals	*24.6*	*139*	*114*	*49*
Other breakfast cereals	*3.84*	*6.96*	*3.12*	*1.3*
Milks	11.5	53.7	42.2	18
Folic acid fortified milks	*0.8*	*35.6*	*34.7*	*15*
Non folic acid fortified milks	*10.7*	*18.1*	*7.4*	*3.2*
Nutritional supplements	0.80	39.8	39.0	17
Fruit & fruit juices	12.5	21.9	9.50	4.1
Breads & rolls	23.5	32.7	9.20	3.9
Non folic acid fortified breads	*23.0*	*27.5*	*4.50*	*1.9*
Folic acid fortified breads	*0.50*	*5.20*	*3.80*	*1.6*
Potatoes & potato products	10.1	12.7	2.55	1.1
Sugars, confectionery, preserves & savoury snacks	4.60	6.90	2.30	1.0
Meat & meat products	14.8	17.0	2.20	0.9
Butter, spreading fats & oils	0.38	2.40	2.02	0.9
Vegetable & vegetable dishes	11.9	13.9	2.01	0.9
Yogurt	3.13	4.37	1.24	0.5
Biscuits, cakes & pastries	4.73	5.79	1.06	0.5
Grains, rice, pasta & savouries	5.84	6.64	0.79	0.3
Soups, sauces & miscellaneous foods	1.43	2.21	0.78	0.3
Fish & fish dishes	1.52	2.15	0.63	0.3
Beverages	1.79	2.41	0.61	0.3
Cheese	2.64	3.21	0.57	0.2
Nuts, seeds, herbs & spices	0.22	0.45	0.23	0.1
Creams, ice-creams & chilled desserts	2.00	2.09	0.09	0.0
Eggs & egg dishes	2.99	2.74	-0.24	-0.1
Total	**145**	**379**	**234**	**100**

Table 9. Consumption patterns of the food groups making the greatest contribution to the difference between high and low dietary folate equivalents intake groups in school-aged children (5-12y) in Ireland (*n* 600)

	Ready-to-eat breakfast cereals		**Folic acid fortified milks**	
	Low *n* 207	High *n* 191	Low *n* 207	High *n* 191
MDI in the total population (g)	13.0	43.2†	1.50	54.6†
% Consumers	68	97*	4	27*
MDI in consumers (g)	19.1	44.7†	36.5	206†
Frequency/4 days	2.4	4.1†	1.9	4.7†
Mean per eating occasion (g)	33.7	46.6†	81.2	173†

†Statistically different (P<0.01) from that in the low intake group via independent sample T-tests and adjusted for multiple testing
*Statistically different (P<0.01) from that in the low intake group via Chi Square test for independence

Table 10. Consumption patterns of folic acid containing supplements between the high and low dietary folate equivalents intake group in school-aged children (5-12y) in Ireland (*n* 600)

	Low *n* 207	High *n* 191
MDI of DFE from nutritional supplements in the total population (µg)	0.78	39.8†
% Consumers of folic acid containing supplements	2	20*
MDI (µg) from folic acid containing supplements in consumers	46.6	196†

† Statistically different (P<0.01) from that in the low intake group via independent sample T-tests and adjusted for multiple testing

* Statistically different (P<0.01) from that in the low intake group via Chi-Square test

Discussion

The aim of this chapter was to identify the current key sources and dietary determinants of vitamin D and folate intakes in school-aged children in Ireland. The main findings of this study were that the key sources of vitamin D were 'RTEBCs', 'meat & meat products', 'milks & yogurts' including 'vitamin D fortified milks & yogurt', nutritional supplements, 'eggs & egg dishes' and 'fish & fish dishes'. Nutritional supplements, 'RTEBCs' and 'fortified milks' were identified as the key dietary determinants of higher vitamin D intakes. For those with higher vitamin D intakes there was a higher proportion of consumers of 'RTEBCs' and 'vitamin D fortified milks', they consumed these foods more frequently and in greater amounts for 'vitamin D fortified milks' (but not for 'RTEBCs'). Those with higher vitamin D intakes were also more likely to use vitamin D containing supplements and to obtain more vitamin D from these supplements. For folate, the key sources included 'RTEBCs', 'bread & rolls', 'milks', 'fruit & fruit juices' and 'meat & meat products'. 'RTEBCs', 'folic acid fortified milks' and nutritional supplements were identified as the key dietary determinants of higher DFE intakes. For those with higher DFE intakes there was a higher proportion of consumers of 'RTEBCs' and 'folic acid fortified milks' and they consumed these foods more frequently and in greater amounts. Those with higher DFE intakes were also more likely to use folic acid containing supplements and to obtain more folic acid from these supplements. The findings of this study are discussed in detail below in context with the literature and the potential implications of these findings.

Dietary sources and determinants of vitamin D intake

The key sources of vitamin D in school-aged children in Ireland (accounting for 80% of intake) included natural sources such as 'meat & meat products' (20%), 'eggs & egg dishes' (9%) and 'fish & fish dishes' (7%), fortified foods such as 'RTEBCs' (22%) and 'vitamin D fortified milks & yogurts' (12%) and nutritional supplements (10%). In keeping with these findings, natural sources of vitamin D such as 'meat & meat products' (20-37%) and 'eggs & egg dishes' (12-25%) were key sources of vitamin D in children in Belgium, Italy, Spain, the Netherlands and the UK (Sette *et al*., 2013, Van Rossum *et al*., 2016, Olza *et al*., 2017, Bel and De Ridder, 2018, Roberts *et al*., 2018). Furthermore, 'milk & milk products' (10-23%) and 'cereal products' (10-30%) were key contributors to vitamin D intake in Belgium, Italy, Spain, the Netherlands and the UK (Sette *et al*., 2013, Van Rossum *et al*., 2016, Olza *et al*., 2017, Bel and De Ridder, 2018, Roberts *et al*., 2018). Nutritional supplements provided similar proportions (6-9%) of vitamin D intake for children in Belgium and the Netherlands compared to the contribution for children in Ireland (10%). A notable difference between our findings and that of other countries was the contribution of 'fats & oils' to vitamin D intake in Belgium, the Netherlands and the UK (14-36%) which can be explained by vitamin D fortification practices in these countries. Belgium has a mandatory fortification policy for margarines (Moyersoen *et al*., 2017) while the frequent consumption of fortified margarines in the Netherlands (Van Rossum *et al*., 2011) may explain the contribution from this food group. In Ireland and the UK, a number of margarines and fats spreads are voluntarily fortified with vitamin D, hence the difference observed in the contribution of this food group between the two countries is likely to be due to the relative contribution of this particular food group in relation to the contribution from other food groups. Furthermore, the contribution of 'fish & seafood' to vitamin D was much higher in Italy and Spain (20-26%) compared to Ireland, Belgium and the UK where the contribution was much less (7-10%) (Sette *et al*., 2013, Van Rossum *et al*., 2016, Olza *et al*., 2017, Bel and De Ridder, 2018, Roberts *et al*., 2018). This is most likely due to the traditionally higher consumption of 'fish & seafood' in children in Italy (40g/d) and Spain (data not available) compared to Ireland, Belgium and the UK (9-14g/d).

Although there has been an increase in vitamin D intake among school-aged children in Ireland since the previous NCFS (2003-04) (4.2 vs 2.5µg/d) (IUNA, 2019), the key sources of vitamin D have remained relatively similar, with the key sources in the NCFS (2003-04) being 'meat & meat products' (17%), 'milk & yogurts' (13%), 'eggs & egg dishes' (5%) and 'fish & fish dishes' (7%). However, 'RTEBCs' (15%) made a smaller contribution in 2003-04 compared to 2017-18

(22%) and nutritional supplements made a larger contribution (26%) in 2003-04 compared to 2017-18 (10%) (Black *et al*., 2014).

Understanding the dietary determinants of a nutrient is one approach to identify strategies to help improve nutrient intakes at population level (Gibney and Sandström, 2001). The first step in this approach is to identify those with high and low intakes of a nutrient. This study found a difference of 7.4µg/d in the MDI of vitamin D between the low intake group (1.4µg/d) and the high intake group (8.8µg/d) with 100% of children in the low intake group and 82% of children in the high intake group having intakes of vitamin D below the EAR. Despite the high prevalence of inadequate intakes of vitamin D in each group, those in the high intake group had a higher intake of vitamin D than those in the low intake group and so it is still useful to investigate the dietary patterns of those in the high group to understand how those in the low intake group could increase their intake. This study showed that over three-quarters of the difference in vitamin D intake between the high and low vitamin D intake groups was attributable to nutritional supplements (43%), 'RTEBCs' (21%) and vitamin D fortified milks (14%).

For nutritional supplements, there was a higher proportion of users of vitamin D containing supplements in the high vitamin D intake group compared to the low intake group (45% vs 2%) and among vitamin D supplement users those in the high intake group had a higher intake of vitamin D from supplements compared to those in the low intake group (7.2 vs 1.1µg/d). These findings are in line with global literature where vitamin D supplement users were found to have higher intakes and a lower prevalence of inadequate intakes of vitamin D in Belgium, Norway, the Netherlands, the UK, the US, Canada and New Zealand (New Zealand Ministry of Health, 2003, Van Rossum *et al*., 2011, Bailey *et al*., 2012, Shakur *et al*., 2012, Bates *et al*., 2014, Bel and De Ridder, 2018).

Although, there is currently no mandatory fortification policy for vitamin D in Ireland, voluntary fortification practices allow the addition of vitamin D to foods (EC, 2009). Voluntary fortified foods such as 'RTEBCs' and 'vitamin D fortified milks' accounted for a further 35% of the difference in vitamin D intakes between the high and low intake groups (21% and 14%, respectively). For 'RTEBCs', there was a significantly higher proportion of consumers in the high vitamin D intake group compared to those in the low intake group (34% vs 22%). Among consumers, those in the high intake group had a higher MDI of 'RTEBCs' (37g vs 29g) and consumed them more frequently over the 4-day recording period (3.6 vs 2.9 times) compared to those in the low intake group. Notably, there was no difference in the mean amount of 'RTEBCs' consumed per eating occasion between the high and low intake groups (42g vs 41g). Studies from the UK, the US, Canada and Australia have also reported a positive association between the consumption of 'RTEBCs' and their contribution to higher vitamin D intakes in children and adolescents aged 2-18 years (Barr *et al*., 2014, Fulgoni and Buckley, 2015, Fayet-Moore *et al*., 2016, Gaal *et al*., 2018). Additionally, a recent modelling study in the UK based on data from the NDNS (2008-2012) has suggested that the daily consumption of 30g of 'RTEBCs' can improve vitamin D status in 4-10 year old children (Calame *et al*., 2020).

For 'vitamin D fortified milks', there was a significantly higher proportion of consumers in the high vitamin D intake group compared to those in the low intake group (34% vs 4%). Among consumers, those in the high intake group had a higher MDI of 'vitamin D fortified milks' (183g vs 32g), consumed them more frequently over the 4-day recording period (4.4 vs 1.5 times) and in higher amounts per eating occasion (163g vs 100g) compared to those in the low intake group. Studies from Belgium, Denmark, the UK, the US, Canada and New Zealand have shown that the consumption of fortified milks increased vitamin D intakes and status in children and adolescents aged 2-18 years (Prentice, 2008, Houghton *et al*., 2011, Madsen *et al*., 2013, Moyersoen *et al*., 2017, Gaal *et al*., 2018).

Dietary sources and determinants of DFE intake

The key sources of DFE in school-aged children in Ireland were fortified 'RTEBCs' (28%) and natural sources (not fortified with folic acid) such as 'bread & rolls' (12%), 'milks' (10%) 'fruit & fruit juices' (8%) and 'meat & meat products' (8%). These findings are in keeping with the dietary sources reported in Belgium, the

Netherlands and the UK (‘milks’ (10-11%), ‘fruit’ (5-7%) and ‘meat & meat products’ (5%)) (Bates *et al*., 2014, Van Rossum *et al*., 2016, Bel and De Ridder, 2018). A notable difference between our findings and that of other countries was a higher contribution of DFE from ‘RTEBCs’ and a lower contribution from ‘vegetables’ and ‘potatoes’ in Ireland compared to Belgium, the Netherlands and the UK. As the intake of vegetables and potatoes are similar across these countries (115-145g/d), this difference is likely to be explained by the relative contribution of these foods in relation to the contribution from other food groups (IUNA, 2005, Bates *et al*., 2014, Van Rossum *et al*., 2016, Bel and De Ridder, 2018).

The intake of DFE in the current study is similar to that reported in the previous NCFS (2003-04), (253µg/d vs 225µg/d, respectively) (IUNA, 2019) with the key sources also remaining similar. The key sources of folate in the NCFS (2003-04) were ‘RTEBCs’ (25%), ‘milks & yogurt’ (14%), ‘bread & rolls’ (12%), ‘fruit & fruit juices’ (8%) and ‘meat & meat products’ (5%). However, ‘potatoes’ (12%) made a greater contribution in 2003-04 compared to 2017-18 (5%) due to the higher consumption of potatoes at that time compared to NCFS II (98 vs 61g/d) (Hannon *et al*., 2006, IUNA, 2019).

This study found a difference of 235µg of DFE between children in the high intake group (379µg) compared to those in the low intake group (144µg) with 61% of children in the low intake group with intakes below the EAR compared to 0% in the high intake group. Over 80% of the difference in DFE intake between the high and low intake groups was attributable to ‘RTEBCs’ (48%), ‘folic acid fortified milks’ (15%) and nutritional supplements (17%). It is important to note that while ‘non folic acid fortified milks’ were a greater source of DFE, they only accounted for a very small proportion (3%) of the difference in intakes between the high and low DFE intake groups indicating a similar pattern of consumption of non-folic acid fortified milks in those with high and low intakes of DFE.

For ‘RTEBCs’, there was a significantly higher proportion of consumers in the high intake group compared to those in the low intake group (97% vs 68%). Among consumers, those in the high intake group had a higher MDI of ‘RTEBCs’ (45g vs

19g), consumed them more frequently over the 4-day recording period (4.1 vs 2.4 times) and in higher amounts per eating occasion (47g vs 34g) compared to those in the low intake group. Studies that investigated the impact of breakfast consumption including 'RTEBC' contribution on micronutrient intakes in children found that children who did not skip breakfast had higher intakes of folate especially among those who consumed 'RTEBCs' compared to those who consumed other foods in the US, Canada and Australia (Barr *et al.*, 2014, Fulgoni and Buckley, 2015, Fayet-Moore *et al.*, 2016).

For 'folic acid fortified milks', there was a significantly higher proportion of consumers in the high DFE intake group compared to those in the low intake group (27% vs 4%). Among consumers, those in the high intake group had a higher MDI of 'folic acid fortified milks' (206g vs 37g), consumed them more frequently over the 4-day recording period (4.7 vs 1.9 times) and in higher amounts per eating occasion (173g vs 81g) compared to those in the low intake group. While 'folic acid fortified milks' have been identified as a key determinant of DFE in this population group, it is important note the overall very low proportion of consumers of folic acid fortified milks in children in Ireland (14%).

For nutritional supplements, significantly more children in the high DFE intake group used folic acid containing supplements compared to those in the low intake group (20% vs 2%). Among folic acid supplement users those in the high DFE intake group had a higher intake of folic acid from supplements compared to those in the low DFE intake group (196 vs 47µg). Studies from the UK, US and Canada have also shown that children who use nutritional supplements had higher intakes of folate compared to those who did not take supplements (Bailey *et al.*, 2012, Shakur *et al.*, 2012, Barr *et al.*, 2014).

Public health implications

While fortified foods and nutritional supplements have been identified as key dietary determinants of both vitamin D and DFE intakes in school-aged children, it is important to understand the implications of these findings in the context of each individual nutrient. Low intakes and poor status of vitamin D have been widely reported among children (and adults) globally with higher intakes and adequate status often attributed to fortification policies and nutritional supplement use (Bailey *et al*., 2012, Shakur *et al*., 2012, Barr *et al*., 2014, Bates *et al*., 2014, Fulgoni and Buckley, 2015, Fayet-Moore *et al*., 2016). While there is currently no mandatory fortification policy for vitamin D in Ireland, it is permitted to be added voluntarily to the food supply. Findings from this study have shown that the voluntary addition of vitamin D to food can make important contributions to intakes in school-aged children in Ireland where those in the high intake group (who consumed more fortified 'RTEBCs' and milks) had a 7.4µg/d higher intake of vitamin D. However, 82% of those in the high intake group still had inadequate intakes of vitamin D which is in line with studies which have suggested that the fortification of a single food group will not be sufficient to adequately increase vitamin D intakes in line with recommendations (Calvo and Whiting, 2006, Black *et al*., 2012, Kiely and Black, 2012, Cashman and Kiely, 2016). The recent 'food-based solutions for optimal vitamin D nutrition and health through the life cycle (ODIN) project' across 19 countries has demonstrated that diverse fortification strategies could safely increase intakes of vitamin D and prevent low concentrations of 25(OH)D in populations subgroups (Kiely and Cashman, 2018). Furthermore, nutritional supplements were shown to have a positive impact on vitamin D intakes among those who consumed them and although the use of nutritional supplements is reliant on the individual, many European countries including Ireland, Denmark, Finland, Iceland, Norway, Sweden and the UK recommend children to take 5-10µg of supplementary vitamin D as part of a healthy diet (SACN, 2007, FSAI, 2012, Nordic Council of Ministers, 2014).

For DFE, 0% of children in the high intake group had intakes below the EAR compared to 61% of children in the low intake group and thus if those in the low intake group were to adopt the dietary patterns of those in the high intake group, the prevalence of low DFE intakes in school-aged children in Ireland could be significantly reduced. Over 80% of the difference in DFE intakes was attributable to 'RTEBCs' (48%), 'folic acid fortified milks' (15%) and nutritional supplements (17%). To the best of this author's knowledge there are no recommendations for children to take supplements containing folic acid globally and thus the use of folic acid containing supplements to increase DFE intakes may not be suitable at population level. However, while there is currently no mandatory fortification policy for folic acid in Ireland, mandatory folic acid fortification of breads and flour is currently under consideration in Ireland and the UK for the prevention of neural-tube defects in women of childbearing age (FSAI, 2016, SACN, 2017). If this policy were implemented, it would also help to improve intakes of DFE in children in Ireland and could be used in combination with the voluntarily fortified food supply to ensure adequate intakes of this key nutrient.

Overall, these findings suggest that natural food sources of vitamin D and DFE are insufficient to meet nutrient requirements in children, and while fortified foods and nutritional supplements can help to achieve higher intakes, an individual approach is needed for each nutrient. In light of the continuously changing food supply including fortified foods and nutritional supplement use and shifting dietary patterns, it is important to continue to monitor nutrient intakes to ensure intakes will not exceed tolerable upper intake levels in population groups.

Strengths & limitations

A key strength of this study is the detailed dietary intake data collected at brand level with the ability to account for nutrient intakes from naturally occurring sources, added nutrients and nutritional supplements. The robust methodology used in this study is also a key strength as this approach has been suggested as part of a framework for developing food based dietary guidelines in the European Union (Gibney and Sandström, 2001). The cross-sectional nature of this survey provides an understanding of the determinants of nutrient intakes at one point in time and so it is important to continuously monitor nutrient intakes particularly with respect to fortified foods and nutritional supplement use.

Conclusion

In summary, the key sources of vitamin D included natural sources such as ‘meat & meat products’ (20%), ‘eggs & egg dishes’ (9%) and ‘fish & fish dishes’ (7%), fortified foods such as ‘RTEBCs’ (22%) and ‘vitamin D fortified milks & yogurts’ (12%) and nutritional supplements (10%). Nutritional supplements, ‘RTEBCs’ and ‘fortified milks’ were identified as the key dietary determinants of vitamin D intakes. For those with higher vitamin D intakes there was a higher proportion of consumers of ‘RTEBCs’ and ‘vitamin D fortified milks’, they consumed these foods more frequently over the recording period and in greater amounts for ‘vitamin D fortified milks’ (but not for ‘RTEBCs’). Those with higher vitamin D intakes were also more likely to use vitamin D containing supplements and to obtain more vitamin D from these supplements. For DFE, the key sources included fortified foods such as ‘RTEBCs’ (28%) and natural sources such as ‘bread & rolls’ (12%), ‘milks’ (10%) ‘fruit & fruit juices’ (8%) and ‘meat & meat products’ (8%). ‘RTEBC, ‘folic acid fortified milks’ and nutritional supplements were identified as the key dietary determinants of DFE intakes. For those with higher DFE intakes there was a higher proportion of consumers of ‘RTEBCs’ and ‘folic acid fortified milks’, they consumed these foods more frequently over the recording period and in greater amounts. Those with higher DFE intakes were also more likely to use folic acid containing supplements and to obtain more folic acid from these supplements. This study provides an evidence base to assist and support policy makers to inform targeted dietary strategies to improve the intakes of vitamin D and folate in children in Ireland.

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Chapter 5

The National Children's Food Survey II Dietary Supplement Database (2017-18)

Introduction:

In addition to natural dietary sources of micronutrients and fortified foods, nutritional supplements were found to make important contributions to intakes of vitamin D, folate and iron and were key dietary determinants between the high and low intake groups (Chapter 4) (Walsh, 2019). Nutritional supplements are concentrated sources of nutrients (such as vitamins and minerals) or other substances with a nutritional or physiological effect (EFSA, 2016). Many different types of nutritional supplements are available in a wide range of potencies, combinations and forms. They are often designed to be taken in small, measured unit quantities referred to as a 'dose' and presented as pills, tablets, capsules or liquids (Radimer *et al*., 2004).

A review of the literature has shown that multivitamin and/or mineral preparations were the most frequent type of nutritional supplements used by children across Europe, the United States (US), Canada, Australia and New Zealand followed by single vitamin D or C and fish oils (New Zealand Ministry of Health, 2003, Barbieri *et al*., 2006, Health Canada, 2007, Sette *et al*., 2013, ABS, 2014, Bates *et al*., 2014, Rhodes *et al*., 2015, Hansen *et al*., 2016, Van Rossum *et al*., 2016, Lopez-Sobaler *et al*., 2017, Bel and De Ridder, 2018, Lopes *et al*., 2018). Across Europe, many countries particularly those at latitudes above 40°N including Denmark, Finland, Iceland, Ireland, Norway, Sweden and the UK recommend that school-aged children take 5-10µg vitamin D supplements daily especially during the winter period when the capacity for UVB sunlight-induced dermal synthesis of vitamin D is much reduced or even absent (SACN, 2007, FSAI, 2012, Nordic Council of Ministers, 2014).

In Europe, under the General Food Law Regulation (EC) No. 178/2002, nutritional supplements are considered foodstuffs and the level of micronutrients per recommended dose is at the discretion of the manufacturer (Directive 2002/46/EC). There are currently no other guidelines at European level for addition of micronutrients to foods or supplements, however national regulations on safe maximum levels have been set in some European countries including Belgium, Germany, Poland, Spain and the Netherlands (EC, 2016, Loyens, 2018, Weißenborn *et al*., 2018, AFEPADI, 2019, Chu, 2019). The United Kingdom (UK) Expert Group on Vitamins and Minerals (EVM) have not set safe maximum levels for the addition of micronutrients to foods or nutritional supplements, but they have set safe upper levels for supplemental exposure to nutrients per day (EVM, 2003). In addition to this, in 2018, three industry trade associations in the UK which represent the vast majority of companies marketing nutritional supplements agreed a common industry position for vitamin D only of 75µg/d as the maximum level per dose in a nutritional supplement (Council for Responsible Nutrition (CRN) *et al*., 2018). In Ireland, the Food Safety Authority of Ireland (FSAI) have recently outlined their intention to set maximum levels for supplements (FSAI, 2020).

In the absence of any guidance, micronutrient levels per dose of a nutritional supplement are often formulated to reflect nutrient reference values (NRV) which are European Union (EU) guidance levels on the daily amount of vitamins or minerals that the average healthy person needs to prevent deficiency (EC, 2008). It is important to note that these values are for the general population and separate NRVs have not been established for children. In this context, it is important to consider the balance between the benefit of supplements addressing nutrient imbalances with the risk of supplements leading to excessive intakes above the tolerable upper level of intake (UL) (Flynn *et al*., 2009). The UL is defined as the maximum level of total chronic daily intake of a nutrient (from all sources) judged to be unlikely to pose a risk of adverse health effects to individuals (EFSA, 2006). For example, excessively high intakes of vitamin D and calcium can lead to a build-up of calcium in the body (hypercalcaemia) which may result in poor bone health and abnormal heart and brain function (EFSA, 2015a). In addition, excess iron intakes may cause liver damage if consumed regularly at toxic levels (EFSA, 2015b).

The FSAI, currently hold a database containing information of all the dietary supplements marketed in Ireland including their title, supplement type (multivitamin/mineral, single vitamin C etc.), form (i.e., powder, tablet, liquid etc.), ingredients and a copy of the label. Although a notification obligation is in place for dietary supplements that are being marketed in Ireland for the first time, the database does not account for actual use nor does it include dietary supplements that may be sourced outside the Irish market. Similar to the FSAI, Denmark, Germany and the Netherlands hold databases on the dietary supplements available on their national markets (BVL, 2019, DVFA, 2019, NEVO, 2019).

New data on dietary intakes in school-aged children (5-12y) including detailed data on dietary supplement use have recently become available from the National Children's Food Survey II (NCFS II) (2017-18) in Ireland. The aim of this chapter is to use these data to develop a database of the dietary supplements currently being used by children in Ireland. This database (NCFS II Dietary Supplement database 2017-18) is intended to update and replace the previous National Children's Food Survey (NCFS) Dietary Supplement Database (2003-04) and will be useful to complement the FSAI supplement database.

Methodology

The analyses for this chapter are based on data from the NCFS II (2017-18). A detailed survey methodology for NCFS II including sampling and recruitment, data collection, food quantification and nutrient composition is described in Chapter 2. The methods relating to this chapter are outlined below.

Dietary supplements

For the purpose of these analyses, dietary supplements were defined as any supplement, nutritional or otherwise (e.g., probiotics or botanical). Nutritional supplements were defined as any supplement that contained at least one single micronutrient or a combination of micronutrients.

Dietary supplement data collection

Dietary supplement intake data were self-reported in the 4-day weighed food diary. Participants were asked to record detailed information regarding the dose, type and brand of all dietary supplements consumed. During data collection, the researcher transcribed the details of any dietary supplements used and a photo of the packaging was taken in the participant's home. If the packaging was not available, the researcher recorded the full name of the product (at brand level) and found the product in the relevant retail outlet (supermarket/pharmacy) and photographed the details from there. If the details were not available in the participant's home or in the supermarket/pharmacy, the manufacturer was contacted for more details regarding the nutritional information and recommended dose.

The NCFS II Dietary Supplement Database (2017-18)

The NCFS II Dietary Supplement Database (2017-18) was manually constructed in an excel file based on the packaging details and photographs of the dietary supplements used by the participants during the recording period. This information was dual entered by two researchers and linked to the NCFS II packaging database and the NCFS II food consumption database via the corresponding food code and brand code assigned to each dietary supplement. It was then fully quality controlled and checked for errors. The database contains a full detailed description of the supplement type (multivitamin/mineral, single vitamin C etc.), brand information, supplement form i.e., pills, tablets, capsules or liquids, ingredients and potency/strength of the recommended dose. For nutritional supplements (micronutrient containing), a full micronutrient breakdown per recommended dose was included. Information including instructions for use from the product package was used to determine the population group that the supplement was intended for.

Categorisation of dietary supplements

The dietary supplements were categorised into the following groups/types:

- Multivitamin/mineral: contained more than one vitamin and mineral
- Multivitamin: contained more than one vitamin only and no minerals
- Single vitamin: contained a single vitamin e.g., vitamin C, D or E
- Single vitamin and mineral: contained a single vitamin and a single mineral
- Single mineral: contains a single mineral e.g., calcium or iron
- Fish oils: contained at least one omega 3-6-9
- Probiotics: contained live bacteria
- Botanicals: contained herbal extracts

Levels of micronutrients in nutritional supplements

The NRV of a nutrient is used as a reference value for nutrition labelling (EC, 2008). This standardised form of labelling provides consumers with clear and comprehensive nutritional information including the amount of the nutrients or substances with a nutritional or physiological effect present per recommended dose in the nutritional supplement (and or foods). In the current study, the quantity of each micronutrient contained in the recommended dose for each nutritional supplement was expressed as a % of the respective NRV and the 25th, 50th and 75th percentile values (P25, P50 and P75, respectively) for the % NRV were determined to gain an insight into the levels of micronutrients that are being provided by nutritional supplements in the NCFS II Dietary Supplement Database (2017-18).

Results

Categorisation of dietary supplements

In the NCFS II Dietary Supplement Database (2017-18), a total of 102 different types (brands) of dietary supplements were included. Among these, 30% were multivitamins and minerals, 25% were multivitamins, 20% were single vitamins (vitamin D: 10%, vitamin C: 9% and vitamin E: 1%), 6% were fish oils, 4% were either a combination of vitamin D and calcium or vitamin C and magnesium and 15% were non-micronutrient containing supplements such as probiotics (6%) and botanical supplements (8%) **(Table 1) (Appendix III)**.

The NCFS II Dietary Supplement Database (2017-18) was designed to update and replace the previous NCFS Dietary Supplement Database (2003-04), where a total of 57 different types (brands) of dietary supplements were previously included. Among these, 25% were multivitamins and minerals, 18% were single vitamins (vitamin C: 12%, vitamin E: 4% and B-complex: 2%), 13% were fish oils, 11% were multivitamins, 4% were single mineral (iron: 2% and calcium: 2%) and 2% were a combination of vitamin D and calcium **(Table 1)**.

Among the 87 nutritional (micronutrient-containing) supplements in the NCFS II Dietary Supplement Database (2017-18), 72% (n=63) were recommended for children, 15% (n=13) were recommended for adults and 13% (n=11) were either not recommended for a specific age group or the targeted population group was not specified. The majority of the multivitamin and/or mineral supplements in the database were recommended for children (87%), while only 50% of the single vitamin D and 11% of single vitamin C supplements were recommended for children **(Table 2)**.

Level of micronutrients in nutritional supplements

The micronutrient content and the level of micronutrients per dose of the multivitamin and/or mineral supplement types varied significantly across the different brands. The level of vitamin D per dose ranged from 10μg to 125μg among the single vitamin D supplements **(Table 1)**. The level of vitamin C per dose ranged from 32.5mg to 1000mg among the single vitamin C supplements. The single vitamin E supplement contained 5mg of vitamin E per dose.

The median value for the % NRV per daily dose of a supplement (as described by the manufacturer) was 50%-56% for vitamin A, vitamin E and folate and was greater than 60% but equal to or less than 100% for vitamin D, vitamin C, thiamin, riboflavin, niacin, vitamin B6 and vitamin B12 **(Table 3)**. The median value for the % NRV per daily dose was 8-39% for minerals: calcium, iron, magnesium and zinc. The P75 value for the % NRV per daily dose of a supplement (as described by the manufacturer) was 81% for vitamin A, 91% for niacin, 100% for vitamin E, vitamin C, vitamin B6, vitamin B12 and folic acid, 116% for riboflavin, 136% for thiamin, 200% for vitamin D and ranged between 15%-68% for minerals: calcium, iron, magnesium and zinc.

Table 1. Categorisation of the dietary supplements recorded in the NCFS II Dietary Supplement Database (2017-18) and the NCFS Dietary Supplement Database (2003-04)

	NCFS II (2017-18)		**NCFS (2003-04)**	
	n	%	*n*	%
Multivitamin and/or mineral	**57**	**55**	**37**	**63**
Multivitamin/mineral	31	30	25	44
Multivitamin	26	25	13	23
Single vitamin and mineral	**4**	**4**	**1**	**2**
Vitamin D and calcium	3	3	1	2
Vitamin C and magnesium	1	1	0	0
Single vitamin	**20**	**20**	**9**	**16**
Vitamin D	10	10	0	0
10µg	3	3	0	0
12.5µg	2	2	0	0
25µg	3	3	0	0
50µg	1	1	0	0
125µg	1	1	0	0
Vitamin C	9	9	7	14
32.5mg	1	1	0	0
100mg	1	1	1	2
125mg	0	0	1	2
200mg	1	1	1	2
250mg	0	0	1	2
500mg	1	1	2	4
1000mg	5	5	1	2
Vitamin E	1	1	2	4
5mg	1	1	2	4
Single Mineral	**0**	**0**	**2**	**4**
Iron	0	0	1	2
Calcium	0	0	1	2
Fish oils	6	6	8	13
Lysine	1	1	0	0
Probiotics	6	6	0	0
Herbal	8	8	0	0
Total	102	100	57	100

Table 2. The number of nutritional supplements in the NCFS II Dietary Supplement Database (2017-18) stratified by the population group they were recommended for

	Population group			
	All	**Children**	**Adult**	**Unstated**
	n			
Multivitamin and/or mineral	**57**	**50**	**5**	**2**
Multivitamin/mineral	31	28	1	2
Multivitamin	26	22	4	0
Single vitamin and mineral	**4**	**2**	**1**	**1**
Vitamin D and calcium	3	2	1	0
Vitamin C and magnesium	1	0	0	1
Single vitamin	**20**	**8**	**7**	**5**
Vitamin D	10	7	3	0
10μg	*3*	*2*	*1*	*0*
12.5μg	*2*	*2*	*0*	*0*
25μg	*3*	*3*	*0*	*0*
50μg	*1*	*0*	*1*	*0*
125μg	*1*	*0*	*1*	*0*
Vitamin C	9	1	4	4
32.5mg	*1*	*1*	*0*	*0*
100mg	*1*	*0*	*0*	*1*
200mg	*1*	*0*	*1*	*0*
500mg	*1*	*0*	*0*	*1*
1000mg	*5*	*0*	*3*	*2*
Vitamin E	1	0	0	1
5mg	*1*	*0*	*0*	*1*
Fish oils	6	3	0	3
Total	**87**	**63**	**13**	**11**

Table 3. P25, P50 and P75 values for the % NRV of each micronutrient present per recommended dose in the nutritional supplements in the NCFS II Dietary Supplement Database (2017-18)

		Nutritional supplements (n=87)			
		n	P25	P50	P75
Nutrient	NRV*		%		
Vitamins					
Vitamin A	800µg	37	49	50	81
Vitamin C	80mg	58	40	75	100
Vitamin D	5µg	57	66	100	200
Vitamin E	12mg	46	42	56	100
Thiamin	1.1mg	31	55	91	136
Riboflavin	1.4mg	34	50	90	116
Niacin	16mg	33	50	63	91
Vitamin B6	1.4mg	42	50	79	100
Vitamin B12	2.5µg	47	40	80	100
Folic acid	200µg	30	37	50	100
Minerals					
Calcium	800mg	16	13	17	27
Iron	14mg	13	3	8	15
Magnesium	375mg	22	31	39	68
Zinc	10mg	24	20	29	50

*EC NRV, (EC, 2008)

Discussion

This study aimed to develop a database of all the dietary supplements currently being used by school-aged children in Ireland (NCFS II Dietary Supplement Database 2017-18) using recent data from the NCFS II (2017-18). This database is intended to update and replace the previous NCFS Dietary Supplement Database (2003-04). This database also provided an overview of the level of micronutrients present in the dietary supplements recorded in the database.

Categorisation of dietary supplements

Dietary supplements are concentrated sources of micronutrients and/or other ingredients (such as herbal extracts etc.) that aim to supplement the normal diet and are available in a wide range of potencies, combinations and forms (EFSA, 2016). They are often designed to be taken in small, measured unit quantities referred to as a 'dose' that are presented as pills, tablets, capsules or liquids (Radimer *et al.*, 2004). In the NCFS II Dietary Supplement Database (2017-18), a total of 102 dietary supplements were recorded. Multivitamin/minerals supplements (30%) were the most frequent type of supplement recorded followed by multivitamins (25%). Single vitamin supplements such as single vitamin D (10%) and single vitamin C (9%) were also frequently recorded. Fish liver oils made up 6% of the types of supplements in the database, while non-micronutrient-containing supplement types made up 15% including probiotics (6%) and botanical supplements (8%).

Similar to our study, national nutrition surveys from European countries, the US, Canada, Australia and New Zealand found multivitamin and/or mineral supplements were the most reported type of supplement used by up to 58% of children (New Zealand Ministry of Health, 2003, Barbieri *et al.*, 2006, Health Canada, 2007, Sette *et al.*, 2013, ABS, 2014, Bates *et al.*, 2014, Rhodes *et al.*, 2015, Hansen *et al.*, 2016, Van Rossum *et al.*, 2016, Lopez-Sobaler *et al.*, 2017, Bel and De Ridder, 2018, Lopes *et al.*, 2018). Single vitamins such as vitamin C and D and fish liver oils were also frequently reported by up to 40%, 18% and 28% of school-aged children respectively in Norway, Spain, the Netherlands, the UK, the US, Canada, Australia and New Zealand (New Zealand Ministry of Health, 2003, Health Canada, 2007, ABS, 2014, Bates *et al*., 2014, Rhodes *et al*., 2015, Hansen *et al*., 2016, Van Rossum *et al*., 2016, Lopez-Sobaler *et al*., 2017).

In the previous NCFS Dietary Supplement Database (2003-04), a total of 57 dietary supplements were recorded. Multivitamin/minerals supplements were also previously found to be the most frequent type of supplement reported. However, single vitamin D and non-micronutrient containing supplements such as probiotics and herbal supplements were not reported in the 2003-04 database. The introduction of single vitamin D supplements may be as a result of recent studies reporting low vitamin D status and vitamin D deficiency in the Irish population (Cashman and Kiely, 2016). In 2011, the FSAI recommended children take a low-dose vitamin D supplement (maximum 10 μg/d) (FSAI, 2011). The observed increase in probiotic supplement use from this data supports similar findings from a recent review on how the use of probiotic and herbal supplements has increased in recent years as a result of a worldwide acceptance and surge in public interest in natural therapies (Ekor, 2014).

In Ireland, the FSAI have a notification obligation in place for dietary supplements that are marketed in Ireland for the first time. This notification requests the supplement title, supplement type (multivitamin/mineral, single vitamin C etc.), form (i.e., powder, tablet, liquid etc.), ingredients and a copy of the label. This information is then compiled into a supplement database of all the dietary supplements marketed in Ireland (FSAI, 2020). Similar databases can be found in the Netherlands, Germany and Denmark (BVL, 2019, DVFA, 2019, NEVO, 2019). In contrast to these databases, the NCFS II Dietary Supplement Database (2017-18) accounts for actual supplement use and includes dietary supplements that may be sourced outside the national market or through on-line sources. Of note, this database also gives an insight on the supplements that are being taken by children even if they are not marketed as such. Among the 87 micronutrient-containing supplements, 72% were recommended for children aged 5-12 years old, 15% were recommended for adults and 13% were not targeted at a specific age group or the target population group was unspecific. This highlights how dietary supplements can be misused by the general public and are being consumed by a population group that they were not recommended for. It is important however to routinely monitor the use of supplements in the population as it is a growing market, and many supplements are now available online as well as in shops/pharmacies.

Level of micronutrients in dietary supplements

The level of micronutrients per dose of multivitamin and/or mineral supplements in the database varied across the different brands with similar levels reported in the supplements recommended for children and adults. The level of vitamin D per recommended dose for the single vitamin D supplements in the database ranged from 10µg to 125µg. However, among the supplements recommended for children the level of vitamin D per dose ranged from 10µg to 25µg. The single vitamin D supplements with levels above 25µg were recommended for adults or adolescents over the age of 16 and not children. The level of vitamin C per recommended dose for the single vitamin C supplements in the database ranged from 32.5mg to 1000mg. Only 1 of the 9 single vitamin C supplements was recommended for children and this contained 32.5mg of vitamin C per dose. The majority of single vitamin C supplements (55%) in the database contained levels of 1000mg per recommended dose and specifically instructed adult use only. The single vitamin E supplement in the database was recommended for children and contained 5mg of vitamin E per dose.

Maximum safe levels of vitamins and minerals in dietary supplements are yet to be established in Ireland or at EU level. Therefore, current maximum levels of vitamins and minerals in dietary supplements in Ireland are at the discretion of the manufacturer (provided the supplement is not unsafe). Micronutrient levels per dose of a supplement are often formulated to reflect NRV, however dietary supplements marketed in Ireland have been shown to provide 100% or more of the NRV per daily amount (dose) for vitamins and minerals. NRVs have been set for 13 vitamins and 14 minerals for the purpose of food labelling and dietary supplement labels are required to list the micronutrients included in the product and give the proportion of the NRV value (% NRV) that is contained within the supplement for each micronutrient added e.g., vitamin C, 80mg, 100% NRV (EC, 2008).

In the current study, the level of micronutrients present in a daily dose of a micronutrient-containing supplement were compared to the NRV and presented as the P25, P50 and the P75 value for the % of the NRV (EC, 2008). This allowed for a quick assessment of the levels of micronutrients present in the supplements in the database in the context of the relevant population group and NRV.

The P75 value for all minerals were lower than the NRV with levels of calcium, iron, magnesium and zinc ranging from 15% to 68% of the NRV. The P75 value for vitamin A (81%) and niacin (91%) was also lower than the NRV. The P75 value for vitamin C, vitamin E, vitamin B6, vitamin B12 and folate containing supplements was 100% of the NRV. Thiamin and riboflavin containing supplements had a P75 value greater than 100% of the NRV with levels at 136% and 116%, respectively. Water soluble vitamins such as vitamin C and some B vitamins are unlikely to pose any risk of excessive intakes at the levels currently seen in EU populations as they are excreted from the body regularly in urine and other bodily fluids (EFSA, 2006). The P75 value for vitamin D was 200% of the NRV however the NRV for vitamin D is 5µg which is half the recommended supplement dose in countries where recommendations exist (EFSA adequate intake: 15µg, SACN Reference Nutrient Intake: 10µg and the Nordic Nutrition Recommendations (NNR) Recommended intake: 10µg) (SACN, 2007, FSAI, 2012, Nordic Council of Ministers, 2014). Interestingly, in 2018 three industry trade associations in the UK which represent the vast majority of companies marketing dietary supplements agreed a common industry position for vitamin D only of 75µg/d as the maximum level for vitamin D in a dietary supplement (Council for Responsible Nutrition (CRN) *et al.*, 2018). Furthermore, two supplements had very high doses of vitamin D (50µg and 125µg) which were specifically marketed for the adult population with the 125µg supplement specifically targeted at athletic adults.

The presence of these high dose supplements being used by children in Ireland highlights the needs for safe maximum levels to be set. Regulations on vitamin and mineral addition to food and supplements have been set in Belgium, Germany, Poland, Spain and the Netherlands (EC, 2016, Loyens, 2018, Weißenborn *et al*., 2018, AFEPADI, 2019, Chu, 2019). In Ireland, the FSAI have also recently outlined their intention to set maximum levels for supplements (FSAI, 2020). The NCFS II Dietary Supplement Database (2017-18) will be useful in the setting of these limits and help to support the information in the FSAI database on the dietary supplements marketed in Ireland.

Strengths & limitations

The key strength of this study is the up to date representative data on dietary supplement use in school-aged children in Ireland that was used to construct the NCFS II Dietary Supplement Database (2017-18). Another key strength of the database is how it is linked to the comprehensive NCFS II packaging database which provides detailed data on the level of micronutrients per recommended dose of the supplements and the NCFS II food consumption database which allows for analysis of micronutrient intake, adequacy and excess in children. The self-reported nature of data collection may be considered a limitation: however, this issue was minimised by a high-level of researcher-participant interaction (three-visits over the 4-day period) by trained nutritionists.

Conclusion

The NCFS II Dietary Supplement Database (2017-18) updated and replaced the previous NCFS Dietary Supplement Database (2003-04). It provides detailed information on the types, potencies, combinations and forms of the dietary supplements used by school-aged children in Ireland. A total of 102 dietary supplements were recorded. Multivitamin and/or minerals supplements were the most frequent type of supplement recorded followed single vitamin D and C supplements. Of note, 14% of the supplements included in the database were recommended for adolescents or adults or did not specify the population group they were intended for highlighting possible misuse of supplements among children. For most nutrients, the P75 of micronutrient content was at or below the NRV. For vitamin D however, the conservative NRV of 5µg together with the inclusion of two supplements that were not marketed for children resulted in a P75 of 200% NRV. If supplements are consumed as per label instructions, this is not a cause for concern. Regular monitoring of dietary supplement use in the population is important due to a rapidly growing and changing market with new supplements being introduced and others being reformulated on a continual basis. The NCFS II Dietary Supplement Database (2017-18) will be useful for research related to nutrition, public health and food safety will support the work of agencies that are responsible for food and nutrition policy and regulation in Ireland and Europe.

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Chapter 6

The role of nutritional supplements in the diet of school-aged children (5-12y) in Ireland: intakes, adequacy and risk of excess

Introduction

It has previously been shown that nutritional supplements made significant contributions to higher intakes of vitamin D, folate and iron in school-aged children in Ireland (Chapter 4) (Walsh, 2019). Together with increasing the supply and consumption of nutrient rich foods and/or fortified foods, the use of nutritional supplements is a possible dietary strategy that could help to increase micronutrient intakes and improve the prevalence of inadequate intakes within populations including children (EFSA, 2016b, SACN, 2016, Marra and Bailey, 2018).

A review of the literature (Chapter 1) has shown that the proportion of children who used nutritional supplements across Europe, the United States (US), Canada, Australia and New Zealand varied significantly (from as low as 2% in Italy to as high as 63% in Norway). Multivitamin and/or mineral preparations followed by single vitamin D or C supplements were the most common types of nutritional supplements used by children across all studies (New Zealand Ministry of Health, 2003, Barbieri *et al*., 2006, Health Canada, 2007, Sette *et al*., 2013, ABS, 2014, Bates *et al*., 2014, Rhodes *et al*., 2015, Hansen *et al*., 2016, Van Rossum *et al*., 2016, Lopez-Sobaler *et al*., 2017, Bel and De Ridder, 2018, Lopes *et al*., 2018, Dubuisson *et al*., 2019). In Ireland, the previous National Children's Food Survey (NCFS) (2003-04) reported that 25% of children used nutritional supplements and multivitamins and/or minerals, fish/cod liver oils and single vitamin C supplements were the most common types used (Walsh *et al*., 2006).

Studies have shown that when accounting for intakes from 'food sources only' (excluding nutritional supplements), a smaller proportion of nutritional supplement users had micronutrient intakes below recommendations compared to non-users in children in the United Kingdom (UK) and the US, but no difference was observed among children in Canada (Bailey *et al*., 2012, Shakur *et al*., 2012, Bates *et al*., 2014). Similarly, in Ireland, a smaller proportion of nutritional supplement users had intakes of vitamin A, vitamin C, folate, calcium, iron and zinc below recommendations when compared to non-users (Walsh *et al*., 2006).

Studies in nutrition supplement users only that have investigated micronutrient intakes from 'food sources only' compared to intakes from 'all sources' (including nutritional supplements) have shown that nutritional supplements increase intakes of many vitamins but have little impact on mineral intakes with the notable exception of iron (New Zealand Ministry of Health, 2003, Van Rossum *et al*., 2011, Rhodes *et al*., 2015, Bel *et al*., 2016, Hansen *et al*., 2016, Roberts *et al*., 2018).

When considering the use of nutritional supplements as a potential strategy to improve micronutrient intakes at a population level, it is important to consider the balance between the benefit of addressing nutrient imbalances with the risk of increasing excessive intakes above the tolerable upper intake level (UL) (Flynn *et al*., 2009). In Ireland, nutritional supplements were previously shown to increase intakes of a range of micronutrients without impacting the risk of exceeding the UL (Walsh *et al*., 2006). Other studies across Europe have also found that the use of nutritional supplements was not shown to increase the proportion of children with nutrient intakes greater than the UL (Van Rossum *et al*., 2011, Bates *et al*., 2014, Pedersen *et al*., 2015, Lopez-Sobaler *et al*., 2017, Bel and De Ridder, 2018). In contrast, in the US and Canada, it has been reported that children who used nutritional supplements had an increased risk of excess intakes of vitamin A, folic acid, iron and zinc compared to non-users (Bailey *et al*., 2012, Shakur *et al*., 2012).

New data on dietary intakes in school-aged children (5-12y) including detailed data on nutritional supplement use have recently become available from the National Children's Food Survey II (NCFS II) (2017-18) in Ireland. This chapter aims to use these recent data to describe nutritional supplement use in school-aged children in Ireland and to examine the impact of nutritional supplement use on micronutrient intakes, adequacy and risk of excess in this population group.

Methodology

The analyses for this chapter are based on data from the NCFS II (2017-18). A detailed survey methodology for NCFS II including sampling and recruitment, data collection, food quantification and nutrient composition is described in Chapter 2. The methods relating to this chapter are outlined below.

Food intake data collection

Food, beverage and nutritional supplement intake data were collected using a 4-day weighed food record. For all participants, the study period included at least one weekend day. A trained researcher visited each participant in their home three times over the recording period to demonstrate how to keep the food diary, use the portable food scales that were provided, and review the diary to check for completeness. Participants were asked to record detailed information regarding the amount, type and brand of all foods, beverages and nutritional supplements consumed, as well as the amount of any leftovers. The cooking method, the packaging size and type, and recipe details were also recorded. To facilitate the collection of such data, the participants were asked to provide nutrition labels from foods, beverages and nutritional supplements consumed over the recording period. If the nutrition labels were not available, the researcher recorded the full name of the product (at brand level) and found the product in the relevant retail outlet (supermarket/pharmacy) and photographed the details from there. For nutritional supplements specifically, if the details were not available in the participant's home or in the supermarket/pharmacy, the manufacturer was contacted for more details regarding the nutritional information and recommended dose.

Nutritional supplement use

For the purpose of these analyses, nutritional supplements were defined as any supplement that contained a single micronutrient or a combination of micronutrients. Nutritional supplement 'users' were defined as children who consumed a nutritional supplement at any time over the 4-day recording period while those who did not use supplements or who consumed a non-nutritional supplement during the recording period were considered 'non-users' of nutritional supplements.

Estimation of micronutrient intakes

Micronutrient intakes from food and beverages were estimated using data from McCance and Widdowson's The Composition of Foods, 7th edition and 6th edition (for a small number of foods) (FSA, 2002, FSA, 2015) and the Irish Food Composition Database (IFCD) (2018) (Black *et al*., 2011). The IFCD (2018) supplements the UK food composition data used and includes recipes of composite dishes, fortified foods, generic Irish foods and new foods on the market. The IFCD was updated with regards to food composition data for vitamin D and folate as previously outlined in Chapter 3.

Micronutrient intakes from nutritional supplements were estimated using data from a detailed dietary supplement database as described in Chapter 5. This database contains a full detailed description of the supplement type (multivitamin/mineral, single vitamin D etc.), brand information, supplement form i.e., pills, tablets, capsules or liquids, ingredients and potency/strength of the recommended dose. For nutritional supplements, a full micronutrient breakdown per recommended dose was included.

Micronutrient intakes (mean, SD, median, IQR) were estimated via the validated National Cancer Institute (NCI)-Method (Tooze *et al*., 2010) using SAS Enterprise Guide© version 6.1 (SAS Institute Inc., Cary, NC, USA). The NCI-Method has been implemented in SAS macros (version 2.1) which were downloaded from the website www.riskfactor.gov/diet/usualintakes/macro.html (date of download: July 2015). Using these macros, distributions of usual intakes were estimated for micronutrients for nutritional supplement users and non-users.

Micronutrient intakes from 'food sources only' refers to micronutrient intakes estimated from food and beverage intake data only and excludes the contribution from nutritional supplements. Intakes from 'all sources' refers to micronutrient intakes estimated from food and beverages but also includes the contribution from nutritional supplements.

Adequacy of micronutrient intakes

The prevalence of inadequate micronutrient intakes was estimated using estimated average requirements (EARs) as cut-off points. This method has been shown to be effective in obtaining a realistic estimate of the prevalence of dietary inadequacy (Carriquiry, 1999). EARs as established by the European Food Safety Authority (EFSA) (EFSA, 2017) were used as cut-offs for assessing the prevalence of inadequate intakes for vitamin A, vitamin C, riboflavin, total niacin equivalents (preformed niacin and potential niacin), vitamin B6, dietary folate equivalents (DFE) (1 µg DFE = 1 µg food folate + (1.7 × folic acid)), calcium, iron and zinc. The UK Department of Health (DOH) EARs were used as cut-offs for vitamin B12 and magnesium (UK DOH, 1991) and the US Institute of Medicine (IOM) EAR was used as a cut-off for vitamin D (IOM, 2011).

As under-reporting of food consumption can result in an overestimate of the prevalence of inadequacy in a population group (Carriquiry, 1999), under-reporters were identified and excluded from analysis when assessing nutrient adequacy. Under-reporting was investigated using Goldberg's cut-off2 criterion (Goldberg, 1991) updated by Black (Black, 2000). In the total population 19.5% (n=117) were identified as under-reporters.

Risk of excessive intakes of micronutrients

The risk of excessive intake of micronutrients was evaluated using tolerable upper intake levels (UL) as a reference value. ULs are defined as the maximum level of total chronic daily intake of a nutrient (from all sources) judged to be unlikely to pose a risk of adverse health effects in humans (EFSA, 2006). For nutrients with established ULs, the proportion of children with usual intakes exceeding the UL from 'food sources only' and from 'all sources' was calculated. ULs have been derived by EFSA/EU Scientific Committee for vitamin A (retinol), vitamin D, vitamin E, pre-formed niacin, vitamin B6, folic acid, calcium and zinc (EFSA,

2017) and by the US IOM Food and Nutrition Board for vitamin C and iron (IOM, 2000, IOM, 2001). The UL established for magnesium applies to magnesium salts (e.g., chloride, sulphate, aspartate and lactate) and compounds often found in nutritional supplements and does not include magnesium naturally present in foods and beverages.

Statistical analyses

Statistical analyses were carried out using SPSS© for Windows™ Version 26.0 (SPSS, Inc., IBM, Chicago, IL, USA). Differences in micronutrient intakes between nutritional supplement users and non-users from 'food sources only' and differences in intakes among nutritional supplement users from 'food sources only' and 'all sources' were assessed using independent sample T-tests regardless of normality (due to the large sample size). As sample size increases so does the robustness of t-tests to identify deviations from normality, thus parametric tests are recommended for large samples (Fagerland, 2012). To minimise type 1 errors (as a result of multiple testing), the Bonferroni adjustment was used by dividing the alpha level (0.05) by the number of comparisons. Therefore, intakes were significantly different from each other if $P<0.01$. Also due to the large sample in this study, even a small difference between group means was highly statistically significant. Thus, greater emphasis was placed on a descriptive, rather than a formal statistical analysis of the data. The differences in the prevalence of inadequate intakes and the risk of excessive intakes from 'food sources only' in nutritional supplement users and non-users and intakes from 'all sources' and 'food sources only' in nutritional supplement users were assessed using Chi-square tests.

Results

Nutritional supplement use

In the present study, 22% of children used a nutritional supplement during the 4-day recording period **(Table 1)**. Nutritional supplements were used by a similar proportion of boys and girls (boys: 22%, girls: 22%) but a higher proportion of 5-8 year olds were nutritional supplement users compared to 9-12 year olds (5-8y: 24%, 9-12y: 20%).

The micronutrients contained in the nutritional supplements used

Table 2 presents the micronutrients that were present in the nutritional supplements used alongside the proportion of children that used a nutritional supplement containing these micronutrients. Vitamin D was the most common micronutrient obtained from nutritional supplements with 87% of nutritional supplement users taking a vitamin D containing supplement. A higher proportion of children took a vitamin D containing supplement in September - February compared to March - August (64% vs 37%) (data not shown). Vitamins A, C, E, B6 and B12 were also commonly obtained from nutritional supplements with 52-63% of nutritional supplement users taking a supplement that contained at least one of these micronutrients. The proportion of nutritional supplement users taking nutritional supplements containing thiamin, riboflavin, niacin, pantothenate, biotin and folic acid ranged from 33% to 47%. A lower proportion of nutritional supplement users (18-28%) obtained calcium, iron, magnesium, zinc, manganese, copper and iodine from nutritional supplements while a very small proportion (2-5%) obtained phosphorus and vitamin K from nutritional supplements.

Micronutrient intakes and adequacy from 'food sources only'

Table 3 presents the distribution of micronutrient intakes (mean ± SD, median (IQR)) from 'food sources only' (excluding nutritional supplements) in nutritional supplement users and non-users. From 'food sources only' intakes of vitamins A, D, E and C were significantly higher in nutritional supplement users compared to non-users, while intakes of thiamin, niacin, vitamin B6 and iron were significantly lower. For all other micronutrients examined, there were no significant differences in intakes from 'food sources only' between nutritional supplement users and non-users.

Tables 4 & 5 present the proportion of nutritional supplement users and non-users with micronutrient intakes below the EAR from 'food sources only' (excluding supplements). For both groups, the proportion of children with intakes below the EAR for thiamin, niacin and vitamin B12 was 0%. From 'food sources only', the proportion of children with intakes below the EAR was significantly lower in nutritional supplement users compared to non-users for vitamin A (users: 7%, non-users: 11%) and vitamin C (users: 19%, non-users: 25%). However, a higher proportion of nutritional supplement users compared to non-users had intakes of vitamin B6 (users: 12%, non-users: 8%), DFE (users: 17%, non-users: 14%) and iron (users: 30%, non-users: 22%) below the EAR. There was no difference in the proportion of children with intakes below the EAR for vitamin D (users: 99%, non-users: 99%), riboflavin (users: 6%, non-users: 6%), calcium (users: 36%, non-users: 38%), magnesium (users: 20%, non-users: 22%) and zinc (users: 30%, non-users: 33%).

Table 6 presents the proportion of nutritional supplement users and non-users with micronutrient intakes greater than the UL from 'food sources only' (excluding nutritional supplements). For most micronutrients examined, the proportion of children with intakes greater than the UL was 0% with the exception of 3% of nutritional supplement users and 2% of non-users having zinc intakes above the UL from 'food sources only'.

The impact of nutritional supplements on micronutrient intakes

Table 3 presents the distribution of micronutrient intakes (mean ± SD, median (IQR)) in nutritional supplement users from 'food sources only' and 'all sources' (including nutritional supplements). When micronutrient intakes from 'food sources only' were compared to intakes from 'all sources', nutritional supplement users had significantly higher intakes of all vitamins, iron and zinc from 'all sources'. Nutritional supplement users had similar intakes of calcium and magnesium from 'food sources only' and 'all sources'.

Tables 4 & 5 present the proportion of nutritional supplement users with micronutrient intakes below the EAR from 'food sources only' and 'all sources'. A smaller proportion of nutritional supplement users had micronutrient intakes below the EAR from 'all sources' compared to intakes from 'food sources only', including vitamin A ('all sources': 1%, 'food sources only': 7%), vitamin D ('all sources': 77%, 'food sources only': 99%), vitamin C ('all sources': 2%, 'food sources only': 19%), riboflavin ('all sources': 2%, 'food sources only' 6%), vitamin B6 ('all sources': 2%, 'food sources only': 12%), DFE ('all sources': 7%, 'food sources only': 17%), calcium ('all sources': 33%, 'food sources only': 36%), iron ('all sources': 19%, 'food sources only': 30%), magnesium ('all sources': 18%, 'food sources only': 18%) and zinc ('all sources': 21%, 'food sources only': 30%).

Table 6 presents the proportion of nutritional supplement users with micronutrient intakes greater than the UL from 'food sources only' and from 'all sources'. For most micronutrients examined, the proportion of children with intakes greater than the UL was 0% with the exception of zinc where 3% of nutritional supplement users had intakes above the UL from 'food sources only' and 7% from 'all sources'.

Table 1. Proportion (*n*, %) of school-aged children (5-12y) in Ireland (*n* 600) using nutritional supplements* by sex and age group

	Nutritional supplement users	
	n	%
All (*n* 600)	131	22
Boys (*n* 300)	66	22
Girls (*n* 300)	65	22
5-8y (*n* 300)	72	24
9-12y (*n* 300)	59	20
Boys (*n* 300)	66	22
5-8y (*n* 149)	35	23
9-12y (*n* 151)	31	21
Girls (*n* 300)	66	22
5-8y (*n* 151)	37	25
9-12y (*n* 149)	28	19

* As recorded in 4-day food diary

Table 2. The micronutrients contained in the nutritional supplements used by school-aged children (5-12y) in Ireland (*n* 600) by the proportion (*n*, %) of children that used them

	No. of children (*n* 600)	Nutritional supplement users (*n* 131)	Total population (*n* 600)
	n	%	%
Micronutrient			
Vitamin A	70	53	15
Vitamin D	114	87	19
Vitamin E	77	59	17
Vitamin K	7	5	1
Vitamin C	82	63	18
Thiamin	43	33	9
Riboflavin	49	37	11
Niacin	60	46	13
Pantothenate	61	47	10
Biotin	46	35	8
Vitamin B6	73	56	16
Vitamin B12	68	52	15
Folic Acid	60	46	10
Calcium	30	23	7
Iron	33	25	7
Magnesium	23	18	5
Zinc	37	28	8
Phosphorus	2	2	0
Manganese	26	20	4
Copper	26	20	4
Iodine	24	18	4

Table 3. Usual intakes of selected micronutrients from ‘food sources only’ and ‘all sources’ in school-aged children (5-12y) in Ireland (*n* 600) by non-users and users of nutritional supplements

	Non-users (‘food sources only’) (*n* 467)		**Users (‘food sources only’)** (*n* 133)		**Users (‘all sources’)** (*n* 133)	
	Mean ± SD	Median (IQR)	Mean ± SD	Median (IQR)	Mean ± SD	Median (IQR)
Vitamin A (µg)	596 ± 244	558(421-726)	624 ± 254*	586 (443-761)	925 ± 360†	874 (669-1124)
Retinol (µg)	243 ± 97.0	230 (173-298)	252 ± 99.7	239 (180-309)	453 ± 163†	435 (337-549)
Carotene (µg)	2284 ± 1673	1856 (1178-2875)	2377 ± 1723*	1938 (1231-3003)	2706 ± 2019†	2184 (1370-3422)
Vitamin D (µg)	3.2 ± 1.9	2.8 (1.9-4.1)	3.6 ± 2.1*	3.2 (2.1-4.6)	7.7 ± 4.0†	6.9 (4.8-9.7)
Vitamin E (mg)	5.9 ± 1.9	5.6 (4.5-7.0)	6.1 ± 2.0*	5.8 (4.7-7.2)	10.5 ± 3.1†	10.2 (8.3-12.4)
Vitamin C (mg)	60.3 ± 28.8	55.5 (39.4-75.6)	63.3 ± 30.0*	58.5 (41.8-79.4)	112 ± 51.6†	104 (75.3-140)
Thiamin (mg)	1.4 ± 0.3	1.3 (1.1-1.6)	1.3 ± 0.3*	1.2 (1.0-1.5)	1.6 ± 0.4†	1.5 (1.2-1.8)
Riboflavin (mg)	1.5 ± 0.5	1.5 (1.1-1.8)	1.5 ± 0.5	1.5 (1.1-1.8)	1.9 ± 0.6†	1.8 (1.4-2.2)
Total Niacin (mg)	28.2 ± 7.1	27.5 (23.1-32.5)	26.7 ± 6.9*	26.1 (21.9-30.9)	31.1 ± 7.7†	30.4 (25.6-35.8)
Preformed Niacin (mg)	16.4 ± 4.7	16.0 (13.1-19.2)	15.3 ± 4.4*	14.9 (12.2-18.0)	19.6 ± 5.5†	19.1 (15.7-22.9)
Potential Niacin (mg)	11.8 ± 2.9	11.5 (9.7-13.5)	11.4 ± 2.9*	11.1 (9.4-13.1)	11.4 ± 2.9	11.1 (9.4-13.1)
Vitamin B6 (mg)	1.4 ± 0.4	1.3 (1.1-1.6)	1.3 ± 0.3*	1.3 (1.0-1.5)	1.9 ± 0.6†	1.9 (1.5-2.3)
Vitamin B12 (µg)	4.3 ± 1.6	4.2 (3.2-5.3)	4.4 ± 1.6	4.2 (3.3-5.3)	5.5 ± 2.0†	5.3 (4.1-6.7)
Total Folate (µg)	202 ± 57.4	196 (161-236)	197 ± 57	192 (157-231)	239 ± 69.1†	233 (190-281)
Dietary Folate Equivalents (µg)	237 ± 81.6	226 (178-283)	232 ± 80.5	222 (175-278)	301 ± 106†	288 (225-362)
Folic Acid (µg)	52.6 ± 59.5	36.5 (11.0-76.3)	50.0 ± 65.7	26.7 (8.3-74.0)	87.0 ± 95.0†	56.5 (24.3-123)
Calcium (mg)	734 ± 239	763 (613-929)	798 ± 242	778 (626-946)	816 ± 245	796 (643-966)
Iron (mg)	8.8 ± 2.2	8.6 (7.2-10.2)	8.3 ± 2.1*	8.1 (6.8-9.6)	9.4 ± 2.5†	9.2 (7.6-10.9)
Magnesium (mg)	193 ± 46.1	190 (161-222)	192 ± 46.1	189 (159-221)	197 ± 47.4	194 (164-227)
Zinc (mg)	7.1 ± 1.8	6.9 (5.8-8.2)	7.1 ± 1.8	6.9 (5.8-8.2)	8.0 ± 2.1†	7.8 (6.5-9.3)

† Statistically different (P<0.01) from that of non-users (‘food sources only’) within the rows via independent sample T-tests and adjusted for multiple testing

† Statistically different (P<0.01) from that of users (‘food sources only’) within the rows via independent sample T-tests and adjusted for multiple testing

Table 4. Proportion (%) of school-aged children (5-12y) with selected vitamin intakes below the Estimated Average Requirement (EAR) (excluding under-reporters) from 'food sources only' and 'all sources' by non-users and users of nutritional supplements in Ireland (*n* 600)

	EAR	Non-users ('food sources only') (*n* 369)	Users ('food sources only') (*n* 114)	Users ('all sources') (*n* 114)
		% below the EAR		
Vitamin A [a]	245μg RE (4-6y) 320μg RE (7-10y) 480μg RE (11-12y)	11	7*	1†
Vitamin D [c]	10μg (4-12y)	99	99	77†
Vitamin C [a]	25mg (4-6y) 40mg (7-10y) 60mg (11-12y)	25	19*	3†
Thiamin [a]	0.072mg/MJ (4-12y)	0	0	0
Riboflavin [a]	0.6mg (4-6y) 0.8mg (7-10y) 1.1mg (11-12y)	6	6	2†
Total Niacin [a]	1.3mg NE/MJ (4-12y)	0	0	0
Vitamin B6 [a]	0.6mg (4-6y) 0.9mg (7-10y) 1.2mg (11-12y)	8	12*	2†
Vitamin B12 [b]	0.7μg (4-6y) 0.8μg (7-10y) 1.0μg (11-12y)	0	0	0
Dietary Folate Equivalents [a]	110μg (4-6y) 160μg (7-10y) 210μg (11-12y)	14	17*	7†

[a] (European Food Safety Authority (EFSA), 2017) [b] (UK DOH, 1991) [c] (IOM, 2011)
* Estimate statistically different (P<0.01) from that of non-users ('food sources only') within the rows via Chi-Square Test and adjusted for multiple testing
† Estimate statistically different (P<0.01) from that of users ('food sources only') within the rows via Chi-Square Test and adjusted for multiple testing

Table 5. Proportion (%) of school-aged children (5-12y) with selected mineral intakes below the Estimated Average Requirement (EAR) (excluding under-reporters) from 'food sources only' and 'all sources' by non-users and users of nutritional supplements in Ireland (n 600)

	EAR	Non-users ('food sources only') (n 369)	Users ('food sources only') (n 114)	Users ('all sources') (n 114)
		% below the EAR		
Calcium [a]	680mg (4-10y) 960mg (11-12y)	38	36	33
Iron [a]	5mg (4-6y) 8mg (7-11y) 8mg (boys, 12y) 7mg (girls, 12y)	22	30*	19†
Magnesium [b]	90mg (4-6y) 150mg (7-10y) 230mg (11-12y)	22	20	18
Zinc [a]	4.6mg (4-6y) 6.2mg (7-10y) 8.9mg (11-12y)	33	30	21†

[a] (European Food Safety Authority (EFSA), 2017) [b] (UK DOH, 1991)
* Estimate statistically different (P<0.01) from that of non-users ('food sources only') within the rows via Chi-Square Test and adjusted for multiple testing
† Estimate statistically different (P<0.01) from that of users ('food sources only') within the rows via Chi-Square Test and adjusted for multiple testing

Table 6. Proportion (%) of school-aged children (5-12y) with micronutrient intakes above the Tolerable Upper Intake Level (UL) from 'food sources only' and 'all sources' by non-users and users of nutritional supplements in Ireland (*n* 600)

	UL	Non-users ('food sources only') (*n* 369)	Users ('food sources only') (*n* 114)	Users ('all sources') (*n* 114)
		% above the UL		
Retinol [a]	1100µg (5-6y) 1500µg (7-10y) 2000µg (11-12y)	0	0	0
Vitamin D [a]	50µg (5-10y) 100µg (11-12y)	0	0	0
Vitamin E [a]	120mg (5-6y) 160mg (7-10y) 220mg (11-12y)	0	0	0
Vitamin C [b]	650mg (5-8y) 1200mg (9-12y)	0	0	0
Preformed Niacin [a]	3mg (5-6y) 4mg (7-10y) 6mg (11-12y)	0	0	0
Vitamin B6 [a]	7mg (5-6y) 10mg (7-10y) 15mg (11-12y)	0	0	0
Folic acid [a]	300µg (5-6y) 400µg (7-10y) 600µg (11-12y)	0	0	0
Calcium [a]	2500mg/d (5-8y) 3000mg/d (9-12y)	0	0	0
Iron [c]	40mg (5-12y)	0	0	0
Magnesium [a]	250mg (5-12y)	0	0	0
Zinc [a]	10mg (5-6y) 13mg (7-10y) 18mg (11-12y)	2	3	7[†]

Discussion

The aim of this chapter was to describe nutritional supplement use among school-aged children in Ireland and to examine the impact of nutritional supplement use on micronutrient intakes, adequacy and risk of excess in this population group. In summary, 22% of children used a nutritional supplement with vitamin D being the most commonly obtained micronutrient from nutritional supplements followed by vitamins A, E, C, B6 and B12. When micronutrient intakes and adequacy were examined from 'food sources only', the food component of the diets of nutritional supplement users was not found to be any more or less nutrient-dense than the diets of non-users with the exception of iron. A higher proportion of nutritional supplement users had iron intakes below the EAR compared to non-users from 'food sources only' (users: 30%, non-users: 22%). For nutritional supplement users, nutritional supplements increased the mean intake of all vitamins examined and of iron and zinc but made no difference to the mean intake of calcium and magnesium (due to their limited presence in the nutritional supplements used). Nutritional supplements were not shown to increase the risk of excessive intakes of any micronutrient examined with the exception of a small increase for zinc.

Nutritional supplement use

This study showed that 22% of school-aged children in Ireland used nutritional supplements (as reported in the food diary) which is similar to the previous NCFS (2003-04) which reported that 25% of children in Ireland used nutritional supplements at that time (Walsh *et al*., 2006).

In the current study, the prevalence of nutritional supplement use among children in Ireland was similar to the prevalence among children in Germany (26%) but higher than children in the UK (16%), Australia (13%), Italy, Spain and New Zealand (<5% each) and lower than in Sweden (34%), the US (36%), the Netherlands (48%) and Norway (63%) (New Zealand Ministry of Health, 2003, Leclercq *et al*., 2009, Stahl *et al*., 2009, ABS, 2014, Rhodes *et al*., 2015, Hansen *et al*., 2016, Van Rossum *et al*., 2016, Roberts *et al*., 2018, López-Sobaler *et al*., 2019). Whilst the reasons for nutritional supplement use were not reported in these studies, other studies have suggested that nutritional supplements are primarily used to help improve or maintain health and it has also been reported that children whose parents use nutritional supplements are more likely to use them (Bailey *et al*., 2013, Dwyer *et al*., 2013). The reason for the differences in the proportion of children using nutritional supplements across the different countries may also be partially due to some countries having nutritional supplement recommendations in place for this age group. For example, many European countries, particularly those at latitudes above 40°N including Ireland, the UK, Denmark, Finland, Iceland, Norway and Sweden, recommend children to take 5-10μg vitamin D supplements daily especially during the winter period when the capacity for UVB sunlight-induced dermal synthesis of vitamin D is much reduced and even absent (SACN, 2007, FSAI, 2012, Nordic Council of Ministers, 2014). It is important to note that in this study, 87% of children who used nutritional supplements, took one that contained vitamin D with a higher proportion of children taking vitamin D containing supplements from September - February compared to March - August (64% vs 37%), which may be due to the FSAI 5-10μg vitamin D supplement recommendation mentioned previously (HSE, 2011). However, at population level a relatively small proportion (19%) of school-aged children in Ireland took a vitamin D containing supplement despite this recommendation.

Other nutrients that were commonly obtained from nutritional supplements were vitamins A, C, E, B6 and B12 with 52-62% of nutritional supplement users taking a nutritional supplement containing these nutrients. These nutrients are commonly included in multivitamin and multivitamin/mineral preparations as previously described in the NCFS II Dietary Supplement Database (2017-18) (Chapter 5). Other B vitamins such as thiamin, riboflavin, niacin, pantothenate, biotin and folic acid were also commonly obtained from nutritional supplements (33%-47%). Overall, minerals were not as commonly present in the types of nutritional supplements used in this study with a smaller proportion of nutritional supplement users (18-28%) obtaining calcium, iron, magnesium, zinc, manganese, copper and iodine from nutritional supplements and a very small proportion (2-5%) obtaining phosphorus and vitamin K from nutritional supplements.

Although few other studies have provided information on the proportion of children obtaining individual micronutrients from nutritional supplements, the overall proportion of children in Ireland obtaining vitamin D from nutritional supplements (19%) is similar to the proportion of children reported to use vitamin D supplements in the Belgian National Food Consumption Survey (18%) (Bel and De Ridder, 2018). Also in keeping with our overall findings, the most commonly used nutritional supplements among school-aged children in other countries are multivitamin and/or minerals (40-58%), single vitamin C (5-27%) and vitamin D (% not shown but reported to be frequently used in countries such as Spain, the Netherlands and Canada) (New Zealand Ministry of Health, 2003, Walsh *et al*., 2006, Health Canada, 2007, Leclercq *et al*., 2009, Stahl *et al*., 2009, ABS, 2014, Rhodes *et al*., 2015, Bel *et al*., 2016, Hansen *et al*., 2016, Roberts *et al*., 2018, López-Sobaler *et al*., 2019).

Micronutrient intakes and adequacy from 'food sources only'

It has been suggested that children who may benefit from the use of nutritional supplements i.e., those with a less nutrient-dense diet and low micronutrient intakes are not the ones using them (Bailey *et al*., 2011, Bailey *et al*., 2012, Bates *et al*., 2014). To determine whether the children who use nutritional supplements are the ones who need them in their diet, micronutrient intakes from 'food sources only' (excluding nutritional supplements) were compared between nutritional supplement and non-users.

When nutrient intakes were examined from 'food sources only', a large proportion of both nutritional supplement users and non-users had intakes below the EAR for vitamin D (99% in both groups). A higher proportion of nutritional supplement users had intakes of vitamin B6, folate and iron below the EAR from 'food sources only' compared to non-users. In contrast, a lower proportion of nutritional supplement users had intakes of vitamins A and C below the EAR from 'food sources only' compared to non-users. Of note, the difference in the proportion of children with intakes below the EAR for vitamins A, C, B6 and folate between users and non-users was <6% suggesting that despite the statistical differences noted differences in clinical outcomes based on these intakes are unlikely. For iron, however, a significantly higher proportion of nutritional supplement users had intakes below the EAR from 'food sources only' compared to non-users (users: 30%, non-users: 22%). Overall, these findings suggest that the food component of the diets of nutritional supplement users are not any more or less nutrient-dense than the diets of non-users with the exception of iron. This is in line with findings from studies in children from Canada and studies in teenagers and adults from Ireland where nutritional supplement users and non-users had similar intakes for most nutrients before the addition of nutritional supplements to the diet (Shakur *et al*., 2012, Browne *et al*., 2013, Black *et al*., 2014). However, our findings are in contrast to studies in children from the UK and studies in teenagers and adults from the US where nutritional supplement users had higher intakes of most nutrients from 'food sources only' compared to non-users (Dwyer *et al*., 2001, Murphy *et al*., 2007, Bailey *et al*., 2012, Bates *et al*., 2014).

Micronutrient intakes and adequacy from 'all sources'

A further aim of the current study was to assess the impact of nutritional supplements on micronutrient intakes and adequacy in school-aged children in Ireland by examining micronutrient intakes in nutritional supplement users from 'all sources' (including nutritional supplements) and 'food sources only' (excluding nutritional supplements).

From 'all sources' nutritional supplement users had higher intakes of all vitamins compared to intakes from 'food sources only'. This resulted in negligible proportions of nutritional supplement users (<3%) having inadequate intakes of vitamin A, vitamin C, riboflavin and vitamin B6 and a low proportion (7%) having inadequate intakes of DFE. However, for vitamin D, even when nutritional supplements were accounted for, 77% of nutritional supplement users still had intakes below the EAR (compared to 99% from 'food sources only'). This is similar to findings in other countries where nutritional supplements were shown to increase vitamin D intakes in school-aged children across Belgium, Norway, the Netherlands, the UK and the US, but overall intakes remained below recommendations (EFSA AI of 15µg/d and US IOM RDA of 15µg/d) (IOM, 2011, Van Rossum *et al*., 2011, Bailey *et al*., 2012, Bates *et al*., 2014, Pedersen *et al*., 2015, EFSA, 2016a, Bel and De Ridder, 2018). For calcium and magnesium, there was no difference in the proportion of children with intakes below the EAR from 'all sources' compared to 'food sources only'. This is likely to be due to the limited presence of these minerals in the nutritional supplements used. While iron and zinc intakes were higher when examining intakes from 'all sources' compared to 'food sources only', it should be noted that a significant proportion of nutritional supplement users still had inadequate intakes of iron (19%) and zinc (21%) even when nutritional supplements were accounted for. Interestingly, for iron, the proportion of nutritional supplement users with intakes below the EAR from 'all sources' (19%) was similar to that for non-users (22%) which is still a significant proportion for both groups.

The findings from this study are similar to other countries where the addition of nutritional supplements to the diet increased vitamin intakes but made little or no impact on the intake of minerals except for a small increase in iron intakes (New Zealand Ministry of Health, 2003, Hannon, 2006, Van Rossum *et al*., 2011, Rhodes *et al*., 2015, Bel *et al*., 2016, Hansen *et al*., 2016, Roberts *et al*., 2018).

Risk of excessive micronutrient intakes

When considering the use of nutritional supplements, it is important to consider the balance between the benefit of addressing nutrient imbalances with the risk of excessive intakes above the UL (Flynn *et al*., 2009). In the current study, the proportion of children with intakes of all vitamins examined and calcium, iron and magnesium above the UL was 0%. However, a small proportion of nutritional supplement users had zinc intakes greater than the UL from both 'food sources only' (3%) and from 'all sources' (7%). However, it has been noted previously that the UL established for zinc is low relative to the observed intakes in several European countries and that the risk of adverse effects is negligible for even the most sensitive of individuals and the probability of individuals suffering adverse effects is low (Flynn *et al*., 2009). In contrast to our findings, studies in the US and

Canada have shown that nutritional supplement use increased the risk of excess vitamin A, folic acid, iron and zinc intakes in children and teenagers, however small proportions of these populations already had excess intakes from 'food sources only' due to fortification practices in these countries (Bailey *et al*., 2012, Shakur *et al*., 2012).

Public health implications

In order to determine whether or not nutritional supplements could play a potential role in improving low micronutrient intakes at population level it is important to focus on nutrients which have been identified as being of concern in this population group. These nutrients include vitamin D, folate, calcium and iron (Chapter 3).

For vitamin D, a large proportion (77%) of nutritional supplement users had intakes below the EAR even when accounting for intakes from nutritional supplements. This suggests that the addition of vitamin D containing supplements to the diet is not enough to overcome the low intakes of vitamin D observed in school-aged children in Ireland. These findings are in line with other studies which have also shown that the use of nutritional supplements alone is not enough to eliminate low vitamin D intakes and improve poor nutritional status (Bailey *et al*., 2012, Black *et al*., 2014, Carroll *et al*., 2014, Moyersoen *et al*., 2017). This study previously reported that higher intakes of vitamin D in children in Ireland are largely driven by the consumption of fortified foods such as ready-to-eat breakfast cereals (RTEBCs) and vitamin D fortified milks (Chapter 4) and so the use of nutritional supplements may be more effective in combination with other dietary strategies such as voluntary or mandatory fortification. Other studies have shown that combined dietary strategies have the potential to increase vitamin D intakes and possibly bridge the gap between current vitamin D intakes and recommendations (Bailey *et al*., 2012, Black *et al*., 2014, Kehoe *et al*., 2017, Kiely and Cashman, 2018).

For folate, when intakes from 'food sources only' were compared with intakes from 'all sources' among nutritional supplement users, nutritional supplements were shown to increase folate intakes and lower the prevalence of inadequate intakes from 17 to 7%. It is important to note that the use of nutritional supplements to improve intakes is highly reliant on the individual and in the current study only 10% of the total population used folic acid containing supplements. To the best of this author's knowledge, there are no recommendations for children to take folic acid containing supplements. Therefore, the use of nutritional supplements may not be a suitable strategy to increase intakes of folate in this population group. As previously reported in this study, higher intakes of folate in children in Ireland are largely driven by the consumption of fortified foods such as 'RTEBCs' (Chapter 4). Of note, mandatory fortification of breads and flour with folic acid is currently under consideration in both Ireland and the UK for the prevention of neural-tube defects in women of childbearing age (FSAI, 2016, SACN, 2017). If this policy were to be implemented, folate intakes would also increase for children and in combination with the voluntarily fortified food supply may provide sufficient intakes of this key nutrient.

For iron, although nutritional supplements were shown to reduce the proportion of nutritional supplement users with intakes below the EAR, the use of nutritional supplements did not eliminate low iron intakes. In this study just 7% of the total population used iron containing supplements. To the best of this author's knowledge, there are no recommendations for iron supplementation for this age group and are only prescribed in the case of proven iron deficiency (Akkermans *et al*., 2016). Thus, there appears to be no feasible public health strategy to increase iron intakes through a nutritional supplement recommendation in this age group. It has recently been shown in this cohort of children in Ireland and in studies of children in the UK, Italy, Spain, the US and Canada that higher intakes of iron are associated with the consumption of fortified foods such as 'RTEBCs' (Sette *et al*., 2013, Barr *et al*., 2014, Bates *et al*., 2014, Fulgoni and Buckley, 2015, Samaniego-Vaesken *et al*., 2017, Walsh, 2019). This suggests that the use of fortified foods and an increased consumption of natural dietary sources of iron may be a more effective dietary strategy.

For calcium, nutritional supplements were not shown to have an impact on intakes, with a significant proportion (33%) of nutritional supplement users having intakes of calcium below the EAR due to their limited presence in the nutritional supplements used. (EFSA, 2015). To the best of this author's knowledge there are no recommendations for nutritional supplements containing calcium in this age group and it has recently been shown in this cohort of children in Ireland and in studies of children in the US that increased consumption of dairy in line with food based dietary guidelines are the main determinant of higher calcium intakes (Fulgoni *et al*., 2004, Moore *et al*., 2008, Walsh, 2019).

Overall, these findings suggest that although the use of nutritional supplements may help to address some nutrient imbalances without causing an additional risk of excessive intakes, it is unlikely that nutritional supplements alone can eliminate the issue of low micronutrient intakes in children. Dietary strategies to increase micronutrient intakes in school-aged children in Ireland may require a combination of approaches relative to each nutrient such as increasing natural dietary sources and compliance with the food based dietary guidelines, food fortification and nutritional supplement recommendations for some nutrients.

Strengths and limitations

A key strength of this study is the detailed dietary intake data collected at brand level with the ability to account for nutrient intakes from naturally occurring sources, added nutrients and nutritional supplements. Another important strength is the use of statistical modelling to estimate the 'usual intakes' of nutrients, resulting in a better estimate of the true distribution of usual intakes with shorter tails at the upper and lower ends therefore improving the estimates of the proportions of the population with intakes above or below a particular reference value (e.g., EAR or UL) which would otherwise be overestimated. Misreporting or under reporting of energy intake, is a known limitation with all dietary assessment. This issue was minimised by a high-level of researcher-participant interaction (three-visits over the 4-day period) by trained nutritionists. We also accounted for this issue by identifying under-reporters of energy intake (19.5%) and excluding them from the analysis on adequacy of micronutrient intake.

Conclusion

This study showed that 22% of school-aged children in Ireland used a nutritional supplement with vitamin D being the most commonly obtained micronutrient from nutritional supplements followed by vitamins A, E, C, B6 and B12. When micronutrient intakes and adequacy were examined from 'food sources only', the food component of the diets of nutritional supplement users were not found to be any more or less nutrient-dense than the diets of non-users with the exception of iron. A higher proportion of nutritional supplement users had iron intakes below the EAR compared to non-users from 'food sources only' (users: 30%, non-users: 22%). Nutritional supplements were shown to increase intakes of all vitamins examined and iron and zinc but made no difference to intakes of calcium and magnesium due to their limited presence in the nutritional supplements being used. However, for nutrients previously identified as inadequate in this population group, a small proportion (7%) of nutritional supplement users had intakes of DFE below the EAR from 'all sources' and a significant proportion had intakes of vitamin D (77%), calcium (33%) and iron (19%) below the EAR. Nutritional supplements did not increase the risk of excessive micronutrient intakes in children.

The findings of this study suggest that while nutritional supplements can help to increase micronutrient intakes it is unlikely nutritional supplements can eradicate the problem of low intakes in children alone and that dietary strategies to increase micronutrient intakes in this population group may require a combination of approaches specific to each nutrient such increasing natural dietary sources and compliance with the food based dietary guidelines, food fortification and nutritional supplements (for some nutrients). The data presented in this study may be of use to policy makers in Ireland in the development and implementation of dietary strategies to increase micronutrient intakes in school-aged children. These data will also inform the industry with regards to the role of nutritional supplements in the diets of this population group.

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Chapter 7

General Discussion

Childhood is an important stage of life due to the rapid growth, acquisition of bone and cognitive development that takes place and as a result, children have increased requirements for many nutrients (including micronutrients) (Serra-Majem *et al.*, 2006). A review of the literature (Chapter 1) has shown that children across Europe, the United States, Canada, Australia and New Zealand had low intakes of vitamin D, folate, calcium, iron and zinc compared to generally accepted recommendations. With regard to dietary patterns associated with increased intakes of these nutrients, the review showed that higher intakes and biochemical status of vitamin D were associated with the consumption of fortified milks. Calcium and zinc intakes were improved with better compliance with recommendations for dairy consumption and higher intakes of vitamin D, folate, calcium and iron were positively associated with 'RTEBC' consumption. Interestingly despite a wide variance in supplement use across countries, nutritional supplements were shown to increase intakes but did not substantially reduce the prevalence of inadequate intakes for any micronutrient examined.

New data on dietary intakes in school-aged children (5-12y) in Ireland have recently become available from the National Children's Food Survey II (NCFS II) (2017-18). The aim of this thesis was to use these new data to estimate current micronutrient intakes, adequacy and risk of excess in school-aged children in Ireland and to determine the role of nutritional supplements in the diet of this population group.

The first finding was that in keeping with findings from other countries, a large proportion of school-aged children in Ireland had inadequate intakes of vitamin D (94%) and calcium (37%) and significant proportions had inadequate intakes of zinc (29%), iron (20%), vitamin C (19%), magnesium (18%) and folate (13%). While there is no evidence of clinical manifestations for low vitamin C, magnesium and zinc intakes in EU populations (Mensink *et al.*, 2013), low intakes of vitamin D, folate, calcium and iron can lead to negative effects on growth, bone health and behavioural and cognitive development during childhood. Hence dietary strategies are needed help improve intakes of these nutrients. In terms of risk assessment, this study showed no risk of excessive intakes for micronutrients with established ULs (retinol, vitamin D, vitamin E, vitamin C, preformed niacin, vitamin B6, folic acid, calcium, iron and magnesium salts) with only negligible proportions of children (<2%) having zinc intakes exceeding the UL. A key strength of this analysis was the detailed dietary intake data collected at brand level to include micronutrient intakes from natural food sources, fortified foods and nutritional supplements. Another strength was the use of statistical modelling to estimate the ‘usual intakes’ of nutrients, resulting in a better estimate of the true distribution of usual intakes with shorter tails at the upper and lower ends therefore improving the estimates of the proportions of the population with intakes above the UL or below the EAR which would otherwise be overestimated.

With vitamin D, folate, calcium and iron identified as nutrients of concern for school-aged children in Ireland, the next aim of this thesis was to identify the key sources and dietary determinants of vitamin D and folate intakes to inform dietary strategies to increase intakes of these nutrients and to complement similar research already completed on calcium and iron (Walsh, 2019). This was carried out using a method proposed by Gibney and Sandstrom (2008) where a proportion of the population with sufficient intakes of a nutrient are identified and the foods and consumption patterns that determined these intakes are compared to those with lower intakes. If those with low intakes can adopt the dietary patterns of those with higher intakes it may help to improve intakes within the overall population. For vitamin D, while the key sources included natural sources such as ‘meat & meat products’ (20%), ‘eggs & egg dishes’ (9%) and ‘fish & fish dishes’ (7%), fortified foods such as ‘RTEBCs’ (22%) and ‘vitamin D fortified milks & yogurts’ (12%) and nutritional supplements (10%), the key dietary determinants of higher intakes were nutritional supplements (43%), ‘RTEBCs’ (21%) and ‘vitamin D fortified milks’ (14%). For those with higher vitamin D intakes there was a higher proportion of consumers of ‘RTEBCs’ and ‘vitamin D fortified milks’, they consumed these foods more frequently over the recording period, and in greater amounts for ‘vitamin D fortified milks’ (but not for ‘RTEBCs’). Those with higher vitamin D intakes were also more likely to use vitamin D containing supplements and to obtain more vitamin D from these supplements. For dietary folate equivalents (DFE), while the key sources included fortified foods such as ‘RTEBCs’ (28%) and natural sources such as ‘bread & rolls’ (12%), ‘milks’ (10%) ‘fruit & fruit juices’ (8%) and ‘meat & meat products’ (8%), the key determinant of higher intakes were ‘RTEBC’ (49%), ‘folic acid fortified milks’ (15%) and nutritional supplements (17%). For those with higher DFE intakes there was a higher proportion of consumers of ‘RTEBCs’ and ‘folic acid fortified milks’, they consumed these foods more frequently over the recording period and in greater amounts. Those with higher DFE intakes were also more likely to use folic acid containing supplements and to obtain more folic acid from these supplements. This robust methodology used to estimate the dietary determinants of vitamin D and folate intakes in this study is an important strength as this method has been suggested as part of a framework for developing food based dietary guidelines in the European Union (Gibney and Sandström, 2001). The findings from this analysis will be useful for informing nutrient and life stage specific dietary strategies to increase intakes of key nutrients.

A further aim of this thesis was to determine the role of nutritional supplements in the diets of school-aged children in Ireland. The first step of this analysis was to develop a database of dietary supplements currently being used by children in Ireland. The development of the NCFS II Dietary Supplement Database (2017-18) was enabled by the detailed information collected on the types, potencies, combinations and forms from the packaging label of the 102 dietary supplements. Multivitamin and/or minerals supplements were the most frequent type of supplement recorded followed by single vitamin D and C supplements. Of note, 14% of the supplements included in the database were recommended for adults or adolescents over the age of 12 or did not specify the population group they were intended for highlighting possible misuse of supplements among children. For most nutrients, the P75 of micronutrient content was at or below the nutrient reference value (NRV). For vitamin D however, the conservative NRV of 5µg together with the inclusion of two supplements that were not marketed for children resulted in a P75 of 200% NRV. Overall, this study found that if supplements were taken as per label instructions there would be no cause for concern. However, it is important to continue monitoring the use of nutritional supplements among population groups including school-aged children.

The next part of this study used the NCFS II Dietary Supplement Database (2017-18) in conjunction with the NCFS II food consumption database to describe actual nutritional supplement use and to examine the impact of nutritional supplements on micronutrient intakes, adequacy and risk of excessive intakes in school-aged children in Ireland. It was found that 22% of school-aged children in Ireland used a nutritional supplement with vitamin D being the most commonly obtained micronutrient from nutritional supplements followed by vitamins A, E, C, B6 and B12. When micronutrient intakes and adequacy were examined from ‘food sources only’, the food component of the diets of nutritional supplement users were not found to be any more or less nutrient-dense than the diets of non-users with the exception of iron. A higher proportion of nutritional supplement users had iron intakes below the EAR compared to non-users from ‘food sources only’ (users: 30%, non-users: 22%). These findings may suggest that for the most part nutritional supplement use is driven by individual choice rather than as a solution to a less micronutrient dense diet.

For nutritional supplement users, nutritional supplements were shown to increase intakes of all vitamins examined and iron and zinc but made no difference to intakes of calcium and magnesium due to their limited presence in the nutritional supplements being used. However, for nutrients previously identified as inadequate in this population group, a small proportion (7%) of nutritional supplement users had intakes of DFE below the EAR from ‘all sources’ and a significant proportion had intakes of vitamin D (77%), calcium (33%) and iron (19%) below the EAR. Furthermore, nutritional supplements were not found to increase the risk of excessive micronutrient intakes in children. These findings suggest that while nutritional supplement use is safe under current practices and may increase intakes, they are not enough to address the nutrients of public health concern in this population group.

Overall, this thesis found that school-aged children in Ireland have low intakes of vitamin D, folate, calcium and iron and these intakes need to be improved to avoid negative effects on childhood growth and development. Fortified foods and nutritional supplements were found to make important contributions to vitamin D and folate intakes and were key dietary determinants between the high and low intake groups. Although, the use of nutritional supplements was found to increase intakes of some micronutrients (mainly vitamins) among those who used them, under current practices it is unlikely they will eliminate the low intakes observed in children. Therefore, dietary strategies aiming to increase micronutrient intakes in this population group may require a combination of approaches specific to each nutrient such as increasing natural dietary sources, increased compliance with the food based dietary guidelines, food fortification and nutritional supplement recommendations. Food fortification refers to the process of adding micronutrients to food. Commonly fortified foods include iodine in salt, folic acid in bread, vitamin A in fat spreads, vitamin D in milk and multiple micronutrients in ready-to-eat breakfast cereals. Advantages of food fortification include that is a cost effective way of improving dietary intake and nutritional status in the population, it does not alter the sensory properties of the food or require individual adjustment (Dwyer et al., 2015). Limitations of food fortification may include overshadowing the importance of dietary diversity, extensive expenses in the process and possibly reducing the shelf life (Dwyer et al., 2015). In comparison, the advantages of nutritional supplement use include that they may help to correct nutritional deficiencies for example supplemental vitamin D in wintertime, they may have placebo affect and there may be specific benefits for specific groups of people. However, the disadvantages of nutritional supplement use include that is highly dependent on the individual, the risk of excessive intakes if consumed incorrectly, cost and the widening of health inequalities (EFSA, 2016).

The data presented in this study will help to contribute to further research related to nutrition. It will also help to educate government bodies such as the Department of Health on the gaps in children's nutrition in Ireland and inform organisations such as Safefood in public health advice. The data presented on nutritional supplement use and the dietary supplement database will be useful to the FSAI and regulators and help to notify them of the nutritional supplements being used in this population group. This database will also be of interest in clinical nutrition practices and aid the work of dietitians. These data will also inform the industry with regards to the role of nutritional supplements in the diets of this population group.

Future analysis could look at examining population characteristics such as social class and location among supplement users and non-users. This research could also be repeated in other population groups in Ireland e.g. adolescents and adults. For example, the ongoing National Teens Food Survey II (2019-20) and the upcoming National Adult Nutrition Survey II (NANS II) will offer new opportunities to examine whether there are similar trends across teenagers and adults in Ireland. Of note, this study has helped to inform the upcoming NANS II by highlighting gaps in this area of research including the opportunity to capture the reason for nutritional supplement use. This will allow for future research to examine the reasons for nutritional supplement use. Further studies regarding food fortification could describe the characteristics of those who consume fortified food products such as fortified milks and their reasons for purchasing these food products.

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Appendix I: Dietary Reference Values

European Food Safety Authority

Population Reference Intake: refers to the level of nutrient intake that is adequate for virtually all people in a population group and is assumed to meet the requirements of 97-98% of the individuals in the population.

Vitamin A: 4-6y: 300µg/d, 7-10y: 400µg/d and 11-14y: 600µg/d

Vitamin C: 4-6y: 30mg/d, 7-10y: 45mg/d and 11-14y: 70mg/d

Thiamin: 0.1mg/MJ

Riboflavin: 4-6y: 0.7mg/d, 7-10y: 1.0mg/d and 11-14y: 1.4mg/d

Niacin: 1.6mg NE/MJ

Vitamin B6: 4-6y: 0.7mg/d, 7-10y: 1.0mg/d and 11-14y: 1.4mg/d

Folate: 4-6y: 140µg/d, 7-10y: 200µg/d and 11-14y: 270µg/d

Calcium: 4-6y: 450mg/d, 7-10y: 800mg/d and 11-14y: 1150mg/d

Iron: 7mg/d for 5-6 year olds and 11mg/d for 7-14 year olds

Magnesium: 3-9y: 230mg/d, 10-14y: 300mg/d

Zinc: 4-6y: 5.5mg/d, 7-10y: 7.4mg/d and 11-14y: 10.7mg/d

Adequate intake: the value estimated when a PRI cannot be established and is the average observed nutrient intake by a population group of apparently healthy people that is assumed to be adequate.

Vitamin D: 15µg/d

Vitamin E: 9-13mg/d

Vitamin B12: 4-6y: 1.5µg/d, 7-10y: 2.5µg/d and 11-14y: 3.5µg/d

Estimated Average Requirement: the amount of a nutrient that is estimated to meet the needs of 50% of a particular population.

Vitamin A: 5-6y: 245µg/d, 7-10y: 320µg/d and 11-12y: 480µg/d

Vitamin C: 5-6y: 20mg/d, 7-10y: 30mg/d and 11-12y: 45mg/d

Thiamin: 5-12y: 0.072mg/MJ

Riboflavin: 5-6y: 0.6mg/d, 7-10y: 0.8mg/d and 11-12y: 1.1mg/d

Niacin: 5-12y: 1.3mg NE/MJ

Vitamin B6: 5-6y: 0.6mg/d, 7-10y: 0.9mg/d and 11-12y: 1.2mg/d

Dietary folate equivalents: 5-6y: 110µg/d, 7-10y: 160µg/d and 11-12y: 210µg/d

Calcium: 5-10y: 680mg/d and 11-12y: 960g/d

Iron: 5-6y: 5mg/d, 7-11y: 8mg, 12y boys; 8mg/d and 12y girls: 7mg/d

Zinc: 5-6y: 4.6mg/d, 7-10y: 6.2mg and 11-12y: 8.9mg/d

Tolerable Upper Level of Intake: the maximum level of total chronic daily intake of a nutrient (from all sources) judged to be unlikely to pose a risk of adverse health effects to individuals.

Vitamin A: 5-6y: 1100µg/d, 7-10y: 1500µg/d and 11-12y: 2000µg/d

Vitamin D: 5-10y: 50µg/d and 11-12y: 100µg/d

Vitamin E: 5-6y: 120mg/d, 7-10y: 160mg/d and 11-12y: 220mg/d

Niacin: 5-6y: 3mg/d, 7-10y: 4mg/d and 11-12y: 6mg/d

Vitamin B6: 5-6y: 7mg/d, 7-10y: 10mg/d and 11-12y: 15mg/d

Folic acid: 5-6y: 300µg/d, 7-10y: 400µg/d and 11-12y: 600µg/d

Calcium: 5-8y: 2500mg/d and 9-12y: 3000mg/d

Magnesium salts: 5-12y: 250mg/d

Zinc: 5-6y: 10mg/d, 7-10y: 13mg/d and 11-12y: 18mg/d

The United States Institute of Medicine

Recommended Daily Allowance: refers to the level of nutrient intake that is adequate for virtually all people in a population group and is assumed to meet the requirements of 97-98% of the individuals in the population.

Vitamin D: 15µg/d

Estimated Average Requirement: the amount of a nutrient that is estimated to meet the needs of 50% of a particular population.

Vitamin D: 5-12y: 10µg/d

Calcium: 5-12y: 1100mg/d

Iron: 4-8y: 4.1mg/d, 9-13y girls: 5.7mg/d and 9-13y boys: 5.9mg/d

Zinc: 5-12y: 7mg/d

Tolerable Upper Level of Intake: the maximum level of total chronic daily intake of a nutrient (from all sources) judged to be unlikely to pose a risk of adverse health effects to individuals.

Vitamin C: 5-8y: 650mg/d and 9-12y: 1200µg/d

Vitamin B12: 5-6y: 300µg/d, 7-10y: 400µg/d and 11-12y: 600µg/d

Folic acid: 4-8y: 400µg/d and 9-12y: 600µg/d

Zinc: 4-8y: 12mg/d and 9-12y: 23mg/d

The United Kingdom Department of Health

Estimated Average Requirement: the amount of a nutrient that is estimated to meet the needs of 50% of a particular population.

Vitamin B12: 5-6y: 0.7µg/d, 7-10y: 0.8µg/d and 11-12y: 1.0µg/d

Magnesium: 5-6y: 90mg/d, 7-10y: 150mg/d and 11-12y: 230mg/d

Lower Reference Nutrient Intake:

Folate: 5-12y: 100µg/d

Calcium: 4-6y: 275mg/d and 7-10y: 325mg/d

Magnesium: 4-6y: 70mg/d and 7-10y: 115mg/d

Zinc: 5-12y: 5.3mg/d

Appendix II: IUNA 19 Food Groups

1. Grains, rice, pasta & savouries

2. Bread & rolls

3. Breakfast cereals

4. Biscuits, cakes & pastries

5. Milk & yogurts

6. Creams, ice-creams & chilled desserts

7. Cheeses

8. Butter, spreading fats & oils

9. Eggs & egg dishes

10. Potatoes & potato products

11. Vegetables & vegetable dishes

12. Fruit & fruit juices

13. Fish & fish dishes

14. Meat & meat products

15. Beverages

16. Sugars, confectionery, preserves & savoury snacks

17. Soups, sauces & miscellaneous foods

18. Nutritional supplements

19. Nuts, seeds, herbs & spices

Appendix III: List of the dietary supplements included in the NCFS II Dietary Supplement Database (2017-18)

Multivitamin and mineral supplements (*n* 31):

Salus Floradix Iron and B Vitamin Tablets

Pharmaton Kiddi Crunchy Chewable Tablets

Haliborange Multivitamins Calcium & Iron Everyday Health Chewable Tablets

Salus Floradix Liquid Iron and Vitamin Formula

Centrum Junior MultiVitamin Chewable Tablets

Sona Multiplus Junior Liquid Food Supplement with Sweetener

Salus Floradix Kindervital For Children Liquid Multivitamin

CaliVita Vit D3 and K2 Tabs

Abbott Pediasure Powder Chocolate Flavour

Vivioptal Junior Orange Flavour Syrup

Rowa Yummy Gummy Bear Multi-Vitamin Mineral Chewable Supplement

Optima Junior Multi Plus Chewable Multivitamin & Mineral

Holland & Barrett Healthy Kids Chewable Vitamin C

Zahler Junior Multi Complete One-Daily Multi-Vitamin Cherry Flavour Chewable

Forever Living Kids Multivitamin

Lil Critters Immune C Plus Zinc

Nature’s Way Alive! Children’s Chewable Multi-Vitamin

Pharmaton Kiddi Health Liquid Multivitamin

Viridian ViridiKid Multivitamin and Mineral Capsules

Kid's One Rainbow Light Food-Based Multivitamin

Fergloblin Liquid (Gentle Iron, Folic Acid and B12)

Nature's Plus Animal Parade Gold Multivitamin and Mineral Food Supplement Vit A, Vit C, Vit D3

Centrum Kids Multivitamin Chewable Tablets

Kirkman Super Nu Thera Caplets

Lidl MinaVit Multivitamin and Iron Tablets

Boot's Kids Chewable A-Z Complete

Tesco Kids Chewable Multivitamin & Minerals

Aldi Activ Max Kids Health Multivitamin Chewable

Pharmaton Multivitamin Capsules with Ginseng

Benevits Kids Multivitamin Syrup

Solgar Kangavites Complete Multivitamin and Mineral Formula Chewable

Multivitamin supplements (*n* 26):

Haliborange Softies Multivitamins Everyday Health Chewable

Haliborange Softies Omega-3 & Multivitamins Chewable

Bassetts Vitamins Raspberry Flavour Chewable Multivitamins

Seven Seas Simply Timeless Omega 3 Fish Oil Plus Cod Liver Oil High Strength Capsules

Haliborange Vitamins A C & D Orange Flavour Chewable Tablets

Lil Critters Gummy Vites Multi-Vitamin & Mineral Formula

Bio Linen Oil

Vitabiotics WellKid Multi Vitamin Smart Chewable

Eskimo 3 Kids Tutti Frutti Liquid Food Supplement

Korean Red Ginseng Kids Food Supplement

Bassetts Vitamins Multivitamins plus Omega 3 Tropical Flavour Chewable

Vitamin Store Children's Jellies A, C, D and E Strawberry Flavour

Juice Plus Vegetable Gummy

Juice Plus Fruit Gummy

Haliborange Mr. Men Little Miss Omega-3 & Multivitamins Softies

Salus Floradix Epresat Liquid Multivitamin Formula

Seven Seas Simply Timeless Omega-3 Fish Oil Plus Cod Liver Oil with Vitamin D Orange Flavour

Eskimo 3 Kids Omega 3,6,9, Vit D and E Liquid Supplement

Optisana Multivitamins Effervescent Tablets Orange Flavour

Kids Health MultiVitamin

Lidl Minavit Cod Liver Oil Capsules

Lidl MinaVit Kids Chewable Multivitamin

Bassetts Vitamins Strawberry Flavour Chewable Multivitamins

Tran Suplement Diety A & D with Omega 3 Capsules

Lil Critters Omega 3 Gummy Fish

Vitabiotics Wellkid Multivitamins & Flaxseed Oil Soft Jelly Pastilles

Single vitamin D supplements (*n* 9):

Vita buer D3

D Lux Vitamin D Oral Spray

Sona Vitamin D Capsule

Tesco Vitamin D Tablets

Vigantol Oel 0.5mg/ml Vitamin D3 Liquid Supplement

Beeline Vitamin D3 Drops

Nature's Plus Animal Parade Sugar Free Vitamin D3

Pure Series Vitamin D3 Capsules

Quest Once a Day Sunshine D Tablets

Kelkin Junior Vitamin D3 Supplement Tablets

Single vitamin C (*n* 9):

Holland & Barrett Immune System Support Vitamin C and Rose Hips Caplets

Sambucol Black Elderberry Liquid

Rutinoscorbin Vitamin C Tablets

Aldi Activ Max Immune Health Vitamin C 200mg Tablets

CaliVita Powdered Vitamin C Supplement

Boot's Immune Health Vitamin C 1000mg Efferescent Tablets

Kelkin Vitamin C Effervescent Tablets

Optisana Vitamin C 1000mg Mandarin Flavour Effervescent Tablets

Tesco Chewable Vitamin C 200mg

Single vitamin E (*n* 1):

Naturell Koenzyem Q10 with Vitamin E Capsule

Single vitamin and mineral (*n* 4):

Lil Critters Calcium and Vitamin D3 Chewable

Tesco Calcium and Vitamin D Tablets

Haliborange Mr. Men Little Miss Calcium & Vitamin D Softies Strawberry Flavour

Bio Care Vitamin C 500mg Capsules

Fish oils (*n* 6):

Potters Family Capsules Naturally Sources Omega-3 with Omega-6

Udo's Choice Ultimate Oil Blend

Clean Marine Krill Oil for Kids

GNC Triple Strength Fish Oil Capsule

Wileys Finest Wild Alaskan Fish Oil Peak EPA

Eskimo-3 Kids Chewable DHA+

Non-nutritional supplements (*n* 15):

Holland & Barrett Mega Acidophilus with Pectin Capsules

Udo's Choice Infant Blend Microbiotics

A. Vogel Echinacea

CaliVita Garlic Capsule Soft Gels

Nature's Plus Animal Parade Acidophi Kidz Chewable Tablet

OptiBac Probiotics

Forever Living Aloe Vera Gel

Forever Living Bee Pollen

Forever Living Garlic-Thyme

Pukka Elderberry Syrup

CaliVita ParaProtex

Klaire Labs Vital-Zymes Compete

Klaire Labs Ther Biotic Complete

Sona L Lysine 1000mg Tablets

Naturell L-Karnityna 250mg (L-Carnitine) Tablet