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The Relationship between Feeding and Non-Nutritive Sucking Behaviours and Speech Sound Development: A Systematic Review

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Keywords
Systematic review · Speech sound development · Speech disorder · Infant feeding · Non-nutritive sucking

Abstract
Background: Children with and without speech sound disorders (SSDs) are exposed to different patterns of infant feeding (breast/bottle-feeding) and may or may not engage in non-nutritive sucking (NNS) (pacifier/digit-sucking). Sucking and speech use similar oral musculature and structures, therefore it is possible that early sucking patterns may impact early speech sound development. The objective of this review is to synthesise the current evidence on the influence of feeding and NNS on the speech sound development of healthy full-term children. ***Summary:*** Electronic databases (PubMed, NHS CRD, EMBASE, MEDLINE) were searched using terms specific to feeding, NNS and speech sound development. All methodologies were considered. Studies were assessed for inclusion and quality by 2 reviewers. Of 1,031 initial results, 751 records were screened, and 5 primary studies were assessed for eligibility, 4 of which were included in the review. Evidence from the available literature on the relationship between feeding, NNS and speech sound development was inconsistent and inconclusive. An association between NNS duration and SSDs was the most consistent finding, reported by 3 of the 4 studies. Quality appraisal was carried out using the Appraisal Tool for Cross-Sectional Studies (AXIS). The included studies were found to be of moderate quality. ***Key Messages:*** This review found there is currently limited evidence on the relationship between feeding, NNS and speech sound development. Exploring this unclear relationship is important because of the overlapping physical mechanisms for feeding, NNS and speech production, and therefore the possibility that feeding and/or sucking behaviours may have the potential to impact on speech sound development. Further high-quality research into specific types of SSD using coherent clinically relevant assessment measures is needed to clarify the nature of the association between feeding, NNS and speech sound development, in order to inform and support families and health care professionals.

Background

There is much discussion and debate in the current literature on the advantages of breastfeeding over bottle-feeding, with positive cognitive outcomes often cited for lan-

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guage in later childhood [1–4]. However, evidence on the influence of feeding type on speech sound development is less readily available (e.g., Fox et al. [5]). Infant feeding (breast-, bottle- and mixed feeding) and non-nutritive sucking (NNS; pacifier/digit-sucking) are typically concurrent practices in the early lives of infants across the world [6–8]; therefore, it is important to consider both of these with regard to the impact on speech sound development. Evidence for an indirect detrimental impact of NNS on speech sound development is indicated with regard to dentition [9, 10] and hearing loss resulting from otitis media [11, 12]; however, the question of a potential direct impact of NNS on speech sound development is of interest due to the shared physical oral mechanisms of these 2 processes.

The mechanisms for successful bottle- and breastfeeding have been described and compared [13], and significant differences in sucking frequency, pressure and muscle activity have been identified and examined [14, 15]. Speech develops after these feeding mechanisms have become established and, given the shared musculature between speech and sucking, it is possible that speech sound development could be influenced by infants' early experiences of feeding and NNS [16, 17]. If this were the case, there may be observable differences in the speech sound production of children who have different patterns of feeding and NNS. Furthermore, it may be that different patterns of feeding and NNS are associated with speech sound disorder (SSD). In taking a mechanistic view of speech sound development, it is imperative to include both feeding and NNS in this review as either and both have significant influence on infants' early sucking experience. While some studies have described feeding, NNS and anatomical development in terms of atypical dentition and general oral development [18], the evidence of the relationships between the effects of feeding, NNS and speech sound development requires specific exploration to inform our understanding of these closely associated physical mechanisms. Many studies report evidence against a relationship between speech and non-speech mechanisms [19–23]. However, the individual work undertaken in such laboratory or clinic-based pieces of research are not compatible with understanding the complex development of that skillset in the very young child. The complexity of the development taking place during the early postnatal period means that consideration must be given to all 3 factors (feeding, NNS and speech sound development) as they are distinct but could also overlap and build on each other. Oral feeding from birth through infancy is a highly intensive and enduring physical behaviour. In addition, NNS behaviours often occur concurrently and can be comparably intensive and enduring from birth through to early childhood. Therefore, these very early intensive sucking behaviours (nutritive and non-nutritive) may have an inevitable influence on the development of motor control and sensorimotor feedback systems for these oral mechanisms and muscle groups. As such, it may be deemed improbable that any use of the oral musculature and articulators, for the purposes of subsequent speech development, from babble through to more refined speech sound productions, could occur in an entirely sterile way. Indeed, there is recent evidence that weak sucking in infants as young as 4 weeks of age is a significant predictor of persistent SSD at the age of 8 years [17]. Bunton [21] states that speech motor control is internally driven relating vocal tract changes to acoustic targets, while non-speech motor control is driven by external visuospatial or proprioceptive targets. However, within the very nature of clinical therapy, speech pathologists routinely employ visuospatial and proprioceptive cues to support speech production with a high frequency of success [24–26]. It can, therefore, be argued that speech and non-speech motor control cannot reasonably be considered entirely distinct. Indeed, some studies suggest a continuum for development between speech and non-speech tasks [27].

The aim of this systematic review is to synthesise the available evidence about the relationships between feeding (breastfeeding, bottle-feeding, mixed feeding methods), NNS behaviours and speech sound development and the incidence of SSD in children from birth to early childhood. This review addresses the following key questions:

- Is there evidence that infant feeding methods and NNS impact the way young children develop speech sounds?
- Is there evidence that children who experience different patterns of NNS as babies have different outcomes in their speech sound development, such as SSD?

This systematic review investigates the literature on feeding and NNS in the development of speech sounds in healthy, full-term, preschool children. For the avoidance of confusion, the term "speech sound development" is consistently written in full, whereas the term "speech sound disorder" is consistently abbreviated to SSD.

Methods

The review strategy was adapted from the Cochrane Collaboration systematic review methodology and uses a narrative synthesis [28] and guidance from Petticrew and Roberts [29]. A narrative synthesis approach was deemed most appropriate due to the mixed

Table 1. Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
– Children aged from birth onwards, with or without identified SSD – Report of infant feeding method AND presence or absence of non-nutritive sucking behaviours – Report of speech sound development outcome – A maximum of 15% of sample population born prematurely[1] – All methodologies and settings – International papers – Published in English language	– Children diagnosed with: – congenital disorders – identified learning difficulties – sensorineural hearing loss – Populations that had received speech pathology prior to or as part of the reported study

SSD, speech sound disorder. [1] Preterm birth classified as before 37 weeks completed gestation; World Health Organisation, https://www.who.int/news-room/fact-sheets/detail/preterm-birth (accessed October 16, 2019).

nature (qualitative and quantitative) of the data likely to be retrieved from the included papers. The review was registered on the PROSPERO database (CRD42018106268).

Identification of Selection Criteria

The Booth and Fry-Smith [30] PICO model (population, intervention, comparison, outcome) guided the development of the search strategy. The population of interest was children from birth into early childhood, with or without identified SSD. Table 1 lists the inclusion and exclusion criteria. Papers that reported samples including children born prematurely (>15% of the total sample), or those with diagnosed congenital disorders, identified learning difficulties, sensorineural hearing loss or populations that had received speech therapy intervention as part of the reported study were excluded from the review as these factors could also impact on speech sound development. This follows principles set out in similar systematic reviews in comparable cohorts (e.g., Roulstone et al. [31]). The intervention (behaviour) of interest was infant feeding, comparing outcomes in speech sounds across 3 comparator interventions – breastfeeding, bottle-feeding and mixed feeding. A second analysis considered presence or absence of NNS and its associations with speech sound outcomes. Only papers reporting both feeding and NNS with regard to speech sound development were included in this review. This systematic review of the current evidence base of journals and abstracts in this topic area considered all methodologies and settings. Globally accessible articles were examined, providing that they had been published, or were available, in the English language.

Outcomes of Interest

All included studies were required to include an outcome for speech sound development, whether qualitative (e.g., descriptive responses to parent questionnaires) or quantitative (e.g., statistical results obtained from objective clinical speech sound assessments; Table 1).

Search Strategy

The search strategy was designed in consultation with all authors and the search terms following a review of the Cochrane database, PROSPERO and database of abstracts of reviews of effectiveness. Discussions with a specialist speech and language pathologist working with children with SSD facilitated the identification of specific search terms relevant to all possible and appropriate terminology for speech sound development and SSD. A combination of "free text" terms with Boolean operators and truncations were used as follows:

Feeding Search Term

(((((((bottlefe*) OR (bottle-fe*) OR (bottle fe*)))) AND (((breastfe*) OR (breast-fe*) OR (breast fe*))))

NNS Search Term

(((dumm*) OR (pacifier*) OR (non-nutritive sucking)))

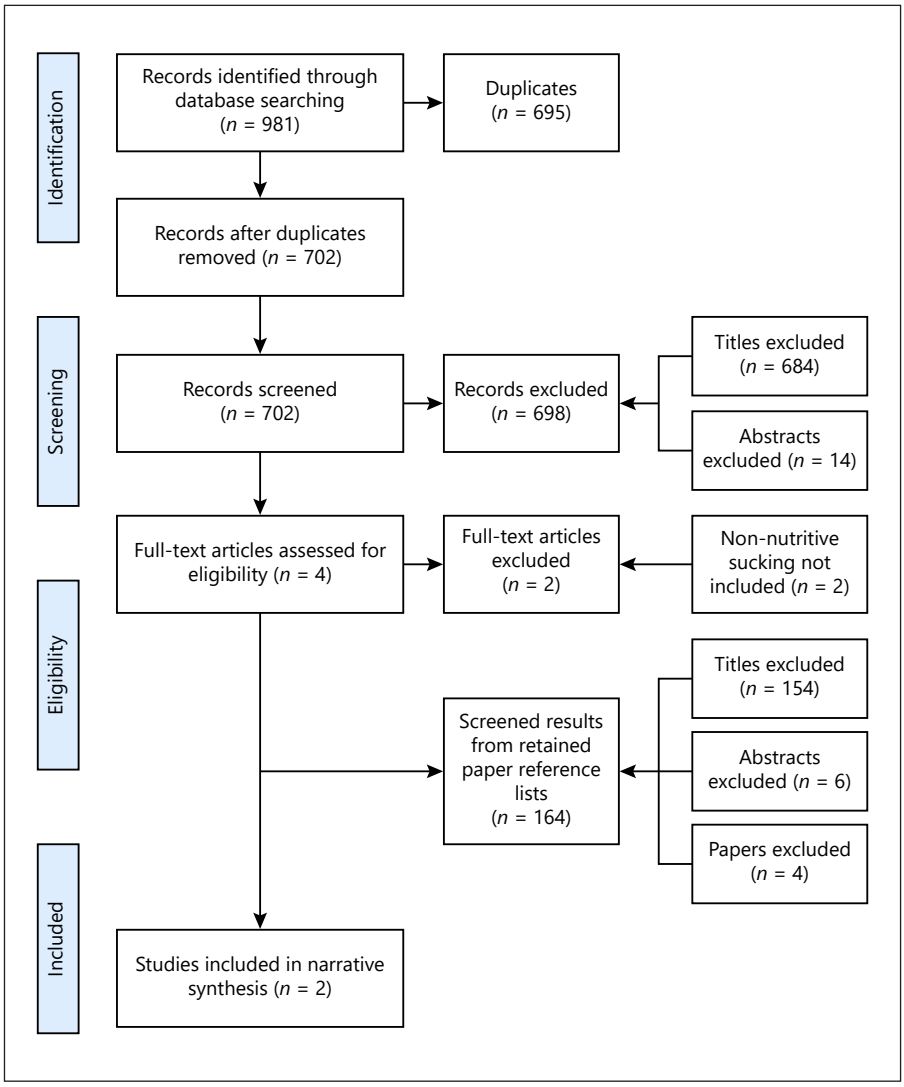
Speech Search Term

(((phon*) OR (speech) OR (speech disorder*) OR (speech impairment*) OR (speech sound disorder*) OR (speech sound difficult*) OR (speech retard*) OR (speech delay*) OR (speech disabilit*) OR (speech handicap*) OR (speech problem*)))))).

Findings of the Search Process

Traditional Search Strategy

The process and screening results for the database searches are described in Figure 1. Six separate searches were conducted in electronic databases: Pubmed (including PubMed Health, PubMed Central and NCBI Bookshelf Database), NHS CRD https://www.crd.york.ac.uk/CRDWeb/, OVID full text Journals, Embase 1974–2018 week 31, Ovid MEDLINE® and Epub Ahead of print, In-Process and Other Non-Indexed Citations, and Daily 1946 to July 27, 2018, CINAHL (including MEDLINE, Chicano Database, Child Development and Adolescent Studies) and AMED (Allied and Complementary Medicine) 1985 to July 2018. The PRISMA checklist [32] was followed, and a flow chart (Fig. 1) details the process of article selection from the formal database searches. Of 981 results, 702 papers were screened (following duplicate removal), and 698 were excluded in accordance with the validity criteria (Table 1). Four full-text articles were assessed for eligibility, 2 of which were excluded as they did not meet the inclusion criteria. All references from the 4 full-text papers were reviewed to check for additional articles. No appropriate papers were identified for inclusion in the full paper review stage. Only 2 papers were retained for inclusion in the narrative synthesis.



Color version available online

Fig. 1. PRISMA flow chart for traditional database searches.

Novel "Google" Search Strategy

An additional search of Google, a major search engine [33], was conducted using the simplified search term (infant feeding, speech development and sucking). Figure 2 shows the PRIMSA flow chart detailing the process of article screening and selection based on the Google search. The first 5 pages of the Google search, which represented 50 results, were screened for title relevance. Of these results, one article/post was a duplicate from the original formal database search and 48 were rejected; one paper was identified for inclusion in the full article review (Fig. 2). The Google search results also included a website with a bibliography, which was scrutinised. All of the papers had been previously identified in other searches.

In addition to the above searches, one unpublished paper [34], identified through discussions with review colleagues, was included in the screening process and subsequently retained. A total of 4 papers were included in the full review: 2 identified from traditional database searches, one from Google and one unpublished paper (Fig. 2).

Search Validation

The first author (S.B.) excluded irrelevant articles by screening titles and abstracts (Fig. 1). The remaining abstracts were fully reviewed by the first author and S.H. independently. Any disagreements were resolved through discussion, and when consensus was not met the article was included in the next stage. Four full-text articles were then retrieved and further considered against inclusion criteria by S.B. and S.H.

Data Extraction

The data extraction was undertaken by the first 2 reviewers using an adapted version of the published data extraction template for randomised controlled trials (RCT) and non-RCTs [35]. The results from the data extraction stage were discussed and agreed between the first and second reviewers.

Quality Appraisal

Selection of the quality appraisal tool was undertaken once the final list of included papers had been obtained and reviewed

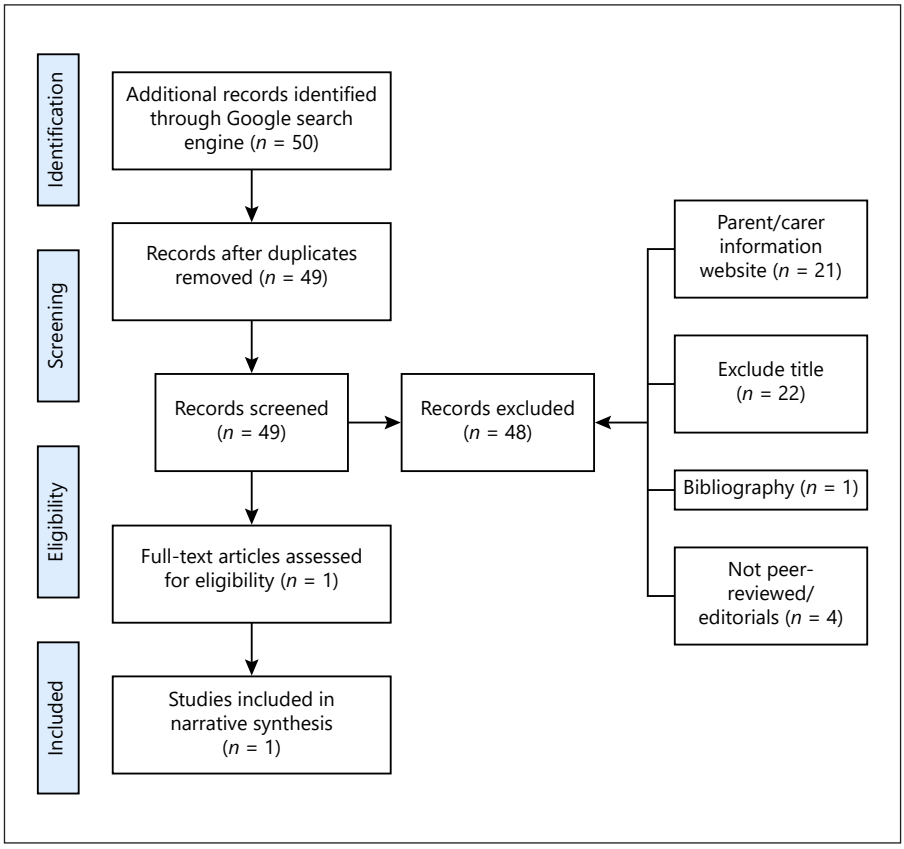


Fig. 2. PRISMA flow chart for Google search.

for their methodology. All 4 papers used a cross-sectional study design and subsequently the Appraisal Tool for Cross-Sectional Studies (AXIS) was used by S.B. and S.H. [36]. This tool was selected as the most appropriate for assessing the quality of the included papers because it has been specifically designed for the critical and quality appraisal of cross-sectional studies. The AXIS comprises 20 questions to appraise each paper's introduction, methods, results, discussion and other issues related to bias and ethical conduct. The authors assigned a score to each of the categories. Two for papers that clearly provide the information required by the AXIS tool, 1 if this information is partially present, but not clearly stated, and 0 if it is not present at all. This led to a maximum possible score of 40 on the AXIS. The quality appraisal of the included papers was completed separately by S.H. and S.B., and scoring consensus was reached following discussion.

Table 2 summarises the total quality scores awarded to each paper. Baker et al. [34] scored highest in the quality appraisal with almost 75% of the maximum score, while Pereira et al. [37] and Vieira et al. [38] obtained the lowest scores with just over 50% of the maximum.

Data Synthesis

Heterogeneity precluded meta-analysis; therefore, a narrative synthesis was used which summarised the findings descriptively and guided the synthesis.

Results

Review of the Data

The following section describes the presentation of the data in each of the 4 included papers.

Statistical Techniques

Variation was found in the statistical approaches employed across the 4 papers (Table 3). In their data Tables, Barbosa et al. [39, pp. 5–6] provided overall calculated probability, or *p* values, relating to each variable when compared with age or speech sound assessment classification. Specific *p* values corresponding to the reported odds ratios (ORs) and confidence intervals (CIs) for more specific associations presented in the results are not provided. In contrast, Vieira et al. [38] consistently reported associated ORs with 95% CIs alongside their *p* values. Baker et al. [34] and Pereira et al. [37] only reported *p* values.

Methodological Approaches

All 4 included papers used parent/carer questionnaires to collect data on participant feeding and sucking histories. Both Vieira et al. [38] and Pereira et al. [37] re-

Table 2. Quality assessment criteria and scoring

AXIS quality assessment criteria		Barbosa et al. [39], 2009	Vieira et al. [38], 2016	Pereira et al. [37], 2017	Baker et al. [60], 2018
Introduction					
1	Were the aims/objectives of the study clear?	2	2	2	2
Methods					
2	Was the study design appropriate for the stated aim(s)?	2	2	2	2
3	Was the sample size justified?	0	0	0	0
4	Was the target/reference population clearly defined? (Is it clear who the research was about?)	0	2	0	2
5	Was the sample frame taken from an appropriate population base so that it closely represented the target/reference population under investigation?	2	2	2	2
6	Was the selection process likely to select subjects/participants who were representative of the target/reference population under investigation?	2	2	2	2
7	Were measures undertaken to address and categorise non-responders?	0	0	0	0
8	Were the risk factor and outcome variable measures appropriate to the aims of the study?	2	1	1	2
9	Were the risk factor and outcome variables measured correctly using instruments/measurements that had been trialled, piloted or published previously?	1	1	0	1
10	Is it clear what was used to determine statistical significance and/or precision estimates? (e.g., *p* values, CIs)	2	2	2	2
11	Were the methods (including statistical methods) sufficiently described to enable them to be repeated?	2	2	2	2
Results					
12	Were the basic data adequately described?	2	2	1	2
13	Does the response rate raise concerns about non-response bias?	1	1	1	0
14	If appropriate, was information about non-responders described?	n.a.	n.a.	n.a.	n.a.
15	Were the results internally consistent?	2	0	0	2
16	Were the results presented for all the analyses described in the methods?	2	2	2	2
Discussion					
17	Were the authors' discussions and conclusions justified by the results?	1	0	1	2
18	Were the limitations of the study discussed?	2	0	2	2
Other					
19	Were there any funding sources or conflicts of interest that may affect the authors' interpretation of the results?	0	0	0	0
20	Was ethical approval or consent of participants obtained?	2	2	2	2
Total (max. 40)		27	23	22	29

AXIS, Appraisal Tool for Cross-Sectional Studies; CIs, confidence intervals; n.a., not available.

ported the use of a "structured interview" approach. Information is not provided on the interviewer or recording of these data. Barbosa et al. [39] and Baker et al. [34] distributed self-administered parent questionnaires. While all studies collected data on the presence and duration of feeding and NNS behaviours, only Barbosa et al. [39] collected data on the frequency of bottle-feeding and pacifier use.

All except one of the papers attempted objective assessment of the participants' speech sound development. Pereira et al. [37] based their findings solely on parent report and provided no objective measure for the speech sound development of the children in their study. Although Pereira et al. [37] referenced specific phonemes in their definition of "speech disorder" or "speech changes," the single item on their parent questionnaire relating to this measure required only a binary yes/no response and asked simply "difficulties/changes in speech?" without reference to specific sounds or clarification on the authors' intended meaning of "speech." As such it is difficult to draw firm conclusions on the basis of this paper due to the potential for variation in respondents' concept of "speech" and therefore inconsistency in their responses.

Sample Populations

Details of the population samples for each study are provided in Table 3. Only 2 of the 4 papers [34, 38] reported any use of exclusion criteria in their sample definitions, and only one of these, hearing loss, was common to both studies (Table 4). Baker et al. [34] reported the most

Table 3. Summary of included studies

References	Study type	Participants/setting	Measures/outcomes	Statistical analysis	Key findings
Barbosa et al. [39], 2009	Cross-sectional	128 children aged 37–70 months 59 females 69 males (3 years [*n* = 58]; 4 years [*n* = 49]; 5 years [*n* = 21]) From 3 public kindergartens in Punta Arenas (Patagonia), Chile Feeding method and NNS behaviours reported for all participants	Self-administered parent questionnaire to provide information on feeding and pacifier/digit-sucking history TEPROSIF standardised phonological assessment for children aged 3–7 years	SPSS 13.0 χ^2 tests compared age and categorical characteristics, and TEPROSIF classifications and categorical characteristics. Two-sided *p* values of association between these variables Multivariable logistic regression of associations between potential risk factors and SSD Adjusted and unadjusted models (age and gender) for OR and 95% CI	(1) Pacifier use, finger-sucking and bottle-feeding are associated with SSD in preschool children (2) Delaying bottle-feeding until 9 months may be protective from subsequent SSD (OR 0.32, 95% CI 0.10–0.98) (3) Children who sucked their fingers were 3× more likely to have SSD (OR 2.99, 95% CI 1.10–8.00, $p = 0.02$) (4) Using a pacifier for >3years increased the likelihood of SSD threefold (OR 3.4, 95% CI 1.08–10.81)
Vieira et al. [38], 2016	Case-control	273 children aged 36–71 months and enrolled at one of 15 state preschools in Recife, Brazil Males (*n* = 173), females (*n* = 100) *Case group* (*n* = 108): presented with speech alterations, as reported by parents *Control group* (*n* = 165): no speech alterations reported by parents Feeding method and NNS behaviours reported for all participants	Self-administered parent questionnaire to provide information on feeding and pacifier/digit-sucking history ABFW Children's Language Test Phonological Evaluation Protocol Subtest. Standardised for Brazilian children aged 2–12 years	STATA/SE 9.0 ORs with 95% CIs and *p* values	(1) Only gender was significantly associated with SSD (OR 1.79; 95% CI 1.03–3.10; $p = 0.038$) (2) No significant association between feeding, NNS and SSD (3) No significant association between SES and SSD (due to authors' claimed homogeneity of sample) (4) No significant association between age and "speech alterations," although most of the case group were aged 3 years
Pereira et al. [37], 2017	Cross-sectional	(Parents of) 289 children aged 1–12 years assisted at a family health strategy unit in northern district of Porto Alegre, Brazil Male (*n* = 145), female (*n* = 144) Feeding method and NNS behaviours reported for all participants	Self-administered parent questionnaire	SPSS 19.0 χ^2 for *p* values	(1) Correlation between SSD and bottle-feeding ($p = 0.056$) (2) Correlation between pacifier use and SSD ($p = 0.046$) (3) Pacifier use <1 year not associated with SSD (4) Correlation between thumb-sucking for up to 4 years' duration and SSD ($p = 0.012$)
Baker et al. [34], 2018	Cross-sectional	199 Australian-English-speaking children aged 48–66 months with and without PI Males (*n* = 121) females (*n* = 78) Children enrolled on the Sound Start study (an RCT for children with PI) Meeting criteria following DEAP assessment for PI only or "no impairment" Feeding method and NNS behaviours reported for all participants	Self-administered parent questionnaire DEAP phonology assessment. PCC score	Statistical package not reported χ^2 for *p* values	(1) Duration of breastfeeding and PI not associated ($p = 0.055$), nor severity ($p = 0.396$) (2) Longer breastfeeding duration showed higher PCC scores in PI group (3) Duration of pacifier use and PI not associated ($p = 0.745$), nor severity ($p = 0.106$) (4) Longer pacifier duration showed lower PCC scores

TEPROSIF, Test para evaluar los procesos fonológicos de simplificación; SPSS, Statistical Package for the Social Sciences; SSD, speech sound disorder; OR, odds ratio; CI, confidence interval; STATA, general purpose statistical software package; ABFW, Andrade, Befi-Lopes, Fernandes, and Wertzner (2000)'s Language Test for Children; NNS, non-nutritive sucking; SES, socioeconomic status; RCT, randomised control trial; PI, phonological impairment; DEAP, Diagnostic Evaluation of Articulation and Phonology; PCC, percentage consonants correct.

Table 4. Summary of exclusion criteria reported by included papers

Exclusion criteria reported by included papers	Barbosa et al. [39], 2009	Vieira et al. [38], 2016	Pereira et al. [37], 2017	Baker et al. [34], 2018
No parent/carer concern	–	–	–	√
Diagnosed developmental delay	–	–	–	√
Congenital malformations	–	√	–	–
Physical or mental disability impacting speech development	–	√	–	–
Hearing loss	–	√	–	√
Cleft lip and/or palate	–	–	–	√
Articulation impairment only	–	–	–	√
Childhood apraxia of speech	–	–	–	√
Diagnosed childhood dysarthria	–	–	–	√

comprehensive exclusion criteria, including genetic, medical and developmental factors known to have some association with SSD.

Definition of SSD

A key challenge for this review was the disparity in what is meant by the term "speech sound disorder" between papers. Barbosa et al. [39] used the terms "speech disorder(s)" and "speech processing," the former of which they broadly describe as having the potential to "impair communication and literacy" [39, p. 2]. Specific reference to distinct types of SSD was not made; however, through their use of the Brazilian speech sound assessment TEPROSIF [40] to "determine the type and number of errors in the child-age related phonological processes" [39, p. 3], the implication was to focus on phonological impairment (PI). Baker et al. [34] were more explicit in stating their specific focus on children with diagnosed PI and defined the group as presenting with "one or more age-inappropriate common phonological error patterns […] with no evidence of motor speech involvement" [34, p. 7]. As Baker et al. [34] themselves acknowledged, "PI is presumed to be a cognitive-linguistic difficulty involving a difficulty abstracting rules about the phonological system, and the abstract phonological representation of speech rather than an articulation difficulty. As such, it is reasonable to suggest that non-nutritive sucking habits would be unrelated" [34, p. 11]. Pereira et al. [37] made reference to both "speech disorder(s)" and "speech changes" and acknowledged that they did not distinguish between types of SSD. They provided some definition of their application of the term "speech disorders" as "those reported by the parents and/or guardians with respect to the production of the phonemes /t/, /d/, /n/, /l/, /r/, /s/, and /z/, considered comprehensively as they are associated with alterations in the SS (stomatognathic system)" [37, p. 2]. The repeated emphasis within this paper on the structures and functions of the stomatognathic system, defined by the authors as comprising the functions of suction, swallowing, mastication, respiration and speech [37, p. 2], indicated the author's intention to explore "speech disorders" relating to articulation, rather than those that are cognitive-linguistic in nature. Vieira et al. [38] also referred to "speech disorders," "speech changes" and the SS, as well as "speech impairment." They defined their case group as children with "omissions, substitutions, additions or distortions of phonemes related to functionality and associated with the motor aspect of speech production" [38, p. 1361]. Vieira et al. [38] specifically stated that "phonemic productions associated with […] chronology of acquisition of children's phonemes" [38, p. 1361] (i.e., age-appropriate developmental phonological processes) were not considered pathological. It may be argued that, as with Pereira et al. [37], this paper focused on articulatory SSD.

Definition of Population

Exclusion criteria for defining the study samples were not included in either Barbosa et al. [39] or Pereira et al. [37] (Table 3). This may mean that their samples included children who had additional difficulties, which, in turn, could have impacted on, or been the underlying cause of, their SSD. Of the 4 included studies, Baker et al. [34] presented the most comprehensive exclusion criteria.

Confounding Factors

Barbosa et al. [39] acknowledged the likely influence of confounding factors in their study; however, they ad-

just only for gender and age (Table 4). Pereira et al. [37] considered only gender, age and number of children per household. No information is provided as to whether their statistical analysis accounted for these factors. Baker et al. [34] collected information for age, gender, hearing, oromuscular structure and function. They also did not state whether these were included in their statistical analysis. Of the 4 included studies, Vieira et al. [38] collected information on age, gender, "shift in educational unit," family income, maternal age, maternal schooling and family history of speech impairments. They did not state whether these were included in their statistical analysis.

Missing Data

Unreported missing data present a challenge in the interpretation of the data tables in Vieira et al. [38]. When case and control group sample size totals for the different variables are manually calculated, the extent of missing data becomes clear. Moreover, when the overall group total (i.e., case and control combined) is calculated for bottle use, the number of cases exceeds the reported sample total, indicating some measurement error [38]. This leads to concern about the validity of the analysis and interpretation of the data in this paper. Manual calculations of group totals in Table 2 of Barbosa et al. [39] indicate missing data across the variables, but this was not acknowledged by the authors. Pereira et al. [37] also failed to acknowledge the extent of missing data within their report. Their paper presents data on the correlation between NNS and SSD (Table 4). One hundred and twenty-seven children were reported as having used a pacifier, but only 119 were included in the analysis. Baker et al. [34] reported the extent of missing data in their analysis.

Exposure Measures – Nutritive Sucking and NNS

All 4 of the included papers reported data on infant feeding type and duration. Three of the 4 included papers [34, 37, 39] collected data on NNS duration. However, only one [39] collected data on NNS frequency.

Outcome Measures – SSD

The SSD outcome measurement approach varied across the 4 papers in this review, and although formal assessment was attempted by 3 studies, the administration quality of the measures was inconsistent. Unusually the questionnaire implemented within Pereira et al. [37] specifically asked for perceived speech sound changes, but they explicitly chose not to collect this information from the parents of children aged 1–3 years. The modification of the questionnaire for this age group was not defended by Pereira et al. [37] and does not find a basis among the current literature, which suggests the potential for identification of SSD within this age bracket [41–43].

Barbosa et al. [39] used the TEPROSIF assessment, which requires the child to imitate a word, either from a spoken phrase or in isolation [40]. Their criteria of "below-normal" speech sound performance as at least –1 SD represents a liberal cut-off as many other studies have used more stringent criteria [44–46]. It must be assumed that the "below-normal" group includes a proportion of children who could be considered typically developing in some other studies. As the authors did not provide specific scoring information, further exploration of this issue is not possible. Vieira et al. [38] also used a published validated assessment, the Children's Language Test [47], to assess speech sound production on both naming and imitation tasks. Only those children who presented with a sound error occurring in both tests were assigned to the "case" group. The authors implied that children presenting with errors pertaining to age-appropriate phonological processes were not included in the case group [38]. As scoring information was not presented for the case or control groups, it is not possible to determine or assess the severity of children's speech sound errors within the case group. Baker et al. [34] provided a clear description and explanation of their selected published assessment tool, the Diagnostic Evaluation of Articulation and Phonology (DEAP) [48]. Following administration of the Phonology Assessment Single Word Naming Test, children were assigned to one of 4 groups based on their obtained DEAP standard score, percentage of consonants correct (PCC) score and error patterns. Only data from the PI group were included in the study. Children assigned to the PI group obtained a DEAP standard score of 6 or less based on their PCC score. A score of 7–13 is understood to fall within the normal range [48].

Managing Bias

The following section considers risk and evidence of bias across the 4 included papers.

Sample Baseline Imbalances

Imbalances between groups of baseline variables, such as age and gender, can influence or bias the outcome, and so it is important to consider these when interpreting the reported findings.

Pereira et al. [37] reported a sample population containing essentially equal genders, although no information was provided on sample selection.

In Vieira et al. [38] there is a reporting error in the paper. They reported equal overall sample sizes for the case and control groups; however, manual calculations of the group totals from the data presented in their analysis [38, p. 1362] indicate a marked group imbalance (Table 1). There is also a significant gender imbalance within the total sample, which contains 73% more males than females. Vieira et al. [38] briefly acknowledged this imbalance in their discussion. Baker et al. [34] also reported a sample gender imbalance, with 55% more males than females in their PI group. The SSD prevalence figures in the wider literature also show a tendency for more boys than girls [17, 49–52].

Barbosa et al. [39] included in their sample children born prematurely (n = 19), and, as acknowledged by the authors, this population is significantly more likely to present with "increased risk of developmental problems with speech" [39, p. 4]. The inclusion of this population, which constitutes 15% of the total study sample, may have some impact on the results as they potentially comprise almost 1/3 of the reported "below-normal" group. Prematurity is often cited in the wider literature as being associated with speech sound difficulties in later development [53–55].

Recall Bias

Inherent in the methodological use of participant questionnaires is the risk of recall bias [56]. While all 4 studies in this review employ this data collection approach, only Baker et al. [34] did not acknowledge the potential limitation. Recall bias is perhaps most problematic with regard to the study of Pereira et al. [37], which relied solely upon parent report for information on early feeding, sucking and speech sound development and included children up to the age of 12 years. The remaining studies focused on the age range of 3–5 years; therefore, perhaps the influence of recall bias in each case may be considered to be broadly equal.

Summary of Findings from Included Papers

Although numerical data from the papers were insufficient to undertake meta-analysis, statistical information such as ORs and CIs are included in each of the 4 papers. As previously stated, provision of this information by the authors is inconsistent across the papers.

Feeding Type and Speech Sound Development

Barbosa et al. [39] suggested an association between bottle-feeding and SSD in preschool children, such that delaying bottle use until after the age of 9 months appeared to show some small protective effect (OR 0.32, 95% CI 0.10–0.98). Pereira et al. [37] also reported a significant correlation between speech sound difficulties and bottle-feeding (p = 0.056). This may indicate a liberal application of their reported adopted 5% significance level [37, p. 2]. Vieira et al. [38] found no significant association between feeding type and SSD. Baker et al. [34] similarly found no association between feeding type and the presence or absence of SSD (specifically PI).

Duration of Feeding Type and Speech Sound Development

Pereira et al. [37] and Vieira et al. [38] both collected data on duration of feeding method and speech sound development but did not report on these data within their papers. Baker et al. [34] suggested a trend whereby longer breastfeeding duration is associated with higher PCC scores, resulting in more accurate speech sound production for spoken words. Barbosa et al. [39] reported that children scoring as normal or 1 SD above normal on the "Test para evaluar los procesos fonológicos de simplificación" (TEPROSIF) speech sound assessment tended to have been breastfed for longer than those scoring below expectation for their age [40]. They asserted that delaying bottle feeding until after the age of 9 months may be to some extent a protective factor against subsequent SSD (OR 0.32, 95% CI 0.10–0.98).

NNS and Speech Sound Development

Barbosa et al. [39] suggested an association between NNS and SSD in preschool children. They found that children who sucked their fingers were 3 times more likely to have speech sound difficulties than children who did not present with this behaviour (OR 2.99, 95% CI 1.10–8.00). It is important here to note the wide CI reported for this finding. Pereira et al. [37] found a correlation between pacifier use and speech sound difficulties (p = 0.046). Neither Vieira et al. [38] nor Baker et al. [34] found a significant association between NNS and SSD.

Duration of NNS and Speech Sound Development

Baker et al. [34] reported that, while the relationship between NNS and presence of SSD was non-significant, they did identify a trend between longer pacifier use and lower PCC scores. Barbosa et al. [39] reported that children who used a pacifier for >3 years were much more likely to present with below-normal speech sound development (OR 3.4, 95% CI 1.08–10.81). Pereira et al. [37] suggested that using a pacifier for <1 year was not associated with speech sound difficulties, whereas digit sucking

persisting for up to 4 years was positively correlated with the presence of SSD ($p = 0.012$). Vieira et al. [38] found no association between NNS and SSD.

Discussion

This review aimed to examine the evidence of the relationship between infant feeding methods, NNS behaviours and speech sound development in early childhood. The deliberate inclusion of only those papers that address all 3 aspects of this relationship is due to the high prevalence of concurrent feeding and NNS behaviours in infancy and early childhood [5–7]. To exclude one or other elements would be to disregard significant relevant factors in this association and to risk drawing false conclusions from incomplete information.

Methodological Limitations of this Paper

Although clear systematic criteria were used for search and inclusion strategies, it is possible that a number of biases may enter into the process by way of variations in definitions (e.g., SSD) and in general by the specific inclusion criteria. For example, by including only studies that contain both feeding and NNS, the possibility of deriving a fuller understanding of the impact of a single type of sucking behaviour on the development of speech sounds is not possible. For the purposes of this review, we purposely searched for evidence that allowed for the comparison of feeding and NNS. The aim was to develop a picture of the current status of comparative findings.

The limited number of studies available for review makes it difficult to draw firm conclusions and develop hypotheses about how differing characteristics and conditions may lead to SSD. It is worth noting that 2 of the included papers, Vieira et al. [38] and Pereira et al. [37], have been translated from the original language. This may have had some impact on the clarity of some of the language and explanations within the papers.

Limitations of Reviewed Studies

The following section discusses the limitations of the 4 studies included in this review.

Definition of SSD

It is evident that, in terms of the defined outcome of SSD, there is an equal division between the 4 included papers. Barbosa et al. [39] and Baker et al. [34] explored a link between physical oral sucking behaviours (nutritive and non-nutritive) and the cognitive-linguistic aspect of speech sound development, which, as Baker et al. [34] acknowledged, is perhaps an unlikely association. Vieira et al. [38] and Pereira et al. [37] attempted to explore a possible relationship between physical sucking and the physical act of speech articulation, which may perhaps present a more probable association, and therefore should be the focus of further research in this area. However, it is important to consider that the nature of the chosen speech sound assessment method does not determine the type of SSD a child may have [57]. For example, children with phonological impairments, which may be identified using the phonology subtest of the DEAP [48], can also present with speech motor difficulties and vice versa. Therefore, while the 4 included studies report findings of atypical speech sound development, these cannot reliably be interpreted as identifying specific types of SSD.

Definition of Population

The lack of exclusion criteria in Barbosa et al. [39] and Pereira et al. [37] significantly weakens, in each case, the reliability of their findings and emphasises the importance of clearly defined sample populations for future research in this area. The decision by Baker et al. [34] to exclude children whose parents were not concerned about their speech may be argued to risk the exclusion of otherwise potentially eligible children from the study on the basis of assumed parent awareness, knowledge or understanding [58].

Confounding Factors

The inclusion of comprehensive confounding factors identified from the literature is crucial in order to isolate the relationship between feeding, NNS and speech sound development as far as possible from these additional factors. Only by including and adjusting for these confounding factors in the statistical analysis can the relationship between NNS and speech sound development be described more accurately.

Missing Data

Unreported missing data were apparent in all but one [34] of the studies included in this review. This presents significant challenges for data interpretation and for the conclusions we are able to draw from the findings.

Exposure Measures – Nutritive Sucking and NNS

The nature of NNS behaviours varies significantly within and across cultures, with some children engaging only in these behaviours before sleep, while others show persistent behaviours throughout the day [59]. It is sur-

prising that NNS sucking frequency was not reported in more of the papers. The authors of the current review would suggest that future research in this area include information on behaviour frequency as well as duration and causation (e.g., self-soothing behaviour at certain times of the day) in order to provide a comprehensive account of sucking behaviours, with which to then explore speech sound development outcomes in relation to early feeding methods.

Outcome Measures – SSD

While the need for inclusion of objective, formalised outcome measures for SSD in the examination of the relationship between feeding, sucking and speech sound development is evident, the nature of these assessments is also vital in establishing a clear speech sound profile for each child. Of the 3 studies in this review that completed objective speech sound assessments, all of them focused on speech sounds at the single word level. There is a substantial and growing body of evidence that advocates the need for broader speech sound assessments to obtain a complete profile of a child's speech sound development; this includes collecting single sound, word, phrase level and connected speech [60]. In considering studies from a broader range of literature, such as those considering either, rather than both, feeding or NNS and speech sound development, no formal speech sound assessment approaches were identified [5, 61–63] and only one study, Baker et al. [34], used the PCC measure. However, it is important to note the inherent weakness in using PCC as a measure to determine SSD type (e.g., participant assignment to PI group), as PCC scores would be lower among children with any type of SSD. The findings of these studies represent an incomplete picture with regard to patterns of feeding and NNS and any observable impact on speech sound development.

Managing Bias

There is significant inconsistency in the statistical reporting of results across the 4 included studies in this review. Indeed, the chosen statistical presentation of some of the results may be considered to risk reporting bias. As illustrated above, ORs are reported by only 2 of the 4 studies [38, 39], and only one of these consistently reported CIs [38]. This paucity of accurate, consistent statistical reporting can lead to misrepresentation of the results, complicates the interpretation of the findings and can be misleading [64].

Recall bias is inherent in studies reliant on participant questionnaires for data collection and applies to each of the 4 studies included in this review. A way to address this would be to carry out a prospective study, such as the Avon Longitudinal Study of Parents and Children [65].

Conclusions

This review has established that the current evidence around the relationship between infant feeding, NNS and speech sound development is very limited, of questionable quality and provides inconsistent findings. Greater clarity is required with regard to the nature of SSD being explored and coherence of approaches to outcome measurement. While the limited evidence examined within this review suggests some association between persistent NNS behaviors and the presence of SSD, the strength of this association is not clear. The question of a relationship between feeding type and SSD per se remains unanswered; however, when duration is considered, there is some limited evidence for a protective effect of longer breastfeeding duration.

Potential Impact of Review Findings

The studies included in this review explore 2 distinct types of SSD: PI and articulation disorder. Several different classifications of SSD are presented in the literature [52, 66, 67]. It has been suggested that an association between physical sucking and physical speech articulation may present a more logical relationship than that between physical sucking and cognitive speech sound processing [34]. The potential impact of the findings of this review is that further research is required to explore the relationship between the physical aspects of sucking and speech sound development. This work should use more precise and detailed measures for sucking behaviours and speech sound development with explicit consideration of the different classifications of SSD. Fundamental to this is the careful consideration of the many documented confounding variables involved in this proposed association [17]. Future research should aim to provide clinically relevant findings that might be easily and usefully applied to the clinical settings where these populations receive support. An optimal outcome measurement approach would include detailed speech sound assessment from single sound imitation through to connected speech samples [60]. Ideally, these data would be captured through video recording in order to facilitate

precise and accurate transcription by a qualified speech and language pathologist. Audio recording of the data with the assessment administration and transcription completed by a qualified speech and language pathologist is recommended as a minimum requirement for future research in this area.

Statement of Ethics

The authors have no ethical conflicts to enclose.

Disclosure Statement

The authors have no conflicts of interest to declare.

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Author Contributions

S.B., T.D. and Y.W.: discussed the aim and objectives of this review. S.B.: completed the initial searches and shortlisted at the abstract stage. S.B. and S.H.: reviewed the included papers and completed the quality appraisal separately for subsequent discussion. S.H.: was a major contributor in writing the final manuscript. All authors read, edited and approved the final paper.

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