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Title Page

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Abstract

Assessing energy intake (EI) in children and adolescents is essential for monitoring population nutrition trends and interpreting clinical outcomes. The aim of this review was to examine the validity of dietary assessment methods for estimating EI in children and adolescents when compared with total energy expenditure (TEE) measured using doubly labelled water (DLW). Six online databases were searched to identify articles published in English. Studies were included if they were conducted in participants aged ≤18 years, if they estimated EI via a dietary assessment method, and if they compared this estimate to TEE measured using the DLW method.

The search strategy identified 240 studies, of which 13 articles (12 studies) (n= 306 children) met the selection criteria. Five studies were carried out in children aged five to 11 years with dietary intake of children reported by parents/caregivers. The most common dietary assessment methods used were food frequency questionnaires (n = 5) and weighed food records (n = 4). All methods were found to have some level of misreporting. Child characteristics including weight status, age and sex were not found to consistently influence the accuracy of reported EI. Five studies employing technology-assisted approaches for assessing dietary intake in children were identified and reported mixed findings.

Validity studies using DLW remain sparse in the literature studies including participants less than five years or older than 11 years and from diverse ethnicities and socioeconomic backgrounds are warranted to explore other demographic differences that may affect the accuracy of dietary assessment methods. While reported in few studies, technology assisted methods were found to perform equally well in estimating intakes when compared to DLW and other traditional forms of dietary assessment.

Introduction

Accurate methods for assessing energy intake (EI) in children and adolescents are essential for monitoring population nutrition trends, interpreting clinical outcomes, and refining energy-based recommendations (1-4). However, research suggests obtaining accurate data on dietary intake among paediatric populations is difficult due to developmental factors present at different ages from early childhood to late adolescence (5). Previous studies have shown children younger than approximately eight years old cannot accurately self-report dietary intake and require parents to be used as proxy reporters, introducing a degree of reporting bias (5). Between the ages of 8 and 12 years, there is a transition period during which children develop and show increased independence and maybe more increasingly used to report their own intakes. There is limited evidence that joint recalls (by parents and child) of children's intake are more accurate than child only recalls, there are currently no recommendations regarding who is the most appropriate reporter of dietary intake during this transitory age range (2, 6). In a previous review it was identified that for younger children parental report is considered good estimate however as the child ages misreporting becomes more pronounced (7). Furthermore, studies have demonstrated older children (15 to 18 years) are more likely to underreport dietary intake compared to younger children (9 to 12 years) (1, 8, 9). Factors from previous studies and reviews suggested to contribute to a higher proportion of underreporting among older adolescent children compared to younger children include irregular eating patterns, an increase in meals away from home, and less enthusiasm for recording food intake (3) (4). Despite difficulties associated with accurately measuring dietary intake in children and adolescents, self- or proxy-reported intake remains an important element of nutrition research (10). As such, there is a need for validated dietary assessment methods for use in paediatric populations (1, 2, 4).

Validity describes the ability of a dietary assessment method to measure the 'true' dietary intake of the individual (1). A method is described as valid if reported dietary intake is not significantly different to actual dietary intake consumed (1). As measuring absolute validity poses significant practical difficulties, nutrition research has often focused on comparative validity (11). Comparative validity refers to the direct comparison of reported intake from a dietary assessment method against an alternative method (often known as the reference method), which has a greater degree of demonstrated validity (11). Total energy expenditure (TEE) as measured by DLW is considered the preferred reference method for establishing relative validity because it provides an objective measure, independent of systematic biases (e.g. recall and reporting bias), and because it allows measurement of individual's EE in their normal surroundings (12, 13). The DLW method has been validated for use in populations ranging from infants to the elderly, and has been shown to be accurate within 1-2% (14). The comparison of estimated EI to TEE (measured by DLW) can be made because it is fair to assume that TEE equals EI under conditions of energy balance, and that the energy used for growth in childhood and adolescence is negligible at ~2% of EI and thus does not need to be accounted for in energy balance studies (15).

A previous review conducted in 2010 (2) (n=15 studies) reported that based on the available evidence, the 24-hour multiple-pass recall method conducted over three days provided the best estimate of EI in children aged four to 11 years, whilst weighed food records provided the best estimate for younger children (6 months to 4 years) and diet histories for adolescents aged ≥ 16 years and no tools were reported with assisted technology components. Rapid advances in digital technologies in recent years such as wearable cameras, smartphones and hand-held devices has seen an evolution of traditional dietary assessment methods to incorporate such technologies. For example, image based methods taken with handheld devices or wearable cameras have been used to assist traditional dietary assessment methods for portion size estimations, whilst image-based methods have been used to capture images as the primary record of dietary intake (16-18). A recent paper by Haddad et al (19) published in Nature states that one of the ten global research priorities is the need to make more data on diets widely available with new technology based tools and adapted methods being developed for use in low income countries to overcome language barriers (20). Currently, the validity of these new technology-based approaches for assessing dietary intake in paediatric populations has not been reviewed.

The aim of this review was to examine newly published evidence on the validity of dietary assessment methods to estimate EI in children and adolescents. A review of such evidence is needed to determine whether new research has emerged addressing evidence gaps identified in the previous review (2) and whether developments in dietary assessment methods, particularly new technology based approaches, change recommendations made by the previous review.

Materials and Methods

The methodology employed for this review update was the same as that used in the previously published review (2). Briefly, relevant articles were identified and retrieved from online database searching, hand-searching reference lists, and cited reference searches (Figure 1). Six online databases were searched including: Cumulative Index to Nursing and Allied Health Literature (CINAHL), MEDLINE, ProQuest, Embase, Scopus and Web of Science. Keywords and combinations used to search databases included child, adolescent, paediatric (pediatric), teen, dietary assessment, food frequency questionnaire, dietary recall, diet record, energy intake, energy expenditure, doubly labelled (labeled) water, and validation. See full search strategy in Supplementary table 1. Articles were included if they met all of the following criteria: 1) included participants who were children or adolescents (aged 0-18 years), 2) reported EI estimated using a dietary assessment method, 3) used TEE measured by DLW as a reference measure, and 4) compared EI with TEE, or reported data to allow such comparisons to be made. Articles were limited to those printed in English-language journals and published between January 2009 and February 2019 to coincide with the inclusion period of the previous review. Studies conducted in participants with medical conditions were not excluded from the review as the objective was to examine comparative validity not factors influencing dietary intake, and it has previously been acknowledged that DLW is a preferred method for determining energy requirements in both healthy and clinical populations (21). The titles and abstracts of studies identified in the literature search were screened independently by two reviewers (TB and JS) to assess eligibility for full-text review. If a decision regarding eligibility could not be determined from review of the abstract, the full-text article was retrieved. Pairs of review authors (TB, JS or SG) independently screened full-texts articles and discrepancies regarding study inclusion was resolved by a third reviewer. For all ineligible studies, the primary reason for exclusion was recorded.

Risk of Bias: The quality of included studies was assessed by three reviewers (SG, DC and TB) using the American Dietetic Association Quality Criteria Checklist of primary studies, which assesses study quality based on participant selection, withdrawals, outcome descriptions and author affiliations (22). A study is rated as having ‘positive’ quality if it satisfies a majority of the quality criteria, including four priority criteria pertaining to 1) Selection of study participants, 2) Comparability of study groups, 3) Intervention description and 4) Outcomes. A study is rated as having ‘neutral’ or ‘negative’ quality based on the number of criteria that are met/ not met (22). Data were extracted from studies by one reviewer (SG) using a standard template and checked by another reviewer independently (TB). The protocol was registered on Prospero CRD42017064545 and reporting adheres to PRISMA guidelines.

The reporting status of dietary assessment methods in each of the included studies was determined from either that listed within the results section of the article, or for studies where this was not listed, was calculated as EI/TEE. The reporting status for each study was classified using three pre-defined categories for reporting accuracy, consistent with other reviews as per the process in the previous review (2). These three categories included: adequate reporters (EI/TEE within the 95% confidence limits 0.84 to 1.16), under-reporters (EI/TEE <0.84), and over-reporters (EI/TEE >1.16), in line with previous definitions (23). Consistent another systematic review on this topic, values of under and over-reporting were expressed as the percent less than or more than 100%. Where available, results were extracted from included studies when dietary method reporting accuracy was correlated to participant characteristics. These characteristics included the sex, age, weight status and ethnicity of children, and parent sex. Limits of agreement (LOA) were extracted from studies where available to determine agreement between reported EI and TEE and the magnitude and direction of any reporting bias. The Bland Altman approach was used in the majority of studies (10 of 11) to assess LOA and this approach for assessing agreement is described in detail in the previous review (2). Dietary assessment methods were classified as technology-based if any form of communication and/or information technology was used, such as mobile or smartphone, the Internet or sensors collecting image, movement or auditory data. The technology could be applied to either the collection, analysis or interpretation of the dietary method.

Results

A total of 240 articles were identified using the search strategy outlined in Figure 1. Of these, 27 studies were retrieved for full-text review and critical appraisal. The critical appraisal process resulted in the inclusion of 13 articles describing 12 studies, which were all cross-sectional in design. Reasons for exclusion at full-text review included adult studies (n= 3), no dietary assessment method (n= 3), EI not reported (n= 2), DLW not used as reference measure (n= 1), outside of included date range (n= 1) and not a study (e.g. conference abstract) (n= 4). Of the 12 studies, four studies were conducted in Australia (24-27), three in Sweden (28-31) , two in The United States of America (32, 33), one in The Netherlands (34), one in Denmark (35), and one as a multi-centre study across two countries (Belgium and Spain) (36). Eleven out of the 12 studies were rated as having positive quality with one study rated neutral quality (37) (Supplementary Table 2).

Table 1 summarises participant characteristics, dietary assessment methods, DLW reporting period, dosage amounts, number of collection days of urine samples, and body weight assessment for each study. Five out of the 12 studies reported participant bodyweight was measured at baseline only (25-27, 31, 35), whilst seven included both pre- and post-dosing measures, with seven reporting no significant change in weight over the DLW collection period and not reporting the results of both measures (33). All but one study (30) reported a urine collection pre-dose of DLW and the total number of urine collections. The length of DLW collection ranged from seven to 14 days, and the number of urine samples collected across the study durations ranged from three to 11 samples per participant.

Measures of both EI and TEE were reported for 306 children and adolescents across the 12 studies. The mean sample size was 26, and ranged from nine to 38 children. Studies included participants who were reported to be community-dwelling individuals with the age of participants ranging from nine months to 11 years. Five studies were conducted in children of primary school age (five to 11 years) (24, 28, 36-38), seven were conducted in in age groups that included younger age groups (<5 years) (25, 26, 30, 31, 33-35), and fewer studies were conducted in adolescents (n = 1) (37). The study by Zhang et al 2015 (37) included participants aged >18years, it was included in this review because the majority of participants were aged ≤18years. In all included studies, the majority of participants (children) were white, however the children in one study by Nicklas et al (33) (n=39 children) participants identified as either African American (n=19) or Hispanic children (n=20). Four studies included participants that were overweight or obese (28, 30, 36, 37), and three studies were conducted in children with medical conditions including Cerebral Palsy (26), Duchenne Muscular Dystrophy (27), and childhood cancer survivors (37). The majority of studies (8 out of 12) used a single dietary assessment method to estimate dietary EI, whilst four studies used two separate dietary assessment methods (25, 28, 29, 31, 37, 39).

The most common dietary assessment methods used were food frequency questionnaires (FFQs) (n = 5) (25, 29, 34, 37, 39) and weighed food records (WFRs) (n = 4) (25-27, 39). Reporting periods for FFQs ranged from one week to six months, and one study used an FFQ administered via online (29). Two studies used 24-hour recalls (36, 37), with one using the multiple pass recall (MPR) method (37), and the other using a computerised self-administered tool (36). Four studies used an image-based method (29-31, 33) all were administered using smart-phones, including three studies that utilised remote food photography (RFPM) (28, 30, 33). One study assessed EI using a pre-coded food record (PFR) (35). Five of the 12 studies examined the relative validity of technology-based approaches for assessing dietary intake in children (28-31, 33, 36). Of the technology-based methods, Bornhorst et al (40) used a computerised 24hr recall and Nicklas et al (33)which investigated the use of an image based method directly compared EI estimated from these methods with the TEE measured using DLW technique only, therefore no inferences can be made from those studies that technology-based methods performed better than traditional methods. In contrast, Johannsson et al (31), Nystrom et al (28, 41) and Henriksson et al (42) compared technology assisted dietary assessment method with DLW and additionally another dietary assessment method which was more often used to compared food groupings rather than energy intake. In these aforementioned studies no significant differences were reported between estimations of EI using the technology assisted method and more traditional methods when compared to TEE. However there were wide variations in the limits of agreement or the technology assisted method was only utilised for a short period of time (i.e. one day) which is not representative of usual intake. The studies that report on a technology-assisted methods demonstrate some evidence that technology based methods perform similarly to other methods. Particularly in the study by Nystrom et al (28, 41), the TECH image-based method which was also reported and used by Henriksson (42)had a smaller under-estimation of EI than the online FFQ, the TECH image based method estimated a mean intake of 5820kJ (TECH) compared with TEE from DLW of 6040kJ ,compared with 4670kJ from online FFQ.

In all studies, EI was measured by the dietary assessment methods within the same time period as the DLW collection period, however for some methods such as FFQ, the reporting period of the tool (i.e. previous six months) covered a longer collection period than the DLW (24, 25). For the majority of included studies, the average EI value of the dietary assessment method was compared with TEE. Participants and/or parents and/ or caregivers were instructed to report usual dietary intakes for studies using 24-hour recalls, WFR, PFR and RFPM. All but one of these studies (30) collected dietary intakes of children on both weekdays and weekends in an attempt to capture diet variation. Dietary intake of children was reported by parents/caregivers in all studies with one study in young children also using teachers in the pre-school setting (33). Only two studies (24, 25) reported the sex of the parent/caregiver (e.g. mother or father) reporting dietary intake, with both mothers and fathers reporting data in one study (39), and mostly mothers reporting data in the other (25). Only two studies used child reported dietary intakes (24, 37), with one of these studies including child reported dietary intake data in addition to parent/caregiver reports (39), and the other using child reported data alone for children aged >12 years (37). EI was estimated from reported dietary intake in all studies a country specific food composition tables and nutrient analysis software was used (25-27, 29, 30, 34, 35, 37, 39).

Table 2 provides a detailed description of the included studies and their LOA for EI compared to TEE, where reported. Across the 12 included studies, all dietary assessment methods produced some degree of misreporting. For FFQs, significant under-reporting was found in three out of five studies (-7% to -23% of estimated EI) (29, 34, 37). However in the study by Dutman and colleagues (34), which investigated four FFQ variations to assess the influence of reviewing and data processing on reporting accuracy, underreporting was only significant for one FFQ variation using standardised beverage portions (see Table 1 - Dutman et al (34) FFQ scenario 4), and only in boys aged four to six years. Substantial over-reporting with FFQ was found in one study by Burrows and colleagues (24), with the magnitude of over-reporting being greatest when mothers reported their children's intake (+44% of estimated EI), followed by fathers' reporting (+21%), then children's reports of their own intakes (+13%). For WFRs, significant under-reporting was found in one (26) of four (24-27) studies (-10% of estimated EI) (26). Significant over-reporting was found in the one study by Gondolf and colleagues using PFR (+24% of estimated EI) (35). All studies reported the level of misreporting at the group level with very few studies reporting the accuracy of the tool at the individual level. Only one study which used a multi-day WFR reported that the tool may be of use individual children (26). In other studies the wide LOA was one of the major reasons for reporting a tool maynot be considered accurate at the individual level.

Table 3 displays information for 3 of the 12 studies for which the reporting status (under-reporter, adequate reporter, over- reporter) was included by the characteristics of the child and/ or parent (24, 34, 36). Studies that did not report this information were not included in the table. Of the three studies that examined associations between reporting status and characteristics of the child and/ or parent including child weight status, child sex and child age and parent sex, misreporting was not significantly associated with child weight status (27, 36, 37) or sex (34, 36, 37). For age, one study found no significant association with reporting status (36), whilst one study in childhood cancer survivors found older children (>12yrs) tended to (self) underreport EI to a greater degree than when parents reported for younger children (< 12 yrs), although differences were not significant (37).

Several studies (n= 5) (27, 28, 30, 34, 36) reported the dietary assessment method used had provided a goodestimate of EI at the group level whereby reported EI did not differ significantly from mean TEE measured by DLW. However, at the individual level accuracy was reduced across all studies, and wide LOA values reported indicate large variations were present. In five studies (25, 29, 30, 35, 36), individual variance between EI and TEE was related to EI magnitude, with greater under-reporting bias at low EI values and over-reporting bias at high EI values however in one study in young children approximately 12months of age no difference was found across varying intake of EI reported by parents (43). Two studies concluded the dietary assessment method evaluated could not be used for assessing EI energy at the group or individual level including one study using RFPM via smart-phone however this hada collection period of 1 day (30), and one study using an online FFQ with a reporting period of two months (29).

Discussion

The purpose of this review was to update a previous review (2) and examine newly published literature on the validity of dietary assessment methods in children and adolescents using the comparative method of DLW. Overall, this review identified 12 dietary validation studies undertaken since the previous review in 2010, which have been conducted in seven counties. The lack of studies conducted in developing countries is most likely due to limited access to DLW; transportation issues including to and from field sites, transport in and/ out of countries with differing importation rules and regulations given analysis facilities are often limited and often located outside developing countries. Additional issues in these regions include a lack of storage options in regions with a lack of electrical supply for refrigeration of samples and the high costs of DLW, despite that this has decreased over time. The overall participant burden for dietary assessment research involving biomarkers remains substantially high as includes the dietary assessment via a specified method as well as urine samples, and research burden involving the protocol for DLW dosing and analysis procedures. Five of the 12 studies in this review investigated the relative validity of a technology-based approaches for assessing dietary intake in children (28-31, 33, 36).

Five studies included in this review were carried out in primary school aged children and seven studies included younger children <5 years suggesting since the previous review a growth in the number of studies in younger children and still few were carried out in adolescent populations. Few studies included ethnic groups other than non-Hispanic white. Interestingly, the update of this review, identified three studies conducted in paediatric populations with specific medical conditions where estimated energy requirements might differ from the general paediatric population. WFRs and FFQs were the most common dietary assessment method used in the identified studies. Despite the age range of children and adolescents studied, parents (mostly mothers) were used as proxy reporters in all included studies. However, in the one included study comparing the EI reporting accuracy of parental proxies, fathers were found to report more accurately when compared to DLW than mothers when using a FFQ (25).

The previous review found inconsistent results concerning the relationship between weight status, age, and sex of children with EI reporting accuracy, however four of the studies in this review that examined these relationships found them to non-significant (2). Child weight status was investigated in three studies with none showing a significant effect on EI reporting accuracy (36, 37, 44). Three studies found no significant effect on EI reporting accuracy by sex (34, 36, 37), one study found no significant effect by age (36), whilst a statistical trend was shown in one study of adolescents where it was reported that adolescents under-report to a greater extent when compared to younger children (37) which is supported by a previous review (7). One study (24) compared the accuracy of child versus parent reports using a FFQ amongst children in the transitional age group for reporting (eight to 11 years) where currently there is no consensus regarding who is the most appropriate reporter of dietary intake (6). This study found children were the most accurate EI reporters, followed by fathers and then mothers. Such findings suggest EI reporting accuracy may be affected by not only the type of dietary method used, but also by reporter, however validation studies are needed on dietary reporting accuracy given the potential implications for future practice. This aforementioned study (24) was limited by a small sample size (n=9) and in addition, a parent also completed a WFR and FFQ who may have had an advantage in terms of knowledge of the child's intake for completing the FFQ over the parent who did/ did not complete the weighed food records. There is no empirical justification (i.e., validation studies) for the use or supposition that joint recalls on children's intake are more accurate than child- only recalls.

Of the 12 studies included in the review, five utilised a form of a technology assisted method (28-31, 33, 36). This number, while still small represents a growth in the field, with none identified in the previous review (2). These technology-based tools in the current review included one study utilising a FFQ completed online (29), one study using a 24-hour recall delivered via computerised method (36), and four studies using image-based/ image assisted food records (28, 30, 31, 33). From two of the three studies evaluating RFPM, one study found no significant differences between reported and measured values at the group level, but not individual. The other study found the RFPM to be not valid for use at the group or individual level (30) however an important note of difference between these studies however was the use of different data collection periods (1 day (30) vs. 4 days (28)). It is also acknowledged that one day of dietary intake is not representative of usual or habitual intake so these results need to be considered and interpreted in this context. Mixed findings and a limited number of studies evaluating image-based methods suggests the current evidence base cannot adequately shed light on the validity of image-based methods in children and adolescents, and more research is needed. Image-based and image-assisted dietary assessment continues to grow, in particular due to the increased ubiquity of mobile devices such as smartphones. Image-based food records collected by mobile phones are considered by adolescents (11-15 years) as an acceptable method for assessing diet , and have been studied in children of young age (45) with one study in this review using child hood pre-school teachers to capture food intake while in care in addition to mothers in the home environment (33) . The FFQ administered and completed online by Nystrom et al (29) was found to have significant misreporting which aligns with broader research suggesting that FFQs have a degree of misreporting. A 2012 systematic review by Illner et al (46) investigating innovative technologies in dietary assessment concluded these tools would be more cost- and time-effective, however bias related to self-report may still need to be addressed. Wearable devices including wrist and bite sensors as well as passive camera technologies present a new addition to the field of dietary assessment; however, these have yet to be tested in paediatric populations.

As evident in the current and existing reviews (47) several statistical tests are currently subjectively applied to evaluate the validity of dietary assessment methods including correlation, percentage difference and Bland Altman analysis, however, such tests provide information on different facets of validity and there is no consensus on the type of test or cut-points that should be applied to reflect ‘acceptable’ validity. This subsequently creates variable definitions of ‘acceptable agreement’ are applied in published studies which examine dietary assessment tool validity, this lack of consensus and subjectivity is a significant limitation for this area of research. A recent review by Lombard et.al (48) highlighted the need for further research to establish standardised measures and cut-points for validating dietary assessment methods. This point requires consideration both for clinical purposes as well as statistical significance for what is defined as ‘acceptable agreement’. The level of misreporting in this review was determined using cut points of EI/ TEE as this has been previously used (2). Many authors make their own judgements within studies about whether their tool is considered ‘acceptable’ ‘good’ or ‘valid’ which adds to the subjectivity in this area of research. Further limitations of this review include the small sample sizes of eligible studies. The inclusion of studies from English language journals only, may have resulted in potentially relevant articles being overlooked by the search strategy. Finally, the findings of this review are subject to the limitations of TEE measured by DLW as a reference standard for dietary assessment method validation studies. Specifically, observation intervals for DLW are time-limited by the biological half-lives of the ^{18}O and ^{2}H isotopes, which vary according to the age and physical activity levels of participants (49) in addition to the ambient temperature. Observation intervals range from three days in young children or extremely active adults to three or four weeks in very sedentary and old participants (49, 50). Due to the biological half-life and water turnover, the change in isotope enrichment can be too small to obtain an accurate measure of the elimination rate, whilst after longer intervals, the final enrichment can be too low to measure precisely (13). Furthermore, relative validation with DLW can only identify the direction and magnitude of reporting bias for only one dimension (i.e energy) of many possible dimensions of dietary intake. The results of DLW studies cannot provide important information regarding the sources of the observed bias, for example, inaccurate estimation of food portions, dietary intrusions (uneaten items reported as eaten) or dietary omissions (items eaten but unreported); nor can it determine whether misreporting was accidental or deliberate, or systematic across the whole diet or specific to certain food groups. This is problematic as previous reports have suggested misreporting of EI, specifically under-reporting, seems to occur with specific food items which are considered 'bad' or 'unhealthy' (51).

Overall, this review identified validation studies for diet assessment methods using DLW as a reference standard in the paediatric population. The review identified that the method of DLW as a validation measure in children remains sparse; studies including older than 11 years and from diverse ethnicities and socioeconomic backgrounds are warranted to explore other demographic differences that may affect the accuracy of dietary assessment methods. Technology-based methods were investigated in few studies with results identifying that methods which incorporate technology (e.g. image assisted or web based methods) for the collection and/or analysis of dietary intake data were found to perform equally well in estimating intakes when compared to DLW and other traditional forms of dietary assessment.

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The authors declare no conflict of interest

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Figure legends

Figure 1 Flow chart of method of determining studies to be included in the review of evaluating dietary methods for children 0-18yrs against the reference standard of doubly labelled water.