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A systematic review of the literature on early vocalisations and babbling patterns in young children

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Early vocalisation, babbling, systematic review, infants, speech

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Abstract

Children's speech development begins in infancy. The pattern of this development has been explored in studies over a number of years using a range of research methodology and approaches to investigation. A systematic review of the existing literature was carried out to determine the collective contribution of this literature to our understanding of early vocalisations and babbling through the period 9-18 months. Eight bibliographic databases were searched as well as the Cochrane library and 13 studies were identified for inclusion, which were mostly longitudinal observational case series. The review identified progressive increases in the complexity and volume of infants' early vocalisations through the period. It also found a broad order of phonological acquisition. Although the studies in this review demonstrated marked individual variation, the review provides indicative patterns of development which can be used as a basis to explore relationships with later speech development in future studies.

Introduction

Studies of early language development have been well documented over the years (Bates & Marchman, 1988; Dale, Bates, Reznick & Thal, 1994; Morales, Mundy, Delgado, Yale, Shwartz & Fenson, 2000) and have contributed to our understanding of the field through comparisons of language domains such as vocabulary growth, morphology acquisition and mean length of utterance with other areas of cognitive development. However, there has been a lack of detailed information regarding early vocal development and growth until recent years. Early studies focused on stages of vocal production and consonant inventories (Locke 1983; Stark 1980), while more recent research has investigated evolution

of vocalisation and babbling (Fagan, 2008; McCune & Vihman, 2001). A critical examination of these studies is necessary to determine their collective contribution to our understanding of the relationship between early vocalisations and later speech and language development.

A range of models have been proposed to explain vocal development. Universal models of speech development typically detail development from reflexive vocalisation (such as crying) to cooing, babbling and finally first words (Kent, 1984). These early aspects of speech development have been linked to later language development, with babbling in particular appearing to play an important role (D'Odorico, Majoran, Fasolo, Salerni & Suttora, 2011).

Babbling is usually cited to occur in infants between 6 and 12 months old (Vihman, 1996). It can be classified in a number of different ways, however, typical models of babbling propose that it moves through distinct stages. Early studies (e.g., Paul & Jennings, 1992; Stoel-Gammon, 1989) adopted the three stage model established by Olswang, Stoel-Gammon, Coggins and Carpenter (1987). This model proposes that babbling begins with level one, in which vocalisations containing a vowel, glottal stop or glide are produced while level two marks the emergence of canonical babbling. Canonical babbling is normally described as the production of well-formed syllables containing at least one consonant (C) and one vowel (V) (e.g. [ba]). Level 2 also includes reduplicated babbling, characterized by utterances containing multiple repetitions of CV syllables (e.g. [da'da]), or sounds that differ only in voicing (e.g. [da'ta]). Level 3, considered the most advanced level in babbling, includes vocalization containing two or more different consonants (e.g. [ba'ti]). This use of different, or non-reduplicated consonants, is usually referred to as variegated babbling.

Investigating early phonetic development in babbling is valuable in terms of understanding its contribution to speech and language acquisition. Phonetic development might be seen in terms of the 'cascade effect hypothesis' a theoretical model proposed by Rose, Feldman, Jankowski and Van Rossem (2008). They hypothesise that basic or essential underlying cognitive abilities support more complex ones, which ultimately influence general

intelligence. This model can be readily applied to speech and language development. The capacity of a child to produce sounds which are within the phonetic inventory of their ambient language and practice them in increasingly complex combinations, is an arguably crucial foundation to the ability to then produce those sounds as part of words and to use those words in a referential way.

There is increasing evidence that early vocalisations provide an indication of later linguistic development, particularly vocabulary acquisition. These studies signify a range of aspects of vocalisation that demonstrate a relationship to vocabulary acquisition. The following factors are associated with increased vocabulary acquisition: increased volume of early vocalisations at 6 months (Camp, Burgess, Morgan & Zerbe, 1987; D'Odorico, Bortolini, Degasperi & Assanelli, 1999), increased complexity of babbling (D'Odorico et al., 2011; Fasolo, Majarrno & D'Odorico et al., 2008;) and consistent use of specific consonants (Keren-Portnoy, Majarano & Vihman, 2009; McCune & Vihman, 2001;). Oller, Eilers, Neal and Schwartz (1999) also found that those children with delayed canonical babbling had smaller production vocabularies at 18, 24 and 30 months, in a large population of at risk infants. Further, babbling might be a useful marker for children who are later identified as language impaired, with such children exhibiting qualitative differences in their earlier babbling compared with typically developing control groups (Fasolo et al., 2008; Stoel-Gammon, 1989;). Despite this, patterns of babbling and early speech have not been reviewed since Locke (1989).

There is some disagreement in the field with regard to the process of acquisition of babbling, including the details of well established models. For example, early models of speech development, such as those referenced by Oller (1980) posit that reduplicated and variegated babbling happen sequentially while other studies suggest that these processes happen concurrently (Mitchel & Kent, 1990; Nathani, Ertmer & Stark, 2006). There is also disagreement over the age at which these stages occur. For example, Oller (1980) reported the onset of canonical syllables at around five to ten months, whereas other researchers report onset after 8 months (Roug, Landberg & Lundberg, 1989; Stark, 1980).

The result is a lack of clarity regarding the early stages of speech development in very young children. Nevertheless, if we are to identify relationships between early and later speech and language development, there is a need to understand the nature and development of early vocalisations. This is difficult because, although there are a large number of studies that have examined babbling and early vocalisations, studies have adopted a range of methods, obtained various outcomes and have interpreted these findings within different theories and frameworks. There is a need to methodically examine the evidence for the development of vocalisations in the early years. The aim of this study was therefore to systematically review the literature with regard to early babbling and vocalisations in children aged between 9 and 18 months with a view to providing information on typical patterns of early development which can be used in future investigations of the relationship between early and later speech development.

Method

Studies were identified through systematic searches of eight bibliographic databases, in addition to the six databases in the Cochrane library. A referencing software was used to manage references found during the review, with all titles and abstracts imported into it.

Preliminary searches were conducted using the Ebsco search engine in order to establish an appropriate search strategy, balancing specificity and sensitivity.

The search strategy focused on two key concepts: infant and babbling. Terminology was harvested through preliminary searches of the databases, using keywords and their synonyms, as well as knowledge of terms in the subject area. Table 1 shows the search strategy that was adopted to search eight bibliographic databases, as well as the results. In addition, Cochrane library (Cochrane Reviews, DARE, CENTRAL, Methodology Register, HTA, NHS EED) was also searched using the terms babbl* vocal* and phon* at title, keyword and abstract. The Cochrane search retrieved 66 results.

Table 1

Papers were included if they examined babbling or early vocalisations in typically developing children aged between 9 and 18 months. It was also a requirement that the infants

were in English speaking countries, since infants in other countries are likely to produce different patterns of vocalisation and babbling that reflect their differing linguistic environment, which is beyond the scope of this review. See Table 2 for the full inclusion and exclusion criteria.

Table 2

Papers were screened at three levels. The first screen was at title level, screening for broad relevance to the topic area. The second screen was at abstract level. This was conducted independently by two sets of reviewers, against the inclusion and exclusion criteria listed in table 2. A consensus rate of 82% was reached, where there was disagreement or if it was not clear if papers met the inclusion/exclusion criteria, full articles were accessed. Finally, full papers were screened against the same set of criteria. These were also independently assessed by two sets of reviewers. There was 95% agreement at this round, for the 3 papers where there was disagreement; discussion took place until consensus was reached.

Thirteen studies were identified that met the inclusion criteria. Figure 1 provides a flow chart of the paper selection process.

Figure 1

Quality appraisal

Finding suitable generic quality appraisal tools for the studies in the systematic review was problematic, since most available tools are fit for large scale epidemiology and intervention studies. Most of the studies included in the review were longitudinal observational case series studies.

A review of 36 appraisal tools for case series studies (Moga, Gu, Schopflocher & Harstall, 2012) was explored for recommendations of the best quality appraisal questions to ask of case series studies. The list of questions that were recommended from the review was adapted to fit the current review, with the removal of questions that related exclusively to intervention studies. This resulted in a final list of 10 questions which are summarised in

Appendix 1. All studies were appraised, and a 10% sample were also appraised, blind, by an additional researcher. Over 80% agreement was reached between the two appraisers, where there was disagreement discussion was had until consensus was reached. The results of the quality appraisal can be found in Appendix 2.

Although there was variation in the quality of the studies, most were rated relatively well on the measures of quality appraisal, with the majority scoring positively on at least 6 of the 10 questions. However, it should be noted that case series studies are low in the hierarchy of evidence. Sample sizes for most of the studies were small, and none of the studies selected participants in a way that would suggest they were representative of the general population. These factors mean that caution needs to be applied in generalising the findings to the broader population.

Results

The details of the thirteen studies, and their key findings are provided in Appendix 3. Eleven of the studies were longitudinal observational case series studies. The remaining two used case control designs (Nathani & Stark, 1996; Nathani et al., 2006): one adopted a cross sectional approach (Nathani & Stark, 1996) and the other a mixed cross sectional and longitudinal method (Nathani et al., 2006). The number of participants in the studies ranged from four to 36. The identified studies were reviewed for content, in terms of how they explored vocalisations and babbling. It was found that the papers could be classified into 3 key themes: classification and patterns of babbling over time (Pob: n=8), volubility (Vol: quantity of babble, n=5) and phonetic inventories (Pi: n=4). The groups were not mutually exclusive, with some studies exploring more than one of these aspects of vocalisation and babbling. Each of these categories is considered in turn. A narrative synthesis then follows, summarising and drawing together the findings of the different papers.

Patterns of babbling over time

These studies each examined varying aspects of the development of babble using a range of terms for classifying increased advancement of vocalisation and babbling, including the more established terms of reduplicated/duplicated and variegated. Several of the studies

in the present review indicate an increase in reduplicated babbling (Fagan, 2008; Rome-Flanders & Cronk, 1995) or an increase in multisyllable vocalisations, including both reduplicated and variegated syllables, (Mitchell & Kent, 1990) from babbling onset at around 7 months. Most of the studies report that there is by contrast, a decrease in reduplicated babble from 12 months, a time normally associated with the onset of the use of words (Fagan, 2008; Rome-Flander & Cronk 1995; Smith, Brown-Sweeney & Stoel-Gammon, 1989). An exception is Vihman, Ferguson and Elbert (1986) who reported that reduplicated consonants remained level from the preword to word period for the 10 children that they studied.

Only three studies examined variegated babbling in isolation. These studies revealed that variegated babble occurs from the beginning of the babbling period, but does not appear to change in its frequency up to around 11 months (Mitchell & Kent, 1990; Smith et al., 1989). At around 12-14 months variegated babble then appears to increase (Smith et al., 1989). MacNeilage, Davis and Matyear (1997) also indicate graphically some increase in variegated babble during this time period, though no statistical tests were conducted to confirm that this difference was significant. These findings contrast with that of Rome-Flanders and Cronk (1995) who report that variegated babble increased from 6- 12 months, and decreased from that point on, except at the 15 month time period. The authors use an additional category of jargon, however, that shows a pattern similar to other studies of variegated babble, that is an increase in use after 12 months. Jargon is defined by them as any utterance with 3 or more syllables with a conventional intonation pattern, meaning that is likely to be inclusive of babble that would be classified as variegated elsewhere.

Although variegated babble is generally seen as more complex than reduplicated babbling, not all studies have drawn a distinction between these two types of babbling. Nathani et al. (2006) and Nathani and Stark (1996) posit a scale of speech motor skill development that groups reduplicated and variegated in the same 'level'. Increasing complexity is marked instead, for example, by the presence of consonant clusters or syllables that start with vowels. Both of these studies found that infants in the older age groups (older

than 9 months) produced vocalisations that were classified as more complex using this scale than the younger age groups.

A noteworthy finding by Vihman et al. (1986) is that the early period appears to see a large amount of individual variation. Although most of the studies support a developmental progression from vocalisation with movement toward increasing complexity, it is clear that children do not all progress at the same rate.

Phoneme inventories

Five of the six studies explored consonant inventories; the remaining study explored vowel inventories. Although the studies used various assessments for establishing a phoneme inventory, some clear patterns in the development of consonants can be seen. Gildersleeve-Neumann, Davis and MacNeilage (2000) made a distinction between what they term as early developing consonants (stops, nasals and glides) and late developing consonants (fricatives, affricates and liquids). Their data supported this pattern with early developing consonants making up over 91% of the utterances produced in the 7-18 month period. The other studies broadly support this. Robb and Bleile (1994) note that oral stops (/p,b,t,d/) and nasals (/m,n/) were the most frequently produced consonants during the 8-12 month period. Among these the alveolar position consonants were reported to be the most frequently occurring (/t,d/) followed by labial (/p,b/). McCune and Vihman (2001) reported a similar pattern with alveolar and labial stops being the only consonants that met the criteria for vocal motor schemes in 50% of participants aged 9-14 months. MacNeilage et al. (1997) also reported /t,d/ to be the most commonly produced consonants from 7-12 months, however, they report slightly higher use of nasals /m,n/ than bilabial stops /p,b/.

Several of the studies report that velar stops /g/ are part of the early sound system (Robb & Bleile, 1994; Vihman et al., 1986;), though they seem to appear a little later than the other stops /t,d,p,b/ (Robb & Bleile, 1994). Other early sounds in the inventories include glottal /h/ (McCune & Vihman, 2001; Robb & Bleile, 1994; Vihman et al., 1986), glides /j,w/ (MacNeilage et al., 1997; Robb & Bleile, 1994; Vihman et al., 1986) and finally liquid /l/ which appears to come a little later (Robb & Bleile, 1994; Vihman, 1986).

The papers appear to be in agreement that fricatives and affricates appear later than the other sounds. Fricatives and affricates were not reported to be used by children in this age group in any of the consonant syllable initial positions. However, several papers report that they are more commonly produced in word-final position during this time period (Gildersleeve-Neumann et al., 2000; Vihman et al., 1986). One study (Robb & Bleile, 1994) found that the alveolar fricative was present in syllable final position for most of their sample from 10 months onward.

Only one study reported vowel inventory (Selby, Robb & Gilbert, 2000). Selby and colleagues reported the use of a wide range of vowels by 18 months with more vowel types being used than reported in previous studies.

An important finding in the studies is that there is considerable individual variation between children, with not all children acquiring the same range of sounds. Robb and Bleile (1994) demonstrate the difficulties in mapping phonetic inventories, with some sounds that appear early, seeming to disappear again at later time points. They argue that children's early word-initial consonants are composed of voiced stops and nasals, and gradually grow to include voiceless stops and fricatives. However, their data set notes an absence of voiceless sounds at the 18 month inventory. Other papers in the present review (McCune & Vihman, 2001) have conflated voiced/voiceless making it difficult to examine this premise in the present study.

Volubility

Four studies in the review examined the volume of vocalisations (volubility) that infants produce. The studies appear to indicate an increase in volubility with age. Two of the studies in the review (Nathani & Stark, 1996; Rome-Flanders & Ricard, 1992), indicate significant increases in volubility across the 6-18 month period. A third study also reported increased volubility over time (Fagan, 2008) though this was based on a measure of the mean number of sounds per utterances rather than the number of vocalisations per se. This might suggest that infants not only increase the amount of vocalisations they make over time, but that within utterances or vocalisations they are using a larger number of sounds.

McCune and Vihman (2001) looked at a different aspect of volubility, examining whether the frequency of vocalisations is related to a language outcome at 16 months. Simple regression found that frequency of vocalisation was a predictor of total referential words produced by 16 months. This suggests that volubility might be a useful predictor of later outcomes. However, stability of infant phonetic production of specific consonants (measured by what the authors term vocal motor schemes), was a stronger predictor of referential words produced at 16 months, indicating that volubility alone might not be the most useful predictor for later outcomes.

Discussion

The present review brought together findings from thirteen studies that examined different aspects of early vocalisations. The task of mapping vocalisations over time is complicated by the adoption of different methods for assessing varying aspects of vocalisation and babbling, making side by side comparison of studies difficult. Nevertheless some emerging patterns in early vocalisations can be seen. Below, the three areas of study in early vocalisation that have surfaced in the current review are addressed in turn, exploring their findings in relation to other studies. Possible reasons for emerging patterns are considered and limitations of the review are discussed. Finally the utility of findings in a clinical context are discussed.

The findings regarding the structure of babble appear to be in line with previous studies that suggest an increase in complexity of vocalisation with age (Oller, 1978, 1980; Stark, 1980; Stark, Ansel & Bond, 1988; Roug et al., 1989). However the picture is not straightforward. Early studies argue that there are two successive stages of multisyllabic babbling moving from reduplicated to variegated (Oller, 1980; Stark, 1980). Oller (1980) proposed that canonical babbling predominates at 7-10 months, and this is replaced with variegated at 11-12 months. The present review to some extent supports this proposition, with studies indicating a general pattern of increased reduplicated babbling up until 12 months at around the onset of speech (Fagan, 2008; Rome-Flanders & Cronk, 1995), and then a subsequent decline (Fagan, 2008; Rome-Flander & Cronk, 1995; Smith et al., 1989). At

around this time of reduplicated babbling decline (12-14 months), variegated babbling increases (Smith et al., 1989; MacNeilage et al., 1997). However, the studies don't fully support the notion that the two types of babbling are sequential, since there is evidence that variegated babble also occurs in the early babbling period (Mitchell & Kent, 1990; Smith et al., 1989), concurrent with reduplicated babbling. Mitchell and Kent (1990) also failed to find evidence of an increase in variegated babble over time, though they only explored babbling in children up to 11 months. As Smith et al. (1989, p.188) notes "two distinct stages may in fact exist, and current models may simply need to adjust their accounts of the time frame during which these stages occur". Indeed, it would seem that the increase in variegated babbling occurs a little later than the early models proposed by Oller (1980) and Stark (1980). The extent that these stages can be seen as distinct is called in to question by the existence of variegated babbling in the earlier time periods.

Other studies in the review reported increased complexity of babbling (Nathani & Stark, 1996; Nathani et al., 2006) but did not draw distinctions between reduplicated and variegated babbling, measuring complexity in different ways. Reasons for infants' increased phonetic complexity over time may indicate increased articulatory motor control as infants move in to the period of early speech. The findings of changes in patterns of babbling around the speech period demonstrate that evidence has moved forward since the Locke (1989, p.195) review who noted "there is no articulatory advance that corresponds to the onset of word use".

For three studies in the present review it was possible to deduce when canonical babbling was present, with two of the papers providing evidence that it occurs as early as 7 months (Fagan, 2008; Mitchell & Kent, 1990) and the other noting there was no reliable canonical babbling data before 8 months (Nathani et al., 2006). These findings appear to be in line with other studies which report canonical syllables at about 8 months of age (Stark, 1980; Roug et al., 1989). It appears that canonical babbling occurs in a relatively distinct time frame since it has been found elsewhere to occur no later than 10 months even in infants who are

preterm, have low socioeconomic status (Eilers et al., 1993) or are from bilingual families (Oller, Lewedag, Umbel, & Basinger, 1992).

The studies that have examined babbling inventories create a relatively clear picture of sounds in this early period which appear largely including stops, nasals and glide. Alveolar (/t,d/) and labial (/p,b/) stops and nasals (/m,n/) were the most frequently produced consonants (Robb & Bleile, 1994; McCune & Vihman, 2001; MacNeilage et al., 1997). Several of the studies in this review report that velar stops (/k,g/) are part of the early sound system (Vihman et al., 1986; Robb & Bleile, 1994), though they seem to appear a little later or less frequently than the other stops. The papers also found that fricatives and affricates appear later than the others sounds. These patterns are in line with the findings of other earlier studies not included in this review (Stoel-Gammon, 1985; Locke, 1983).

A range of reasons for the sounds that predominate babbling has been proposed with two studies noting relationships and interactions of early sounds with first words (Vihman et al., 1986; MacNeilage et al., 1997). Indeed it has been noted elsewhere that “the same sounds and patterns characterize babbling and words” (Macken, 1992). The predominant theory on speech sound acquisition however, appear to suggest that early sounds are determined by their ease in production. For example McCune and Vihman (2001) propose that bilabials are often the first sounds due to their simplicity and their strong visual and proprioceptive cues. Gildersleeve-Neuman et al. (2000) suggest that babbling acquisition is determined primarily by mandibular (jaw) movement, i.e. "frame dominance theory" (Davis & MacNeilage, 1995), a theory supported by the MacNeilage et al. (1997) study. The later acquisition of fricatives, which might otherwise be surprising given they are very frequent in the English language (Kent & Read, 1992), lends more weight to this theory. The low frequency of fricatives and affricates in early consonant inventories seems to reflect their relative difficulty in pronunciation, which requires greater motor control abilities.

Only one study in the review was found to examine the inventory of vowels, making it hard to draw conclusions about the nature of early vowel production. Nathani et al. (2006 p.363) notes that vowels seemed to often be over looked in studies of early vocalisation and

that this might be because they are produced for a long period, yet it is noted that for certain populations such as infants with hearing impairments, they may play an important role in identification of speech issues.

The four studies that examined volubility indicate an increase in volubility with age. This appears to be in agreement with studies elsewhere (Delack, 1978; Stark, Bernstein & Demorest, 1993). It seems reasonable to hypothesise that this increase is a result of a range of factors: an increased interest in sound exploration, a growing capacity to efficiently control their vocalising behaviour, and phonetic progress as they are becoming able to produce words. The study by McCune and Vihman (2001), which linked volubility to later language outcome, supports the suggestion that this particular marker of phonetic progress is linked with the emerging development of a lexicon.

The papers in this review note some clear patterns in particular of early emerging sounds and increased volubility and phonetic complexity with time. The findings would appear to support the 'cascade effect hypothesis' (Rose et al., 2008). That is, the notion that fundamental or basic abilities underpin more complex ones. In this case infants see clear progression from simple vocalisations to those that increase in volume and complexity, as well as in phonetic variation.

There is already a body of evidence that indicates early vocalisations provide indication of later linguistic development, including vocabulary acquisition (Camp et al., 1987; D'Odorico, et al., 1999; Fasolo et al., 2008; Keren-Portnoy et al., 2009). Only two of the studies in the present review have examined the relationship between early and vocalisation and later linguistic development (McCune & Vihman, 2000; Rome-Flanders & Cronk, 1995) both of which found a link. The findings of these, and similar, studies suggest early vocalisation could be a useful marker for children who go on to be language impaired, although this remains an area that has been under explored. Such markers have potential implications for speech and language therapy services; where early identification and intervention have been recognised to be essential (Bercow report, 2008). Early vocalisation indicators for children that are at greater risk of poor language development would allow

services more means and opportunities to monitor them from a very young age, and if necessary intervene earlier.

By mapping out the patterns of early speech development, this review provides information which can be used to relate to later speech development in future longitudinal cohort studies. The review has noted a wide range of individual variation which indicates the need for larger scale studies to further discern patterns. Individual difference in infants vocalisation profiles over time have long been noted (Locke, 1989). Catano, Barlow and Moyna (2009) note children have highly variable development of sound, and as a result normative data do not necessarily reflect any one child. However, the general universal patterns that have been noted in these papers serve as a useful comparison point for investigating other children, and particularly more vulnerable populations that might be more likely to have profiles that fall outside of 'typical' variation.

Conclusions

This review is the first to assess the literature relating to typical infants' early vocalisation in a systematic way. The identified papers indicate some clear trends in the period of development from 9-18 months. In particular, the evidence indicates progressive increases in the complexity and volume of infants early vocalisations, as well as a broad order of phonological acquisition. However, the studies in this review have demonstrated a lot of individual variation in how infants move through early vocalisations and babbling. Further, since the studies in the review are relatively low in the hierarchy of evidence it cannot be concluded to necessarily be representative of the population at large. Nevertheless, the review does provide clear indicative patterns in children's early vocalisations and babbling that can be used in future longitudinal research on larger samples to further our understanding of the relationship between early and later speech development.

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Table 1
Systematic review search strategy

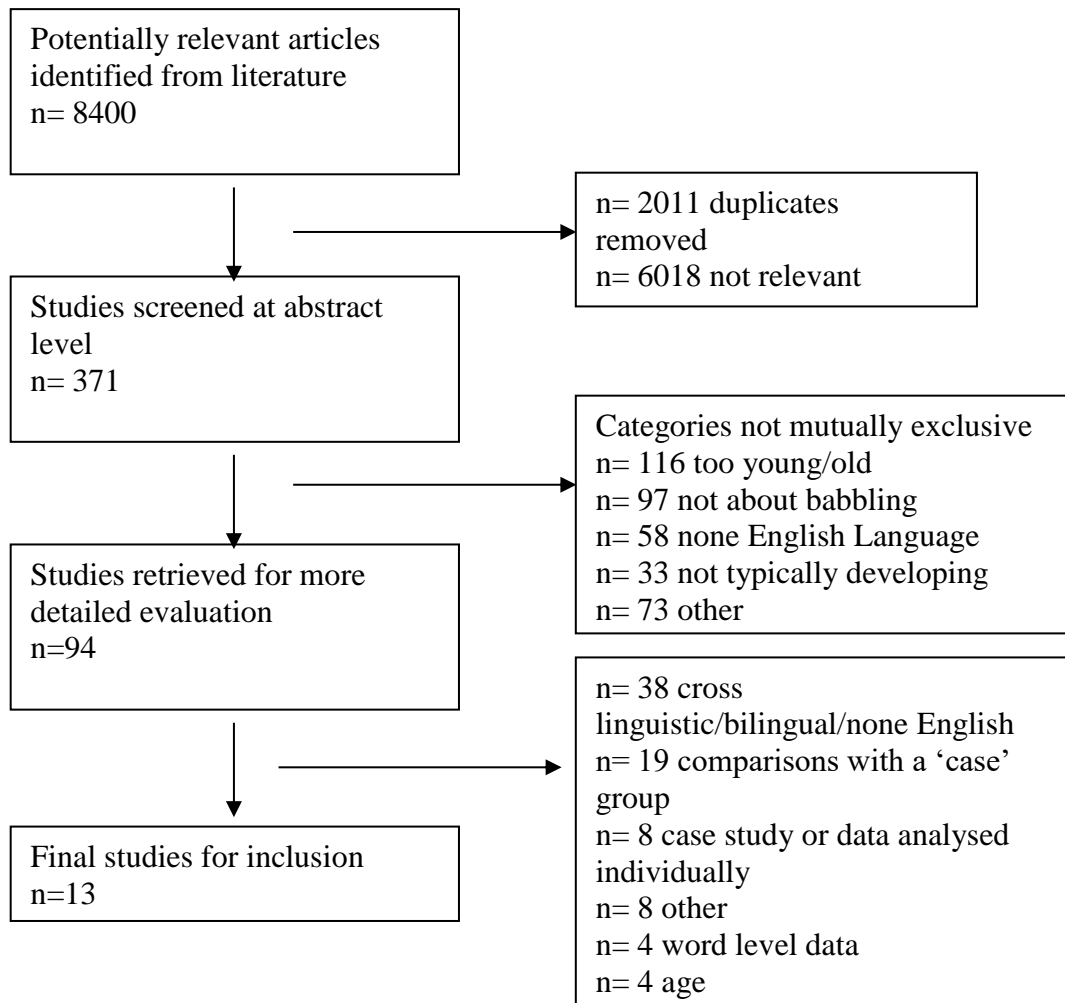
Search number	Date	Host	Databases	Search string	@	Number of results
1	01/04/2014	Ebsco	AMED, BEI, CINAHL plus, Medline, PsychArticle, PsychInfo, ERIC	(TI OR DE infant or child* or baby or babies)	Title, heading or keyword	1, 340, 681
2	01/04/2014	Ebsco		TI (babbl* or vocal* or phon*)	Title	51,293
3	01/04/2014	Ebsco		DE (babbl* or vocal* or phon*)	heading or keyword	78,735
4	01/04/2014	Ebsco		2 and 3		101,617
5	01/04/2014	Ebsco		1 and 4		20,063
5+				Limit to 1984 + peer reviewed		8,334

Table 2*Inclusion and exclusion criteria for studies in the systematic review*

Inclusion criteria	Exclusion criteria
Typically developing children	Focus on speech at the word level
Examining speech sounds/vocalisations /babbling in pre-linguistic and proto-word utterances	Focus on language
Direct data taken (rather than parent report)	Focus on influence of input on speech
Participants aged above 9 months and up to 18 months	Focus on auditory discrimination
English speakers	Infants that have known risk factor for speech development (e.g. hearing impairment, neurological condition)
Published from 1984 onwards	Single case study design (including multiple cases but where data is presented for individuals alone)
Peer reviewed	Case control design with at risk groups
	Cross linguistic study
	Bilingual or multilingual participants

Figure 1

Process of identifying studies for review



Appendix 1

Quality appraisal questions

1. Is the hypothesis/aim/objective of the study clearly stated?
2. Are the characteristics of the participants included in the study described?
3. Are the eligibility criteria (i.e. inclusion and exclusion criteria) for entry in the study clearly stated?
4. Were the outcomes measured with appropriate objective (e.g. gold standard tests or standardized clinical tests), and/or subjective (e.g. self-administered questionnaires, standardized forms, or patient symptoms interview forms)
5. Were the statistical tests used to assess the outcomes appropriate?
6. Was the length of follow-up reported?
7. Was the loss to follow-up reported?
8. Does the study provide estimates of the random variability in the data analysis of relevant outcomes?
9. Are the conclusions of the study supported by results?
10. Are both competing interests and sources of support for the study reported?

Appendix 2
Quality appraisal of studies

Appraisal questions	1	2	3	4	5	6	7	8	9	10
Study name										
Fagan (2008)	y	y	y	y	u	y	y	y	y	y
Gildersleeve-Neumann et al. (2000)	y	y	u	y	n/a	y	n	n	y	u
Macneilage et al. (1997)	y	n	n	y	y	n	u	n	y	u
McCune and Vihman (2001)	y	y	n	y	y	y	n	y	u	u
Mitchell and Kent (1990)	y	y	y	y	y	y	y	n	y	u
Nathani et al. (2006)**	y	u	n	y	y	y	y	y	y	n
Nathani and Stark (1996)**	y	y	y	y	y	n/a	y	n	y	u
Robb and Bleile (1994) (8)	y	y	u	y	n/a	y	y	n	y	n
Rome- Flanders and Cronk (1995) (9)	u	u	y	y	y	y	n	n	y	u
Rome-Flanders and Ricard (1992) (10)	y	y	y	y	y	y	n	n	y	u
Selby et al. 2000	y	y	y	y	n/a	y	y	n/a	y	n
Smith et al. 1989	y	y	n	u	u	u	y	n	y	n
Vihman et al. 1986	u	y	n	y	n/a	y	y	y	y	u

*Numbers refer to the questions described in Appendix 1

y= yes, u= unclear/partially reported, n= no

** It should be noted that this study design compared age groups among different children

Appendix 3

Summary of studies included in the review

Study	Design	No. of participants	Age range	Data collection	Outcome measures	Theme	Study findings
Fagan (2008)	case series	18	3m to onset of word use (m11.8)	Data collection was part of a larger study of vocalisation and gesture. Infants and caregivers were videotaped in their homes twice a month.	Vocalisations were phonetically transcribed using broad phonetic transcription and IPA notation. Transcribed vocalisations were categorized according to vocalisation type and type of repetition	Vol, Pob	The mean age of reduplicated babble onset was 7.1 months. CV syllables saw a linear trend in growth, with a significant increase at babbling onset. Number of repetitions saw a quadratic trend, with flat growth before babble onset, increase at babble onset, and a decrease on word production (around 12 months).
Gildersleeve-Neumann et al. (2000)	case series	4	7-18m	Data collection began from the onset of babbling, infants were seen weekly for one hour in their home environment. Data collection was part of a larger	Canonical babbling were analysed for their phonetic features, including place and manner of articulation.	PI	Stops, nasals and glides made up 91.2% of consonant on average (mean), fricatives, affricates and liquids made up 8.8%. Few affricates were produced. Considerable individual variation in fricative, liquid and affricate productions.
Macneilage et al. 1997	case series	4	babbling onset 7m-42m	longitudinal study. Analysis of 152 hours of audiotapes.	All speech like canonical babbling and word forms were analysed. Analysis included consonant types, frequency of reduplication and variegations in utterance strings.	PI, Pob	Babbling sounds 7-12 months, averages: p/b 17% (SD 9.8), m 16% (SD 14), w 5% (SD 2.5), t/d 37% (SD 11), n 21% (SD 9) j 11% (SD 7.5). Bar chart indicates a slight increase in variegated babble with age, and a very small decrease in total duplication

Study	Design	No. of participants	Age range	Data collection	Outcome measures	Theme	Study findings
McCune and Vihman (2001)	case series	20	9-16m	The infants were video recorded monthly in the home during 30 minutes of play with their mothers.	Data were transcribed phonetically from video/audio. Phonetic measures included volubility, vocal motor schemes (VMS10 or more occurrences of a given consonant), proportion of utterances containing consonants	PI, Vol	Consonants t/d and p/b and glottal /h/ were produced by >50% of participants. Regression examined volubility, proportion of vocalisations including a consonant and VMS with referential word use at 16 months. Each of these was a significant predictor, with VMS the strongest accounting for 43% of variance.
Mitchell and Kent (1990)	case series	8	7-11m	Infants were audiotaped in their homes in interaction with a parent for 2 30 minutes sessions at 7, 9 and 11 months	Samples were categorised by babble, repetitive or non-varied multisyllable babble and varied (variegated) multisyllable babble.	Pob	The mean proportion of multisyllable vocalisations and single vocalisations increased across the age range. Repetitive babbles were found to dominate samples of multisyllabic vocalisation. Phonetic variation was found to occur at onset of multisyllable vocalisations and not increase with age.
Nathani et al. (2006)	cross-sectional case control	36	3-18m, 6 infants in 3, 6, 9, 12, 15 and 18m	Infants were video recorded in their home, with their mother and the laboratory, with experimenter, for 30 minutes.	Utterances produced in a 30 minute period were counted. A best 10 minutes period was also selected of each to analyse the complexity of vocalisation, using a seven level scale.	Pob, Vol	Younger infants (3, 6 and 9 months) produced simple vocalisations and less complex vocalisations, than older infants (12, 15 and 18 months) ($p<0.05$). Higher numbers of vocalisations were seen for the older aged group ($p<0.05$).

Study	Design	No. of participants	Age range	Data collection	Outcome measures	Theme	Study findings
Nathani and Stark (1996)	cross-sectional case control	30	0-20m, 5 infants in 6 age groups	Each infant was recorded 5 times in time span of their age group and the first and last recording were taken.	Approximately 40-50 consecutive and clearly audible utterances were analysed for each session. These were grouped into five ascending levels using Stark Assessment of Early Vocal Development-Revised (SAEVD-R).	Pob	Older infants attained higher developmental levels on the SAEVD-R than younger infants, indicating a pattern of increasingly complex vocalisation types with age ($p < 0.05$).
Robb and Bleile (1994)	case series	7	8-14m followed for 13 months	Infants were audiotaped at approximately monthly intervals on 12 occasions over a 13 month period	Vocalisation were phonetically transcribed with IPA. Acquisition of a consonant was determined by it being present in a child at least twice in a month and at least 60% of children acquiring it.	PI	The study details consonant inventories each month from 9-16 months. Oral and nasal stops were the most frequently produced consonants during the 8-12 month period (e.g. t/d, p/b, m/n). Alveolars (e.g. d/t, n, l) were the most frequently occurring consonants across the study followed closely by labials (e.g. p/b, m).
Rome-Flanders and Cronk (1995)	case series	25	6-24m	Infants were videoed in a laboratory with their mothers at 6, 9, 12, 15, 18 and 24m	Developed an 8 point classification system of vocalisations from primitive vocalisations to multiple word expressions.	Pob	Reduplicated and variegated babbling increased until 12 months, and decreased after. Jargon and pre-lexical comments in contrast, increased from 12 months and decreased at 24 months. It's concluded that there is a developmental progression to vocalisation. Infant vocal behaviours at 12, 15 and 18 months were predicative of language abilities at 24 months.

Study	Design	No. Of participants	Age range	Data collection	Outcome measures	Theme	Study aims
Rome-Flanders and Ricard (1992)	case series	25	6-24m	Infants were videoed in a laboratory with their mothers at 6, 9, 12, 15, 18 and 24m	Frequency of infant game relevant gestures and vocalizations were recorded. Only positive and neutral vocalisations were coded.	Vol	The total frequency of positive vocalisations was found to increase significantly with age ($p < 0.01$). Game relevant gesture also increased with age in two different game types.
Selby et al. (2000)	case series	4	15-36m	Data were collected from the children at 15, 18, 21, 24 and 36m, sampling lasted approximately an hour	1404 vowel tokens were taken, facilitated by examining the acoustic characteristics of formant frequency, duration and fundamental frequency.	PI	Vowels at 15 months α, i, u, Λ , vowels at 18 months $\alpha, i, u, \Lambda, \sigma, \text{æ}$, based on 75% occurrence across the four children.
Smith et al. (1989)	case series	10	6-18m	Infants were seen at approximately 4 month intervals, and were audio recorded for approximately half an hour.	Transcripts were prepared with IPA and added special diacritics. Only reduplicated and variegate babble were analysed.	Pob	No significant differences for reduplicated and variegated babble were seen between 6-9 and 10-13 months. However between 10-13 months and 14-17 months there was a significant increase in variegated babble, and a decrease in reduplicated babble.
Vihman et al. (1986)	case series	10	9-16m	Infants were videoed over a 7 month period from about 9m every week, for 30 minutes, in their own home	Detailed phonetic transcripts were prepared from audiotapes of about 60% of the play sessions, using IPA and additional diacritic notations. Child vocalisations were classified into words or non-words.	Pob	Large amount of individual variation were found. Increases in range of consonants occurred, while reduplicated consonants remained level as knowledge of language increased. Increased uniformity was seen in terms of consonants used and their place of articulation as well as between children over time.

